

Propagation of Woody Plants

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Part one :

Woody Plant Propagation from Stem Cuttings

(pp. 1 - 54)

Part two :

**Practical Aspects of the Propagation of Temperate Ornamental
Woody Plants from Seed**

(pp. 55 - 382)

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**An Introduction to
Vegetative PLANT PROPAGATION
a schematic classification**

This schematic is included, in these notes, to indicate the scope of vegetative plant propagation. It is significant to remember that the great majority of what is practiced as plant propagation from vegetative parts is not a normal growth pattern; although the plant is capable of responding via a regenerative process - ie there is an inherent ability to regenerate which, presumably, has developed as part of the evolutionary process.

-Natural

- Rhizomes
- (Stolons)
- Tubers
- Bulbs
 - Tunicate
 - Scaly
- Corms
- Runners
- Offsets
- Foliar plantlets
- Floral plantlets

-Artificial

-Micropropagation

- Tissue Culture
- Cell Culture

-Macropropagation

-Division

- Solid Crowns
- Diffuse Crowns

-Grafting

-Approach

- Inarch
- Approach

-Detached Scion

-Apical

- Whip
- Based Whip
- Whip and Tongue
- Cleft
- Wedge
- Crown
- Others

-Side

- Veneer

- Wedge
- Regeneration of parts**
 - Stems**
 - Layering**
 - Stooling
 - French Layering
 - Trench Layering
 - Simple
 - (Air)
 - Serpentine
 - Cuttings**
 - Hardwood
 - Semi-ripe
 - Deciduous
 - Evergreen
 - Conifer
 - Greenwood
 - Softwood
 - Roots**
 - In situ
 - Cuttings
 - Leaves**
 - Leaf Petiole cuttings
 - Leaf Lamina cuttings

Woody Plant Propagation from Stem Cuttings

The Capacity to initiate Roots in relation to Parental Age, Rejuvenation and Vegetativeness

After the Second World War the major thrust in advancing the efficiency of plant propagation in the Nursery Industry, as part of the plant production process, was to enhance the ability to initiate roots on stem cuttings. This was prompted by the need to reduce the reliance on various forms of grafting which had traditionally been practiced - because of the inability to root stem cuttings of so many plants (eg Rhododendrons) economically.

This advance was essentially associated with a) the use of 'Auxins' - which eventually came to be known as Plant Growth Regulating Substances, b) the practice of wounding the basal portion of the cutting and c) an understanding of the necessary functions of the rooting medium. A better understanding of all of these factors - and in their various combinations - did have a considerable impact in forwarding success and this is evidenced in the literature of the time.

However the practice of plant propagation and any advances in success, at that time, tended to be jealously guarded as 'trade secrets' by individual propagators (even the literature tended to avoid useful detail) and it was difficult for the novice to put together efficient regimes. However by the late 1960s attitudes changed dramatically (with the advent of International Plant Propagators' Society, in the UK, in 1968) and plant propagation quickly became an open book.

At this time a large and extensive 'experiment' was convened, by the Society, in which several nurseries and institutions conducted a comprehensive investigation in an attempt to determine the importance and relative effects of PGRS, wounding and medium composition on the rooting of particular plants. The results of this were inconsistent and inconclusive, especially so between sites. An exact repetition as possible was instituted the following season to determine if the results were at least consistent, on an annual basis, on any one site. On at least half the sites, the results were markedly at variance with the previous

year - especially so for those contributors who used the same stock plants for their propagating material. They found that this iteration was generally highly successful in terms of the regenerative success, produced only marginal differences between the treatments and thus vastly improved the overall total response - leading to the conclusion that if the material was 'good' then the effect of treatments was marginalised.

This result then focussed attention on the condition of the propagating material and the stock plant itself as the major influence in successful propagation rather than the treatment of the propagation material after it had been isolated. In turn this led to the consideration of the age of the stock plant from which the propagating material was taken and its treatment - a factor which had already been widely noted in the rooting of stem cuttings of Leyland's Cypress.

Currently, after a period of forty years, the received wisdom is that the major influence controlling the successful vegetative propagation of woody plants from stem cuttings is determined by the inherent level of regenerative capacity present in the material selected for propagation and by inference that this is a function of the physiological status (age) of the plant from which it is selected.

PARENTAL AGE

This regenerative capacity, ie the ability of the stem to initiate roots, does not occur as a constant function throughout the life of the plant but declines as the plant ages. This context has particular significance for the continuous clonal propagation of a woody plant insofar as the physiological condition of the material is not represented by the immediate age of the individual donor stock but is a function of the actual (and hence physiological) age of the original selection - however many vegetative generations it is removed from the current material (ie the physiological 'age' of the donor plant, providing propagation material, is the same as that of the original selection from which it is derived).

The relative capacity to regenerate between different families, genera and even species varies considerably but is normally constant - this implies that there is a

spectrum of this capacity which, at the extremes, means that stem cuttings of a taxon may be 'difficult' (eg *Quercus* and *Tilia*) or 'easy' (eg *Fuchsia* and *Forsythia*) to root. Thus the inherent capacity varies significantly and is not the same among all woody plants.

The Phases of Ageing

When a seed germinates it starts into a life cycle which will consist of four phases - initially the **Embryonic** - which becomes the **Juvenile** at germination. This is the stage at which, the vegetative growth produced, builds the individual to a size and condition at which it is volumetrically large enough, sufficiently physiologically developed and properly established to be capable of flowering and producing seeds. This is the primary method by which a species is regenerated. During this phase the ability to regenerate asexually by vegetative means is high. The next phase is described as the **Mature** phase and is when the sexual mode initiates and dominates and it is at this stage that the plant develops and increases its capacity for flowering and seed production until it reaches its full, mature size. At this stage the ability to regenerate vegetatively declines dramatically at the phase change and continues to decline steadily, through time, until growth ceases and the last phase is reached. Thus the plant moves into the **Senile** phase when it concentrates all of its reserves and energy into seed production and this is associated with a complete loss of asexual reproductive ability.

The term **Ontogeny** is used to describe the chronological age of this sequence in an individual and represents the periods and phases of development from germination to death - similarly **Morphogenesis** is also used.

It should be emphasised that the great majority of woody plants do not reproduce asexually unless there is a specific stimulus to cause them to do so - normally the ability to reproduce asexually by vegetative means is latent and although many plants even have stems which have developed preformed root initials, no further development occurs unless the stem becomes separated from the parent.

A woody plant, thus, progresses through **three phases** during its life cycle after germination - **Juvenility**, **Maturity** and **Senility**. The potential asexual regenerative capacity during this cycle declines in the expected (and normal)

sigmoid curve fashion. The highest level of this regenerative capacity occurs during the juvenile phase (declining only slightly as time progresses); at the onset of sexual maturity, however, the capacity declines markedly and continues to decline steadily until the senile phase is reached when this potential is virtually lost. At this late stage in life the normal reaction of the plant before dying is to flower profusely and produce a large quantity of seed. This pattern leads to the conclusion that vegetative regeneration is only significant in the plant when it is in a non-flowering condition.

In practice the habit and the abilities of the plant in its phases can be catalogued as below:-

Juvenility is characterised by:-

a relatively fast growth rate, absence of the physiological ability to flower and produce seed, a high level of vegetative regenerative capacity and often exhibiting distinct morphological characteristics to those of the mature phase. This is exemplified by:-

Malus in which the juvenile stems are often spiny, and the stems and leaves are hairy;

Hedera in which the juvenile phase is climbing in habit and the mature is shrubby;

Passiflora has small cordate leaves as compared with the highly divided leaves of the adult phase;

Plagianthus has roundish leaves as compared with lanceolate and a wiry twiggy habit as opposed to the mature condition of a single trunked tree and

many conifers - most noticeable that in the juvenile phase the foliage is distinct - in many *Cupressaceae* it is 'feathery' and very different - giving rise to the 'genus' *Retinospora* in Victorian times.

The duration of the juvenile phase will also have some relevance and according to genus or species this can be quite extensive - tree *Magnolia* species in excess of fifteen years, in *Wisteria* around a period of seven years but in *Cornus capitata* it may be as little as three years.

As the plant reaches sexual maturity there is inevitably a physiological change and the duration of this change can vary so that, in some tree species, it may extend over several years (as many as fifteen years) - this is known as the **Transitional** phase and while it adjusts the reproductive abilities reflect the condition - that although the plant may produce flowers (probably not seeds)

it still retains a degree (although continually declining) of capacity to regenerate vegetatively.

Maturity is characterised by:-

the onset of flowering and the production of seed, however in the early stages of maturity the plant is still putting the preponderance of its food reserves into continued growth and an increase in size and hence leaf area - it is not until the plant has reached towards its full mature size and status that it maximises flower and seed production by diverting major food reserves to this activity.

As this maturing process increases steadily so does the capacity for vegetative regeneration decline.

Senility is characterised by:-

a virtual cessation of the ability to regenerate vegetatively and as the maximum size is reached it switches into a substantial flower and thence seed production mode giving up its food reserves in the process.

The significance then of this pattern has particular relevance in the vegetative propagation of clonal material (normally cultivars) as the physiological age of the plant is not regressed in any way as a result of a new generation being vegetatively propagated from stem cuttings - the physiological age is still that of (or what would have been) the original selected parent. This probably accounts for the demise of, or the extreme difficulty in rooting cuttings of, many cultivars from earlier times.

An example of this status is provided by the original varieties of Ghent Azaleas, which are now 200+ years old and (despite generations of macropropagation) they have, over the years, become progressively difficult to regenerate from stem cuttings. Subsequent deciduous Azalea groups such as Mollis (1880s), Knaphill (inter War years), and Ilam (1960/70s) are progressively easier to root. This factor is true even when the presence of viruses is allowed for.

Observations, conducted on *Ribes sanguineum* cultivars, have demonstrated a similar decline in regenerative capacity with age. In the 1960s 'Pulborough Scarlet' (c1930s) was regarded as 'easy' and 'King Edward VII' (c1890s) less so. Nowadays the former is regarded as relatively 'difficult'

and the latter as still more difficult. Newer cultivars such as 'White Icicle' (1970s) however are seen as easy.

In all these instances the current donor (stock) plant, however 'young', is far removed from the originally selected plant but it will necessarily still be the same age physiologically. It is therefore relevant to determine whether it is possible to recover any of the advantages of improved vegetative multiplication that is associated with juvenility

REJUVENATION

The most productive rooting of stem cuttings in the mature phase therefore appears (logically?) to be associated with the non-flowering condition (ie the juvenile phase) and is borne out by the fact that regenerative capacity declines steadily, with ageing, through the mature phase as the capacity to flower increases. Hence it would appear that the ability to regenerate asexually declines with an increasing ability to regenerate sexually.

The definition of Juvenility as previously indicated, in this context, is that period from the onset of germination to the point of sexual maturity.

This characterisation however is complicated by the fact that the same morphological and thus presumably physiological characteristics will also arise when a stem is regenerated from an adventitious bud - as from a root or from an epicormic origin. This might then provide an opportunity to exploit this condition - which is of course theoretically possible but if quantities of plants can be produced by this route why bother to produce stock plants to produce stem cuttings?

Although it is evident that a stem with apparently juvenile characteristics is produced from an adventitious bud and that this stem will exhibit the increased capacity to initiate roots it is not clear what the duration of the effect will be.

Speculation once suggested that the rapid propagation of alternative generations of root cutting and stem cuttings (where it was possible) could push the juvenility factor back up the scale and ease propagation by a massive increase in regenerative capacity. However it may adversely

affect the development of the desired characteristics of the mature phase and there was some doubt as to how long the effect might last.

When sexual maturity is reached there is a marked decline in regenerative capacity (ie at the shoulder of the sigmoid curve). The problem, however, is that it is not until the mature phase has been reached that the plant will be selected for its particular desirable characteristics and by which time it has lost the greater proportion of its regenerative capacity.

VEGETATIVENESS

The issue then, which affects the propagator, is to determine whether any of this regenerative capacity can be recovered in the mature phase by the manipulation of the parent plant.

Observation on the patterns of growth during the mature phase reveals that heavy pruning (by whatever means) causes the production of stems which do not flower and that as a corollary they also recover a considerable degree of regenerative capacity - for want of a better term this condition can be referred to as 'Vegetativeness'.

Further investigations will demonstrate that the greater is the proportion of stem material that is removed, the faster will be the replacement growth as the plant seeks to replace the stem tissue removed and restore the root/shoot ratio. The faster the growth, achieved by this process, the higher is the level of regenerative capacity regained.

Effectively therefore it is the speed of growth which is the critical factor in determining regenerative capacity and morphologically this is represented by upright growth, anatomically by an attenuation of the sclerenchyma sheath surrounding the conducting tissue and physiologically by a non-flowering condition. Not surprisingly the rate of growth of this replacement tissue is not constant but again the pattern seems to respond to that of the sigmoid curve.

This effect can be demonstrated by establishing a vigorous, relatively easily rooting, plant such as *Salix daphnoides* and then stooling it in the late winter. The consequent growth during the following growing season will be considerable and virtually upright shoots around 4m long

will be developed. In the autumn, just after leaf fall, these shoots can be severed flush with the stool (incorporating the basal swelling) and then from the base making successive 15cm hardwood cuttings. These can be inserted in a suitable soil bed and at the end of the following growing season they can be assessed on the basis of root and shoot production. The results will show that the quality of the new plant is greatest when derived from the basal cutting - with, progressively, a declining quality to the tip of the cutting. The advantage of incorporating the basal swelling into the basal cutting can similarly be demonstrated by removing it in some of the basal cuttings to make a comparison.

The importance of the incorporation of the basal swelling, in the ultimate success, can also be readily demonstrated with early season, softwood cuttings of the large flowered cultivars of Lilac (*Syringa*).

Thus in the propagation of woody plants from stem cuttings the significant pointers to maximum success - especially with those subjects which are designated as being difficult to root - are that the basal swelling is incorporated into the cutting and that only this particular cutting is likely to be successful. This basal swelling which develops as a result of the initial surge of growth from the dormant bud represents the fastest rate of growth - ie the top of the sigmoid curve. This phenomenon is not a new concept - it was ably demonstrated at East Malling, in the late 1950s and 1960s, in the recommendations for using the Garner Bin technique of rooting hardwood cuttings of fruit tree rootstocks and was also applied at that time to a variety of ornamental subjects.

The effect of this particular manipulation is relatively transient and fortunately is effectively lost by the second season after propagation so that it does not impair the development of the mature plant characteristics for which the clone had been selected.

The practical significance, to the propagator, of this particular status will therefore be related a) to the age of the 'variety' (bear in mind that date of introduction is not an absolute and that the plant must have been germinated well before - as it is the adult features which recommend it) in determining its potential (and relative)

regenerative capacity and b) the ability to recover regenerative capacity by manipulation of the parent plant.

Woody Plant Propagation by Stem Cuttings

An Analysis of the Process

The overall cycle of production, involved in the vegetative propagation of a crop of ornamental hardy woody plants by stem cuttings, consists of a chronologically determined sequence of phases. All of these phases are significant and are necessary considerations in determining influences on an ultimately successful outcome. However these influences are inevitably inter-related - as each factor comes into play - and should not, prudently, be considered in isolation.

The object of this analysis is to inform - so that a series of organised and sequential protocols can be developed, which will result in the production of a high quality end product and the maximisation of productivity from the stock available.

The Production Process can be conveniently catalogued and divided into five phases:-

1. The Preliminary phase
 2. The Preparatory phase
 3. The Regenerative phase
 4. The Establishment phase
- and
5. The Production phase

The first four phases combine to determine the propagation sequence which will result in a suitable, autotrophic, young plant (a liner) which is capable of, seamlessly, being moved into the production schedule.

Although these notes have been allied to the propagation of the crop by stem cuttings - because it is the most widely practiced technique in the industry - the notes can equally well be transposed to apply to any technique of vegetative propagation when suitably modified.

This process will allow the factors which affect 'quality' to be determined at each phase of production so that only material of the most satisfactory status moves on to the next phase.

The assessment of quality in the production of nursery stock (because of the wide diversity of plants produced) is

inevitably a nebulous concept and this can only be defined with exactitude and precision on the perceptions determined by an individual operation. Otherwise it is simply a matter of waffling about being 'well grown', 'true to name' and 'vigorous' - whatever that means.

The process relies on the inherent ability of a particular part of the plant (in this case stems) to exhibit a capacity to regenerate the requisite missing components (ie roots) and so produce, when these two components have become anatomically and physiologically integrated, a complete new plant capable of a separate autotrophic existence.

Inevitably the initial status of the regenerative process will be defined by the inherent capacity for vegetative regeneration exhibited by any particular plant. This is not a constant feature - in some genera the ability is high and these will be deemed 'easy' to propagate (eg *Fuchsia*) while others will only respond (at the extreme) after considerable manipulation (eg *Fagaceae*) - while the remainder may effectively not respond at all.

Why any plant should have this ability is not generally clear and why one species and not another should vary from the other is a similar conundrum. In general, the capacity also varies with the status of the material to be propagated - young (immature) material will regenerate more successfully than the same material as it progresses through the season of growth and becomes more differentiated.

In the commercial nursery industry the process depends on a complete and integrated sequence of events. All phases need to be implemented and are required to produce a crop of new plants (liners) of the same genetic complement as the identified parent and of a designated quality.

The main component of quality - especially in wholesale production - will be the consistency of the uniformity of the product. Each phase of the process provides a platform for the next and ideally all the material will move on from phase to phase. However under even the best nursery conditions there will inevitably be some variation from the standard. Thus the numbers started, originally, in the process should take account of an anticipated level of discarded material that is required to maintain a standard

of quality and uniformity. This level of discard should decline at each phase - as material discarded late in the sequence constitutes a higher level of financial cost.

In the last fifty years production in the Ornamental Hardy Nursery Stock Industry has become increasingly stratified and it is quite feasible that each phase, in the future, could be carried out by individual and separate businesses. Indeed it is partially stratified already

The Propagation Process

The plant production process thus broadly consists of five phases - of which four constitute the propagation element - the end product of which is a physiologically integrated young plant capable of normal and active growth without further special treatment and of a size which is compatible with the continuing requirement of the production process (a liner); ie the fifth phase - the Production Phase.

1. Preliminary Phase

This phase determines the precursors to production but is an essential element in the production process. It covers the introductory processes which govern the fundamental factors which will ultimately influence the outcomes.

a) Parental (Stock) selection,

This consists of the determination of:-

Taxonomic identity

Although this feature is apparently obvious it is important that the stock is 'true to name' and represents 'what it says on the tin'. This is particularly significant in today's global market place.

Clonal selection

The propagation by vegetative means of a cultivar implies the reproduction of a clone - ie individuals of identical genetic complement representing that particular cultivar description; however for those popular plants which have been propagated continuously or extensively, and/or over a long period, it is quite feasible that some genetic variation (mutation) will have occurred. This variation may then have, unwittingly, been multiplied up to provide effectively a different clone. This may be an improvement or otherwise but it is no longer the original. If this has occurred several times then a melange of variants will have been created. A view then needs to be taken on the

situation and some form of selection will, at some time, be necessary.

Health

It will be obvious that the multiplication of material infected with fungal or bacterial diseases would be counterproductive. Many plants are subject to virus infection and in most cases this is to the detriment of the vigour of the subject and such material should be avoided or discarded and virus free material selected or created. However in some cases the virus is part of the accepted characteristics of the cultivar - some variegated plants and some woody plants in which the particular shape of the plant (eg Sato-Zakura Cherries) is affected.

Such screening and assessment will enable and provide the selection, establishment and production of reliable parental stock providing known characteristics and identifiable nomenclature.

b) Parental Age

When propagating any particular cultivar there are two influences which relate to the age of the stock plant and which can dramatically affect the potential capacity of the propagules to regenerate.

i) the actual age of the cultivar itself will affect the potential capacity to regenerate ie its real chronological age - the date at which it germinated as a seedling will thus determine its current age (this is not the date of introduction). A plant progresses through three phases during its life - Juvenility, Maturity and Senility and through this duration, the vegetative material declines in its capacity to regenerate (by the accepted sigmoid curve phenomenon). Although it is well known that capacity is highest in the juvenile phase it is (usually) not until the plant reaches maturity that particular attributes deem it suitable for cloning. Through the mature phase capacity continues to decline until at senility it is virtually lost. Hence regardless of the age of any individual stock plant it is physiologically the same age notwithstanding how many generations it is separated from the original individual seedling. Thus cultivars (clones) do age and as they get older their ability to regenerate declines until it virtually disappears.

ii) the age of the individual stock (donor) plant - as determined by its own propagation date - is also a factor insofar as there is much reported evidence that the 'younger' and more vigorous (see later) is the plant then

the higher is the regenerative capacity of its propagules. Hence there is a requirement for a programme of renewal of the stock plants in order to maintain an enhanced and acceptable level of capacity.

c) Plant Husbandry of the Parental Stock

This is simply a function of maintaining a suitable and satisfactory mode of husbandry to keep the stock plant growing properly and without constraint. It will involve attention to:-

- Nutrition

- Irrigation

- Light

- Competition - weed and pest and disease prevention and control

Where the regenerative capacity of a crop plant is naturally high and the subject is regarded as easy to propagate - then propagules are, more often than not, taken from a growing crop in the process of pruning and shaping. However the same assessments and practicalities still apply.

2. Preparatory Phase

When a plant is sufficiently difficult to propagate or it is not possible to remove cuttings satisfactorily from the growing crop or there is some particular treatment required to enhance the capacity to regenerate - then it is necessary to establish stock plants which can be prepared or manipulated to provide the required amount of the desired propagules with an acceptable level of capacity.

a) Plant manipulation

The phase involves the manipulation (ie the preparation and the treatment) of the parent plant to develop the most productive system for the production of potential stem cuttings both in terms of numbers and regenerative capacity. Primarily this is an understanding of the development of material with the greatest potential **capacity** to regenerate. This will relate to:-

- i) The age of the parent material - and its relation to the potential regenerative capacity - has been alluded to above and this phase concerns the treatment of the plant in order to enhance the inherent regenerative capacity where this is necessary.

The regenerative capacity of a particular cultivar has so far been shown to be a function of the inherent status of the species and its physiological age (ie how far it has progressed down the decline in capacity during the mature phase). Evidence also shows that the capacity can be enhanced if the donor plant can be manipulated and so induced to develop a high degree of 'vegetativeness' - initially this was associated, physiologically, with the non-flowering condition or juvenile phase - but it is effectively a response to the speed of growth of the stem, upright growth patterns and thus also the potential attenuation of the pericyclic sheath.

Practically this is achieved by relatively severe annual pruning so that considerable regrowth is engendered and this will necessarily be fast in order to correct the balance of the root/shoot ratio. Over the course of the growing season this will be speediest at bud break and will progressively slow throughout the season until it reaches balance when approaching dormancy. The highest regeneration will be obtained, therefore, in cuttings which incorporate the swollen base of the annual growth - ie when the bud burst and the stem grew fastest.

However it should not be ignored that the increased capacity associated with the juvenile phase is not just associated with seed germinated material but can also be derived from material developing from adventitious bud production. Away from the mainstream of nursery production there has been some attention to increasing capacity using these techniques but as an industrial application they are unlikely to be very high on the agenda.

There are examples in the nursery industry of particularly sophisticated treatments of which one example (which was popular for a while) was **Etiolation**. This involved excluding light from the base of the new season's shoot as soon as it was feasible; it involved wrapping the base of the current season's shoot in an opaque material in order to encourage the initiation of roots but its application is time consuming and like other techniques it is not widely practiced.

ii) The maximisation of the number of propagules produced is also a significant economic factor and the pruning (and perhaps the pinching) of the plant - depending on its growth habit - will govern this factor; eg if Rhododendrons

are cut back the regrowth tends to produce a single thick shoot but if this is pinched it will develop an 'umbrella' of thin shoots - which also, coincidentally, generally show an improved capacity to root (probably this is a function of the attenuation of the pericyclic sheath).

3. Regeneration Phase

This phase considers the factors influencing the **performance** of the material - ie the actual physical expression of the potential capacity (root production) once the cutting has been removed from the parent.

a) Seasonal influence

This relates to the variation in the expression of any regenerative capacity as a function of the influences of the seasonal condition of the plant; hence the timing of operations when capacity is at its most potent. An example being that hardwood cuttings respond most satisfactorily if taken at leaf fall (leaf abscission).

b) Treatment

The degree to which this capacity is expressed may be improved by the physical or chemical treatment of the propagules in order to enhance the inherent regenerative capacity, especially if it is sub-optimal.

Chemical treatment

Just before the Second World War it was discovered that plants (like animals) produced 'hormones' and that one particular group of these 'Auxins' could encourage the initiation of roots on isolated stems. The most effective were NAA, IAA, IBA and IPA - at relevant concentrations - and for a period in the 1950s to the mid-1970s were regarded as a panacea, however once the effect of vegetativeness became more widely accepted it became apparent that their value was limited to sub-optimal material or to enhance the capacity of subjects with low inherent response. In recent time these materials have been referred to as 'Plant Growth Regulating Substances'. The placing of such agents when treating is significant as it is evident that the concentrations of Plant Growth Regulating Substances which will initiate regeneration are higher than those necessary for root growth.

Physical treatments

One identified constraint to the initiation and/or emergence of roots, in certain species, is the structural presence of the pericyclic sheath which may prevent the

external application of Plant Growth Regulating Substances getting to the required sites for root initiation or conversely it may impair their development and emergence. This can be overcome by applying a longitudinal **wound** to the base of the cutting either as a slice or a score - so damaging the sheath.

An obvious *sine qua non* in the regenerative process is the maintenance of **polarity** - Plant Growth Regulating Substances generally move in the stem in response to gravity and it is therefore important to keep the material 'the right way up' - this may seem too obvious to mention and with leafy cuttings is not usually a problem - however it is not difficult to envisage hardwood cuttings being inserted upside down!

c) Environment

The provision and/or adaptation of environmental conditions to:-

- a) ensure the survival of the propagule - chiefly the maintenance of water status and a suitable temperature and
- b) encourage and optimise the expression of the inherent capacity to regenerate the relevant 'missing parts' - usually a function of temperature, nutrition and water availability.

This will be a function of the assessment and optimisation of the following elements of the environment as they affect the survival of the cutting in 'good' condition (ie the cutting is not under stress from any of these parameters) and the enhancement of the regeneration process:-

- temperature,
- water status/stress,
- light,
- atmosphere,
- hygiene,
- protection
- and
- the structure and condition of the rooting medium.

The provision of particular environmental conditions will necessarily be adapted to the type and condition of cutting material that is to be propagated.

4. Establishment Phase

Once regeneration has occurred and become established, the aim is to achieve the continuing development of the

material to produce a physiologically integrated young plant capable of an autotrophic existence. The end product is a suitably prepared and established 'liner' plant. This represents the transformation of the regenerated propagule to a physiologically integrated young plant.

Although most plants will regenerate roots and develop to a physiologically integrated condition in the available normal growing season, there are some plants which do not and if they progress into dormancy before integration is achieved there is a very real possibility that they will be unable to respond to stimulation when suitable growing conditions are resumed. Hence the provision of those conditions and/or the timing of the operations required to ensure the development of physiological integrity and the subsequent development of normal growth patterns will be significant. This may involve extending the active growing season either by advancing the season of availability of propagules or by manipulating the environment (usually temperature, daylength and nutrition) to extend the season.

The integrated condition can be determined by the development of stem extension growth - albeit minimal. At this stage the material can be allowed to become dormant with every expectation that the plant has become physiologically integrated and that it will respond to environmental conditions, exit from dormancy and develop normally the following spring.

5. (Production Phase)

Further development of the liner plant to larger sizes.

Woody Plant Propagation From Stem Cuttings

Adventitious Root Formation Site, Origin and Development

The initiation and development of adventitious roots on a stem cutting is a fundamental process to achieving a successful conclusion to this mode of vegetative plant propagation and although scientists have been intrigued by this process for two or three centuries - the practicalities still appear to be a matter of debate. The questions which arise can simply be catalogued as:-
Where do they arise?
What causes the initiation?
How do they develop?
When are they initiated?

The scenario presented here represents a resume of the current position and conclusions which are garnered from the limited basket of current observations.

Although some woody plants (eg Poplar, Willow, Apple, Jasmine and Flowering Currant) are capable of initiating and developing root initials in stems as a normal growth process, it is exceptional and, in general, adventitious rooting is not initiated in stems unless there is an external stimulus to do so - this stimulus is provided by the separation of the stem from the parent and it would appear that the wound thus caused is the primary agent in stimulating this activity.

When a stem is separated from the parent plant (as in making a cutting) it creates a wound at the cut base of the stem. The natural process is for this wound to be healed. This happens with the development, initially, of a necrotic plate of cells which suberise, this is followed, internally, by the production of a layer of parenchyma cells which also thicken and form a barrier, described as callus, of thickened cells. This activity then produces a further response, which is presumably 'auxin' controlled, to initiate root production. This initiation occurs in parenchyma cells in the region of the vascular bundles (within or surrounding) and inside the pericyclic sheath.

These cells begin the process of de-differentiation which implies that they no longer function in their current role and revert to a meristematic condition. This is followed by a differentiation as the cells reconfigure their function and future development into root initials. This can be observed microscopically as these cells,

which normally divide lengthwise clinally (parallel with the circumference), begin to divide at right angles (anticlinally) and a three dimensional group of cells becomes apparent - the root initial.

The sites at which this process actually happens are diverse. Although these sites are usually inside the pericyclic sheath and close to the vascular tissue - predominantly in the phloem ray cells - but can be found in the inner cortex, the cambium, medullary rays and almost anywhere that suitable parenchyma cells are found. In any particular stem cutting the initials are not necessarily confined to any one type of site but may be found with different sites of origin.

Once the root initial is created it then proceeds to differentiate into a root primordium. Eventually this primordium differentiates as a root, together with its root cap, and penetrates the pericyclic sheath, through the cortex and bark to the exterior. Concurrently the root is also connecting to the vascular tissue so that the root has a normal and developed connectivity with the conducting tissues of the stem.

The final issue concerns how long this process will take and there is no definitive answer - as there appears to be a wide divergence in the speed at which the initiation is triggered and how fast the development will occur.

Although it is, logically, reasonable to suppose that the rooting response is initiated by the activity of plant growth regulating substances, it is certainly not clear how this happens or what is the cue for a particular site to become active. Presumably the process is controlled by particular genes - but this takes the process to another area of comprehension!

Woody Plant Propagation from Stem Cuttings

The Pericyclic Sheath

'A Resume - an explanation of a poorly investigated condition'

Despite the recognition of the existence of this structure, as a significant part of stem development, for at least a century, there has been no significant investigation in terms of its influence in stem cutting propagation until recently and then only fairly cursorily in limited anatomical and physiological studies. Its correlation with the development of adventitious roots and their emergence has received scant attention and requires some relevant investigation (if only from an economic standpoint) as it is evident that in some woody plants it is a significant factor in limiting the potential rooting of stem cuttings.

During the secondary thickening phase of the vascular tissues in the development of the stems of woody plants, there is a concurrent development of a sheath of cells within the inner limit of the cortex - in developmental terms it represents the outer perimeter of the stele. It is surmised that this is a protective mechanism against pathogens and, when thickened, also provides some structural rigidity. It is variously described as the **Pericycle**, **Pericyclic Sheath** or **Sclerenchyma Sheath**.

In many plants this sheath develops no further than consisting of parenchyma cells but in many woody plants, structurally, it consists of a layer cells which are principally of sclerenchyma cells (as fibres or sclereids); this may be several cells thick but can vary in the density of its structure and texture - ie it can vary in the degree to which parenchyma gaps occur and the degree to which the sclerenchyma cells are thickened.

It surrounds and encloses the vascular bundle complex. Its apparent significance in propagation is in the way that it may act as a barrier to root emergence (or may influence and hinder root initiation) as it is normally within the vascular complex that adventitious root initiation occurs and the root primordia develop.

In many (usually regarded as easy to root) species the sheath is not sufficiently 'strong' to impede root penetration to the exterior and the root (with its root cap) will rupture the sheath and push through readily. However there is evidence that a 'strong' sheath can impede root emergence and roots will deviate downwards

when they encounter the barrier, and emerge through the base of the cutting.

Variation in 'density' and 'mesh' - ie the continuity of the sheath and hence the occurrence of parenchyma (or sclereid free) gaps, thus, more often than not equates to, and reflects in, 'ease of rooting' - and a complete and dense sheath usually heralds poor rooting.

Although there has been little (or virtually no) detailed observation on the effects of the speed of growth of a new stem on the proportion of parenchyma gaps, it is reasonable to propose that the improved ease of root initiation associated with this activity, has caused a decrease in the density of the sclerenchyma cells and an increase in the occurrence of the sclereid free gaps.

Recently a similar effect has been reported for the effects of Etiolation treatments to stems of *Carpinus betulus fastigiata* - the indications are that, after such treatment, the sheath contains a greater proportion of sclereid free gaps than are found in non-etiolated shoots and that this can be correlated with an improved rooting response - the response was evident for three months (1996, Maynard and Bassuk, J. Amer. Soc. Hort. Sci. 121(5) 853-860).

Adventitious roots may not be able to penetrate to the exterior therefore they may have to turn down and emerge from the base of the cutting - this is often evident in Hardy hybrid Rhododendrons - when using a single thick extension shoot as a stem cutting; conversely a thin shoot emanating from an umbrella of shoots - usually developed as a result of disbudding and which, as a result, 'grow faster' will develop roots laterally through the stem. The thick shoot as a cutting also tended to respond to a shallow, basal slice wound or scoring - a process which reduces the integrity of the sheath - and enhanced rooting when propagation was attempted.

The following paper has reported that there is a direct correlation between the rooting response and the proportion of sclereid free gaps in the sheath for two species of North American Oaks - *Quercus bicolor* had more sclereid free gaps than *Q. macrocarpa* and also demonstrated a much greater root production on stem cuttings (2008, Amissah, Paolillo and Bassuk, J. Amer. Soc. Hort. Sci. 133(4) 479-486).

A similar response has also been reported in a comparison of two apple rootstock varieties in which M5 roots readily and M25 does not and that this is directly related to the proportion of sclereid free gaps in the sheath.

Woody Plant Propagation from Stem Cuttings

Topophysis

'A low profile feature in Stem Cutting propagation but significant especially in Conifers'

This term describes the influence of the apical meristem of a stem cutting on the growth habit of the newly created plant. The orientational and organisational state of the meristem which determines the growth habit of a shoot is fixed by the position of the lateral bud from where the cutting emanates and from which it originates. Consequently the habit of growth which this shoot has adopted, on the donor plant, will become that of the new plant - it is the inherent characteristic of a propagule to grow in the same orientation as the branch from which it was isolated. This condition remains stable through vegetative propagation. It should be emphasized however that these influences are, in the majority of plant species, very short lived and do not significantly affect the production of a normally oriented plant.

It is particularly this effect which has given rise to the various prostrate varieties of Sequoia sempervirens - where the cutting material has been taken from the tips of the mature downward sweeping branches and the habit of the resulting new plant continues in a prostrate fashion. This cannot even be mitigated by attempting to train the stem vertically up a cane - as soon as the constraint is lifted at the top of the cane the stem will revert to becoming prostrate. Eventually the habit from an apical bud may revert to the orthotropic upright habit.

*Cutting material taken from shoots of Alnus glutinosa **Pyramidalis** will only produce true to type erect plants when the material is selected from orthotropic upright shoots, the plagiotropic lateral shoots do not grow erect.*

The same response was found in Gingko biloba where only vertical shoots produce the patterns of typical growth.

The normal pattern of growth is described as **orthotropic** and the habit of growth from a particular lateral bud is described as **plagiotropic**. Eventually the exhibited plagiotropic growth in the new plant will revert to the normal orthotropic growth and in most species this occurs almost immediately but in others this may take some long time - ie there is a species related duration to this influence. The influence of plagiotropism appears to be hormonally

controlled as the effect increases from the apical meristem - affecting the lateral buds and increasing in influence in a basipetal direction.

The effect of topophysis is particularly apparent in the selection of cutting material from Conifers and has been demonstrated especially so in Araucaria, the Redwoods, Abies, Picea, Pinus, Pseudotsuga, Tsuga, Taxus and Podocarpus.

However there has been some investigation into the effects of topophysis on less obvious characteristics which may influence the quality and uniformity, albeit only marginally, of an otherwise normal broadleaf crop. These influences are often short lived but can affect the uniformity of a relatively fast growing crop. These investigations have chiefly been conducted on Roses grown for cut flower production - where the uniformity of crop responses and exacting production schedules are an essential feature. It has been shown that a stem which has been divided into successive single leaf bud cuttings will demonstrate differing characteristics according to the acropetal position of the bud on the original stem - affecting the thickness of the shoot, internode length and size and precocity of flowering on the resultant plant.

In woody plant propagation practice this consideration is only significant when regenerating those species in which this characteristic is sufficiently dominant to affect the outcome.

Woody Plant Propagation from Stem Cuttings

The Factors involved in the efficient operation of a Mist Propagation unit

The advent of the intermittent mist propagation unit, in the early 1960s, as a commercial piece of equipment, was a major advance in the then technology for environmental control in plant propagation. It permitted the regeneration of soft wood cuttings (with their high inherent regenerative capacity) to be achieved relatively easily and successfully by maintaining their survival during the root initiation and development process. It allowed a much greater range of plants to be propagated from soft wood cuttings and this substituted many of the traditional techniques which had been necessary and costly in order to achieve their propagation.

The principle aim of the system is to maintain the normal water status of a soft wood cutting - by reducing water loss from transpiration to a minimum and increasing atmospheric humidity. This reduces the chances of wilting and will maintain the turgor of the cells at optimal status. This condition enhances root initiation and at the same time the system provides suitable and relevant levels of light, carbon dioxide and temperature for the cutting to develop without stress.

The operation of the system is achieved by spraying fine water (50 to 100 μm) droplets, from above, onto the surface of the cuttings to create a complete water film. As a result of evaporation this film is reduced until it is no longer a complete cover and a sufficient amount is then applied, automatically, to replace the film.

The required effect is achieved by the action of evaporation - this cools the exposed leaf surfaces and the surfaces of the internal cells so that the intercellular spaces have a high vapour pressure and thus does not encourage water loss from the cell surfaces. In addition there is a cooling of the immediately surrounding atmosphere.

If however the cutting does become stressed the stomata (usually on the lower side of the leaf) will close to reduce water loss but this will also mean that the movement of carbon dioxide into the leaf for photosynthetic activity is curtailed.

The success of operating the system is to develop the efficacy of the control mechanism so that it applies only sufficient water to maintain the evaporating water film and to ensure that on reduction it is replaced without delay.

Excess water application leaches nutrients and minerals from the leaves and so reduces the efficiency of root initiation, development and subsequent establishment. This factor becomes more significant the longer the cutting takes to root and therefore is more important for those species which are difficult (slow) to root and occupy the unit for long periods.

The excessive application of water will also necessarily cool the rooting medium unnecessarily and, in order to maintain the required temperature in the medium for rooting, will inevitably increase energy costs. It may also reach, if not properly monitored and controlled, a level at which the medium becomes waterlogged and thus affects the level of aeration of the medium. Hence the constituents used in the composition of the rooting medium must permit satisfactory drainage.

The system also allows the access of light - which enhances the potential for photosynthesis. However maximum summer light is not necessarily required as the amount of carbohydrate production required for the physiological activity in the production of adventitious roots is not particularly high - apparently there is some evidence to suggest that high carbohydrate levels can even be counterproductive.

Light is a source of energy and hence high light intensity will raise the ambient temperature to the detriment of maintaining the balance of humidity in the atmosphere surrounding the cutting and inside the leaf itself. Thus it is probable that shading in summer may be necessary to mitigate this effect and, as indicated above, this may not be detrimental.

Heating of the rooting medium will be required to maintain the temperature level of 'bottom heat' needed to optimize root initiation - this is generally set at 20°C for the great majority of subjects.

Thus the efficient operation of a mist unit is to achieve a balance of all the environmental factors such that the survival of the cutting and its normal metabolism and activity are not compromised. This involves attention to the relationship and balance between the following environmental features:- water, temperature, light, carbon dioxide, oxygen and nutrition.

For the most efficient operation of an intermittent mist unit the significant feature is to create the most effective and evenly spaced application of the water droplets so that the entire system is operating uniformly and that this is achieved with minimum water usage. As the normal system of control for water application is to provide an artificial leaf surface that will produce an evaporative response equivalent to that of a leaf, the reaction will therefore very much be a response to local weather conditions. The trick therefore is to site the artificial leaf so that it successfully achieves the required responses.

Because of the high humidity and temperature levels maintained in such a unit the situation is ideal for the development of disease especially and it therefore paramount that intensive attention is paid to the maintenance of hygiene in the entire unit.

Attention will also need to be paid to the quality of the water and the regular maintenance and servicing of the water delivery system so that it remains efficient and uniformly effective. Problems can arise with hard water, the development of algae and the occurrence of liverworts and mosses on the benches and rooting medium.

Although the operation of an intermittent mist system can be seen as a simple, elegant and useful adjunct for the propagation of soft wood cuttings - and it has indeed revolutionized the potential for the successful propagation of such cuttings - its operation is in fact a complex of many factors which need to be monitored regularly and individually for an efficient outcome.

In conclusion although it is reasonably clear as to what can be done to maintain the efficiency of the unit - in practice the unit is subject, in the context of the British climate, to the vagaries of the local situation and will require individual attention to local conditions. Latitude also has an input insofar as daylength - varying through the seasons will also have its influence.

Woody Plant Propagation from Stem Cuttings

Softwood Cuttings

This type of stem cutting is made from the mainly non-lignified, actively growing, soft growth (in the very early stages of the initiation of secondary thickening) of the current season's extension. Because of the relatively elementary level of cell differentiation it has, generally, a high capacity to develop adventitious roots (as it inevitably has little de-differentiation to discard) - assuming that the plant has an acceptable level of inherent capacity to regenerate. However this advantage is balanced by the difficulty of maintaining the material in a viable and effective condition so that it can respond. This implies, especially because of the susceptibility to desiccation, that a sophisticated system of environmental control is required. In the UK, with its continuous variation in weather patterns, it is customary, for this purpose, to use an intermittent mist system or fogging unit. (see article - Mist Propagation)

1. Those deciduous woody plants which have an acceptable level of regenerative capacity will regenerate throughout the season when softwood material (usually tip growth) is available and this will root and establish quickly until quite late in the growing season eg:-

Abeliophyllum

Deutzia

Forsythia

Hydrangea

Philadelphus

Weigela

2. However the most difficult group to deal with are those genera which have a limited season of response from bud break until more or less this flush of growth declines (often as little as 4-6 weeks) and there is effectively no further flush of growth during the year - in practice this energy is diverted into flower and seed production. Thus there is only this limited window of opportunity - as capacity to regenerate vegetatively declines very quickly after this phase.

The practical and economic implications for cutting production determine that the stock plants are manipulated to develop the maximum number of suitable cuttings. The object is to produce shoots from lateral buds which are of an average caliper, as these develop the most satisfactory rooting response. This will involve

pruning back the tips (which if left, tend to produce thick, stocky shoots - these tend to depress lateral growth and exhibit lower regenerative capacity). The operation should be conducted sufficiently early in the dormant season so that these lateral buds lose the influence of the apical dominance and will then break uniformly along the branches and grow at an even and comparable pace so that a maximum, uniform crop of cuttings is available.

The cuttings are collected as the spring flush of growth begins to decline and at this stage the base of the cutting is just beginning to lignify. The cuttings should be severed from the parent, flush with the previous season's growth, so that the basal swelling is incorporated.

Generally these plants only develop the one flush of growth annually and the window of opportunity (ie when regenerative capacity is maintained) can be quite short (4 to 6 weeks for deciduous azaleas). The cuttings will be relatively small (short) - about 3-5 inches for the deciduous azalea.

These subjects are deciduous and often slow to root and establish physiologically - it is important, therefore, that, before the onset of dormancy, they develop as an 'integrated' plant in order to survive over the winter and emerge from dormancy satisfactorily in the Spring. This implies that the cutting develops shoot extension growth and that this is part of the overall pattern of normal growth so that the new plant is physiologically integrated. Thus it is capable of a normal autotrophic existence and can produce and store carbohydrate for overwinter survival.

Examples of this group of plants include:-

Deciduous Azaleas (*Rhododendron*)

Large Flowered Lilacs (*Syringa*)

Flowering Dogwoods (*Cornus*)

Fringe Trees (*Chionanthus*)

Japanese Maples (*Acer*)

Smoke Trees (*Cotinus*)

as well as:-

Corylus

Corylopsis

Hamamelis

Fothergilla

Parrotia

Pistacia

Stewartia

Styrax

Halesia

Deciduous *Euonymus*
Viburnum - *Carlesii* types

The incorporation of the basal swelling of the current season's extension growth is a significant contributor to the success of this technique as it is this area of the stem which has developed a high level of regenerative capacity - largely because of its structure and the vigour and speed of its development.

Practically the most significant part of the propagation process is concerned with maintaining the turgidity and optimum water status of the material and this is important from the moment the cutting is severed from the parent. Thus the material is best collected when it is turgid, collected in small batches and processed quickly.

When the cuttings have been collected they require little or no further trimming unless basal leaves need to be removed in order to facilitate insertion into the rooting medium - this should be done with clean sharp cuts.

As these subjects are on the cusp of a satisfactory rooting potential, it is probable that they will benefit from the application of a suitable 'hormone rooting material' to enhance the rooting potential. This should be applied to the base of the cutting only and not dipped so that it coats the outside of the bottom of the cutting - as those concentrations needed for rooting are likely to inhibit root emergence through the side of the cutting.

Once treated and inserted into a relevant rooting medium they should be placed in, and subjected to, a relevant system of environmental control which will maintain a suitable water status, with adequate light to maintain photosynthetic activity at an advantageous level and an effective temperature regime which provides for root development and prevents excessive aerial stem growth until regeneration begins. Conventionally this is achieved in a mist propagation unit with bottom heating to maintain a temperature of 20°C (the optimum economic level for root production in soft wood cuttings) - although fogging systems are also effective. It is relevant to ensure that the water application system is operating only at the required level as the often extended rooting period will cause leaching of the cuttings if the application is greater than that which achieves the desired effect.

The commonest problem, which is encountered, is that the cuttings, although producing roots, do not develop sufficient shoot growth,

before the advent of dormancy inducing conditions, to create a physiologically integrated young plant and develop a sufficient carbohydrate store. It requires such a status in order to respond to the stimuli which will allow it to emerge from dormancy when conditions are suitable in the spring.

These dormancy inducing conditions (reducing day length and lowering temperatures) can be reached by early August for some species. Thus practically it may be necessary to extend the season of potential development by extending the day length, maintaining temperatures and ensuring high enough potash levels to ensure a response to the stimuli. The alternative is to extend the season forwards by growing the stock plants under protected conditions so that the shoot growth is produced earlier in the season and the rooted cutting has a longer natural season in which to establish.

3. Another significant group of woody plants, often with a limited pattern of capacity to regenerate root initials, which will respond to a similar process and regime, is the deciduous woody members of the **Rosaceae**.

The season of rooting capacity is not so critical to this group although in some cases, because of the lengthy period needed to achieve root production, the season is therefore confined to the early months as there is not the same spurt of spring growth and the season of capacity may well last through the season. There is, of course, considerable variation in the ability of the many species to regenerate.

Deciduous **Rosaceae**

The pome group are generally slowish to root and benefit from the early season propagation in order to give time for the production of a well established liner before the onset of dormancy:-

<i>Amelanchier</i>	<i>Aria</i>
<i>Aronia</i>	<i>Cormus</i>
<i>Chaenomeles</i>	<i>Sorbus</i>
<i>Crataegus</i>	<i>Torminaria</i>
<i>Cydonia</i>	
<i>Malus</i>	
<i>Mespilus</i>	
<i>Pyrus</i>	

That group which are best described as 'Spiraea' like are generally more easy to root and establish reasonably quickly and can thus be propagated in mid-season:-

Spiraea
Holoduscus

Neillia
Physocarpus
Sorbaria
Stephanandra

Generally the Plums, Peaches, Almonds, Cherries etc are slow and require the full season to establish:-

Prunus
also
Exochorda
Lyonothamnus

Woody Plant Propagation from Stem Cuttings

Hardwood Cuttings

The propagation of woody plants by hardwood stem cuttings is, by definition, limited to deciduous subjects which are designated as being in the dormant condition and therefore leafless. The technique involves the regeneration of pieces of the current season's stem growth which have fully matured and are then also at a reduced level of physiological activity during this period.

Structurally the stems at the hardwood stage have completed their growth and differentiation for the year and are fully mature. All the cells have completed their differentiation and the lignification of the relevant tissues has been fully developed. At this time the cells are farthest removed from an ability to de-differentiate and to re-orient for root initiation - thus the process will be at its most complex and time consuming - and the capacity for root production in such material will inevitably be less than when in the soft or semi-ripe condition.

Consequently the range of subjects which will respond to this method even with support and enhancement techniques is necessarily relatively few.

The seasonal effect on the expression of the capacity for root initiation

One of the most underestimated aspects of the process is the significance, for those subjects with a marginal response, of the influence of season on the capacity for regeneration ie the development of root initials. The season available for making hardwood cuttings will begin at leaf fall and end with bud break. The assumption could well be made that the capacity for regeneration remains constant during this period - however it does not necessarily respond in this way. For subjects which already have preformed root initials present in the stem, the seasonal influence will be negligible. However for those subjects which have an inherent capacity but do not have the preformed root initials, the process of root initiation has to begin from scratch and it is for these more critical (and therefore more difficult) subjects that a varying response can be detected.

If comparable cuttings are made at intervals throughout the dormant season it will be found that the rooting response varies. It is highest at leaf fall, declines quite quickly to a base level, in

the sigmoid curve fashion, then remains more or less constant until just before bud break when it rises again, in the reverse sigmoid curve fashion as the buds break - although that base level is not necessarily particularly low.

The above concept looks fairly foolproof - however it lacks one defined parameter - the definition of 'leaf fall' and in those subjects which are marginal in their response it could be economically significant. As far as the plant is concerned the plant has become dormant when it abscisses its leaves and it is this activity that appears to be crucial - leaf fall is not when the leaves actually detach but is when the abscission layer is complete.

The actual timing of the completion of the leaf abscission layer is not a constant feature to all deciduous woody plants and in any one species may vary according to the level of maturity of the individual stock plant and its manipulation, the particular growing season and the latitude. In this particular context, where the stocks have been stooled to produce vigorous stems in a vegetative condition, leaf retention is more often than not delayed beyond the normal mature condition. Stooled apple rootstock stems, for example, do not absciss their leaves until December in the south of the UK whereas stems in a 'normal' growing condition will absciss some six to eight weeks earlier.

Maximising the capacity of the material to regenerate by the manipulating the stock plant to develop maximum vegetativeness

The capacity for the initiation of roots in hardwood cuttings has been shown (Article 2) to be a response to the increased growth rate of the stock plant stems - described as 'vegetativeness'. This is characterized by the upright growth of the stems and a lack of flowering potential. This has been achieved by the establishment of stock plants and then stooling or hedging them during the dormant season to induce a considerable reduction in the existing root-shoot ratio and hence cause the development of rapidly grown and vigorous shoots during the growing season to return the growth pattern to balance.

Methods employed to encourage successful propagation

Unless it is otherwise indicated, the separation of the cutting from the stock plant is conducted at leaf abscission. What this concept indicates is that there is a fairly attenuated season (over several weeks) for propagation by hardwood cuttings when dealing with the diversity of subjects available.

For conventional purposes hardwood cuttings are made according to the following template - to achieve ease of handling, the productive use of the available resource and a cutting which is of a sufficient size to survive, regenerate and establish.

If the subject has a reasonable capacity to root it would be assumed that the whole length of the year's growth, which is mature and fulfills the parameters, can be used. If the subject has lower capacity it will probably be prudent to limit to the cutting which incorporates the basal swelling

Cuttings +/-15cm long

Bud at top diagonal cut above

Horizontal cut at the base (or below a node if hollow stemmed or soft pith present)

Thick caliper for food storage

Use sharp, scissor style secateurs (not anvil type which will crush the tissue).

Bundle in convenient sized units

Treat with a liquid PGRS

When the cuttings are inserted they should be to a depth that about 3-4cm are left exposed

There are, in general terms, four methods (relating to the degree of influence which may be available for environmental control) for subsequently dealing with hardwood cuttings in order to achieve regeneration:-

Direct sticking

Callus bin treatment

Cold frames

Heated (Garner) bin treatment

Direct Sticking without pre-treatment

Unless the environmental conditions, during the winter season, are particularly benign this method is limited, in cold temperate climates, to those subjects which have pre-formed root initials already present in the stem and are therefore 'ready to go' and will demonstrate an acceptable level of productivity. The system involves making the cuttings (which may or may not have been cold stored) and inserting directly into field conditions without further treatment.

Examples of suitable subjects include relevant Willows (*Salix*), Poplars (*Populus*) and Flowering Currants (*Ribes*).

Callusing bin prior to direct sticking

As has been shown elsewhere (Article 1) that although callus formation is usually a precursor to root initiation and the same conditions are needed for its development, it is a concurrent process and not directly related. The advent of root initiation in hardwood cuttings appears, nevertheless, to benefit from the same conditions that encourage the development of callus tissue and thus treatments that encourage callusing will usually enhance the rooting potential. For those subjects which will respond and initiate roots fairly readily, within this scenario, the callusing of the base of the cutting prior to sticking will enhance the process.

The process may be further enhanced by the application of rooting hormones to the base of the cutting, using a suitable concentration.

Callusing is usually achieved by ameliorating the environment around the cutting, especially at the base where the increased temperature, provided by the protection from frost etc, will enhance activity. A sufficient effect can be realized by using a straw bale bin to achieve the desired results - the details of construction are well documented in the literature.

The following genera contain species which will respond to this method - be aware that the response is not all encompassing but is species (or even varietal) related:-

Forsythia, Jasminum, Spiraea, Holodiscus, Physpocarpus, Neillia, Rhodotypos, Stephanandra, Deutzia, Philadelphus, Sambucus, Tamarix, Buddleia, Cornus (coloured bark dogwood types), *Viburnum* (*V. farreri* and *V x bodnantense* types) *Euonymus, Symphoricarpus, Ligustrum, Laburnum, Platanus* and *Weigela*.

The usual practice is to line out from the bin (as for direct sticking) in the spring as soil temperatures begin to improve.

Cold Frames

The benign environment of a cold frame will achieve the same end product as the previous callus/direct sticking method but can be operated in the early winter and the cuttings left in situ over the winter season and for the ensuing growing season (with protection removed in the early spring).

Heated (Garner) bins prior to direct sticking

Fundamentally this method is a sophistication of the callus bin technique but chiefly improving the rooting response by the use of bottom heat.

During the post war years Robert Garner at East Malling Research Station was continually attempting to improve the rooting response of fruit tree rootstocks from hardwood cuttings - chiefly apples but also plums, cherries and quince. He recognized the quality of 'vegetativeness' and then by gradual sophistication he modified the various environmental factors that improved rooting in a callus bin. This culminated, in the mid-1960s, in the development of the 'Garner' bin - this concept harnessed, the use of bottom heat and 'rooting hormones' together with the manipulation of the stock material to produce better regenerative response. This work was carried on by Brian Howard and reference should be made to his papers of that time. Subsequently advances in technology have improved the equipment available, the critical aspects of the use of rooting hormones and the materials for construction of the bin. The details of construction can be readily access.

This technique has also been applied to various ornamental subjects and has proved successful (*inter alia*) for *Morus* and *Platanus* - but has not 'caught on'.

There are many variants on the theme in modifying hardwood cutting for particular end products:-

Longer cuttings where the end product is required with a leg - currants and gooseberries

disbudding - removing all but the top two buds to avoid subsequent suckering - *Rosa multiflora* for rootstock use

Longer cuttings for fruit tree rootstock use to be budded at +/- 20+cm

Long cuttings to create 'standard stems' - *Rosa rugosa*, *Salix* for top working with Kilmarnock Willow etc.

Woody Plant Propagation from Root Cuttings

'Some notes on an underexploited method of Propagation'

Among the several intensive systems of vegetative plant propagation, the production of plants from root cuttings offers one of the simplest and least complex techniques available, as it makes effective use of limited quantities of suitable propagating material and does not require any of the sophisticated systems of environmental control favoured for the regeneration of leafy cuttings.

The object of the process is to initiate adventitious bud development in a separated piece of root and then to establish the resultant new plant as a liner.

The propagation of plants from root material is basically a simple, reasonably rapid and economic process but despite these not inconsiderable virtues it is a technique which has not generally been widely accepted or extensively practiced within the nursery industry - except for a few particular subjects such as Seakale, Horseradish, some Poppies, the various Sumachs, border Phlox and some Alpines.

The regeneration of plants from root material is by no means a new or innovative concept - for as long ago as 1662, John Evelyn was writing in his famous *Sylva* of the possibility of cutting a root from a tree and leaving it *in situ* to develop. By 1731, Philip Miller, in *The Gardener's Dictionary*, was describing the propagation of certain trees from root cuttings as an established practice. Since that date various reviews of the literature related to this technique (eg Stoutmeyer 1968) reveal that hundreds of tree and shrub species have been demonstrated to respond to this technique. However it has nevertheless never become an established practice except as above.

Such surveys indicate the undoubted potential of the technique but it is relevant to enquire why the technique has not taken its place in propagating schedules when other more complex systems (eg mist propagation) have been widely accepted. The answer almost certainly lies in the perceived unreliability of the process - for despite propagating with apparently ideal material and providing the required environmental conditions, regeneration often fails.

The problem has been that in the past, quite simply, not all the components of the technique have not been fully understood - the

process has never been intensively analysed - so that particular limitations have not been recognized. Because of this uncertainty of the outcome the whole concept was often ignored or discarded and relegated to the position of being 'difficult'.

The technique however can be a successful enterprise and large quantities of plants can be produced from relatively small quantities of suitable propagating material. It is therefore incumbent on the propagator to analyse the process, highlight the relevant features and apply suitable process in order to eliminate uncertainty and achieve success.

The primary consideration in determining success in regenerating plants from pieces of root is that the material has an inherent capability to actually regenerate and that this is sufficiently dominant to allow an economic production - a feature that is accountable in any propagation system. An exemplar list will be found in the following article.

The chief problem associated with this technique has been the unreliability of success when otherwise apparently very suitable propagation material has been used. However it is now sixty years since this problem was elucidated. Hudson (1954, 1955) in a simple and elegant piece of work demonstrated for Raspberries that there was a seasonality of response and that this plant only responded in the winter period. It is therefore a mystery as to why this technique of propagation has been so shunned.

The factors which influence the successful propagation of plants from root cuttings do not differ significantly from other techniques of regeneration from other plant pieces. Thus as long as the process is properly analysed and the factors are sequenced then a successful outcome should be achieved.

A few plants (eg *Rubus*, *Rhus*) are readily regenerated from root cuttings - largely because they develop pre-formed adventitious buds as part of the normal growth process and can usually be recognized as they develop suckers readily.

Plants produced from root cuttings will by definition have developed their stem system from adventitious buds and this will, initially at least morphologically and physiologically, be in the 'juvenile' condition - however there is no indication that this effect is more than relatively transient and the plant soon reverts to the mature condition.

The adventitious buds are initiated in the pericycle close to the vascular tissue - but sites may vary. Normally parenchyma cells de-differentiate and then become thin walled and develop large noticeable nuclei and dense cytoplasm.

As with any system of vegetative plant propagation, the production cycle can be defined in five phases:-

1. Preliminary phase

The various factors which govern the selection of the propagation stock are the same as for stem cuttings in terms of identity, clonal variation, age of variety, health etc. (Reference should be made to Article 1)

2. Preparatory phase

There will, probably, be little opportunity to remove suitable material, for root cutting propagation, from a container grown crop or indeed a field grown crop - as would be possible for stem cuttings. It will therefore be necessary to establish stock beds for the purpose.

The primary condition affecting successful regeneration is the **age** of the parent plant and this is a function of two aspects - the physiological age of the parent material and the actual age of the individual donor plant being used. Although an often ignored concept this is always a relevant consideration in determining the economic level of regenerative capacity required. In order to maintain vigorous growth of the stock plants it is prudent to have a regular replacement programme.

a) Stock Plant Manipulation

The preparation or manipulation of the stock plant to produce propagating material is effectively no different, in principle, to the processes required for the production of stem cuttings with improved capacity. As with stem cutting propagation - the emphasis is on engendering the highest regenerative capacity feasible in the roots which are to be used for propagation and in this respect the principles involved are very similar. Thus the stock plant is manipulated to develop, annually, a vigorous, rapidly grown root system in a 'vegetative' condition - a process which is analogous to that adopted for the production of stem material with a high capacity. However the process is inevitably made more complicated by the fact that the propagation material is developing underground and is not readily monitored.

The chief practical feature to be addressed is to determine the proportion of the root system which can be removed from the stock plant so that a sufficient amount remains for the successful re-establishment of the parent, but at the same time producing propagating material of sufficiently high capacity (produced as a result of rapid, vigorous growth) and inducing, by sufficiently rigorous pruning, the production of an adequate harvest during the following season. This factor is virtually ignored in the texts and in practice has to be determined by trial and error. For any commercial system it is important that a sustainable, regular and economic yield is achieved so that the quantity of propagation material meets a scheduled demand on an annual basis.

The production of an adequate supply of root cutting material can readily be achieved in most herbaceous plants if the roots of the stock plant are severely pruned - often virtually back to the crown - they will withstand this severity. However the response in woody plants is less tolerant and will normally require a less traumatic treatment. They will also require considerable attention to the development of suitable soil conditions for an adequate response.

b) Practicalities

The area where the stock plants are to be established and grown must be based on a properly and effectively ameliorated soil - which allows an unimpeded development of the root system. This conditioning will require the development of soil conditions which also allow:-

- a) ease of lifting so that the entire root system can be extracted without causing damage to the individual roots and
- b) a texture which is easily washed from the roots to provide a clean sample.

When the root system is lifted it is important that any separated roots are collected in such a way that the correct polarity can be maintained.

Attention will also need to be paid to the provision of adequate nutrition and irrigation in order to ensure that there is no limitation to root growth.

The logistics of the lay out of the stock beds also requires some attention in order to:-

- a) avoid any overlap of root development from other adjacent stock plants, to prevent misidentification of relevant material,
- b) determine whether there will be a replant issue (growth inhibition) if the stock plants are returned back on the same site, this is a potential hazard for several members of the *Rosaceae* and

c) ensure the land is clean and not contaminated with any remaining pieces of root from a previous crop which, potentially, may develop and cause confusion.

3. Regeneration Phase

This phase incorporates those factors which will influence the performance of the propagating material once it has been separated from the parent stock.

a) Seasonal influence

Although it can be shown that a particular subject has the capacity to regenerate from roots there is, as with many systems of propagation, often a distinct variation in response according to the season. It is the seasonal response of woody plants that has caused the issues with the technique in the past as it was not widely recognized that the 'on-season' was limited to the dormant period - as the conventional propagation of many herbaceous plants from root cuttings do not exhibit any variation with season.

Virtually all temperate woody plants that will regenerate from roots exhibit a distinct seasonal effect insofar as the 'on season' is associated with the dormant condition. As the plant becomes dormant there is a rapid increase in the capacity to regenerate which develops on the expected sigmoid curve pattern - when the maximum has been reached the level remains constant until just prior to bud break when the capacity declines rapidly in a reverse sigmoid curve pattern.

b) Treatment

1. Polarity

As with stem cuttings the best rooting response is achieved if the cutting is propagated in a vertical position and 'the right way up'. It is often the practice that those subjects with a fibrous root system and which develop thinnish roots are chopped into suitable lengths and set horizontally. This practice will normally produce regeneration but often with many pieces not responding (a suitable method if the quantity of material is not limiting).

However if the roots are selected for reasonable caliper and are inserted vertically the response is virtually 100% and the time taken to regenerate is significantly quicker.

The conventional practice for making root cuttings, and to ensure that the 'right way up' can be recognised, is to make the cuttings with a diagonal cut at the base and a horizontal cut at the top.

2. Plant Growth Regulating Substances

The conventional chemical aids to rooting in stem cuttings - NAA, IAA, IBA, Gibberellins etc - do not aid adventitious bud formation in roots and in fact are generally regarded as counterproductive. Although there is evidence to suggest that cytokinins (kinetin is often quoted) will enhance bud initiation in roots there is no readily available resource from which to obtain these materials and there is little or no information to determine which chemicals are most effective and certainly not in assessing the concentration to use.

3. Fungicide

As the cuttings are to be effectively buried in soil or compost, and as such are not readily monitored, it would probably be prudent to dress the cuttings with a fungicide for protection.

c) Environment

Depending on the 'hardiness' of the subject the regenerative environment can be as stark as the open ground or the limited protection of a cold frame or, for less successful material, the benign protection of a glasshouse. The potential for success will generally increase with increased protection and higher temperatures. This is usually represented by a more speedy regenerative response.

Until such time as regeneration begins there is virtually no need to provide moisture as the root cutting virtually has no capacity to take up water - it is merely necessary to maintain an adequate surrounding humidity to prevent desiccation of the cutting.

d) Practicalities

The portion of the root exhibiting the highest capacity (ie the fastest growth rate) will be the proximal end of the root where it emanates from the existing root system and grew fastest - for 'difficult' subjects this may be the only cutting that will respond.

1. Size of cutting

Factors governing the size of the cutting will be of significance as this will determine the quantity of cuttings which can be obtained from the resource available.

The size of the cutting will initially be related to the caliper of roots that the particular subject develops. However in theoretical terms the root will need to contain

a) a sufficient food reserve to initiate and develop an adventitious bud and

b) enough food reserve to sustain the root through this process until it produces a leaf area sufficient to become autotrophic.

The length of the cutting and hence the actual amount of food reserve required will be determined largely by the environment (chiefly the temperature) to which it is subjected as this will in turn determine the length of time the cutting has to survive before it becomes self-supporting.

As there is a wide variation in the characteristics of the root systems and the available environments to be used it will require an individual assessment of each subject to determine the most economic size of cutting.

2. Insertion

The cutting is inserted vertically into the compost or soil so that the top of the cutting is at the surface. The medium is then top dressed with perlite/ vermiculite/ grit to ensure good drainage and maintain maximum aeration at the site of regeneration

The root system of the new plant may develop from the root cutting so that the cutting becomes an integral part of the new plant or it may develop from the base of the developing adventitious shoot

4. Establishment Phase

Once regeneration has occurred (ie the cutting has produced an adventitious bud) the cutting can be moved on to a relevant liner container although it would probably be prudent to wait until the new root system has begun to develop - the operation will largely depend on the current workload and programme schedule.

Development will then depend on the provision of a conventional growing on programme with attention to the balance of the environment, nutrition, water etc.

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**Woody Plant Prpopagation
from Root Cuttings**

**A selected list of genera in which the capacity for root
regeneration is feasible**

Acacia	Fabaceae
Actinidia	Actinidiaceae
Aesculus	Hippocastanaceae
Ailanthus	Simabouraceae
Akebia	Lardizabalaceae
Albizzia	Fabaceae
Amelanchier	Rosaceae
Aralia	Araliaceae
Aronia	Rosaceae
Bignonia	Bignoniaceae
Brousonettia	Moraceae
Campsis	Bignoniaceae
Catalpa	Bignoniaceae
Cedrela	Meliaceae
Celastrus	Celastraceae
Chaenomeles	Rosaceae
Chilopsis	Bignoniaceae
Cladrastis	Fabaceae
Clerodendrum	Lamiaceae
Clethra	Clethraceae
Comptonia	Myricaceae
Cydonia	Rosaceae
Daphne	Thymeleaceae
Datura	
Dendromecon	Papaveraceae
Descainea	Lardizabalaceae
Doxantha	Bignoniaceae
Eccremocarpus	Bignoniaceae
Eleutherococcus	Araliaceae
Elliotia	Ericaceae
Embothrium	Proteaceae
Euonymus	Celastraceae
Fatsia	Araliaceae
Ficus	
Gleditsia	Fabaceae
Gymnocladus	Fabaceae
Indigofera	Fabaceae
Kalopanax	Araliaceae
Koeleruteria	Sapindaceae
Lagerstroemia	Lythraceae
Lapageria	Philesiaceae

Liquidambar	Altingiaceae
Maackia	Fabaceae
Maclura	Moraceae
Malus	Rosaceae
Maytenus	Celastraceae
Morus	Moraceae
Meliosma	Sabiaceae
Myrica	Myricaceae
Orixa	Rutaceae
Pandorea	Bignoniaceae
Passiflora	Passifloraceae
Paulownia	Paulowniaceae
Phellodendron	Rutaceae
Picrasma	Simaroubaceae
Populus	Salicaceae
Prunus	Rosaceae
Pyrus	Rosaceae
Rhus	Anacardiaceae
Romneya	Papaveraceae
Rosa	Rosaceae
Rubus	Rosaceae
Salix	Salicaceae
Sambucus	Adoxaceae
Sassafras	Lauraceae
Sophora	Fabaceae
Spiraea	Rosaceae
Symphoricarpos	Caprifoliaceae
Syringa	Oleaceae
Tecoma	Bignoniaceae
Ulmus	Ulmaceae
Ungradi	Sapindaceae
Viburnum	Adoxaceae
Xanthoceras	Sapindaceae
Zanthoxylum	Rutaceae

These notes were developed as a response to explaining why a particular propagation technique could aid a student in gaining both useful knowledge and confidence in their ability in knifework and at the same time allow the instructor to impart the widest range of relevant and related information.

Woody Plant Propagation Bench Grafting of *Aesculus*

During the 1970s the teaching of the practical aspects of Nursery Practices and the related plant propagation practice was still in its infancy and there was much knowledge to be collected, assembled and refined and then incorporated into the teaching programme. This was especially true when it came to the determination of which practical skills were to be taught, how the practice was to be demonstrated and what additional information could be disseminated in the process.

The 'Bench Grafting of *Aesculus*' as a teaching aid arose out of this exercise as it could be used to fulfil so many of the criteria expected.

One of the chief stumbling blocks faced by a student in propagating plants is the use of a knife - they are often chary of the implications and lack confidence in their ability not to damage themselves or to make the carpentry cuts correctly. However if they have been taught, initially, the ergonomics of how to hold and use a knife - then the crucial first step is to conduct operations on easily cut material (avoiding hard or otherwise difficult subjects).

The initial premise in seeking suitable subjects and techniques to develop was centred around refining the ease of the operation and that the materials could be readily used and manipulated in order to simplify the whole process. Thus among several techniques which were refined for this purpose, the bench grafting of *Aesculus* was one example but it can be used to demonstrate the simplicity of the approach and the wide spectrum of knowledge which can be associated during the process.

Prior to this stage, initial instruction would have included the demonstration of the types of knives (and the characteristics of their blades), the types of cutting actions involved in using secateurs and the acquiring of the skills involved in the sharpening of knives and secateurs as well as the inculcation of the importance of maintaining such kit in clean and usable condition. It is also at this stage that the basic ergonomic

movements in cutting plant material to achieve flat matching surfaces would have been demonstrated.

The refinement of the process included:-

a) the choice of carpentry joint to be used

A based whip graft was chosen because it required fairly simple cuts and that the joint provided a stable and rigid system for the tying in process - something that the novice finds somewhat difficult to achieve when using the conventional whip graft.

b) the subject to be employed

Aesculus was chosen because the texture of the wood in both one year old scions and the hypocotyl of the seedling is relatively soft and hence easily cut - it is not dissimilar to cutting into a bar of hard soap. Thus the student could quickly achieve proficiency and gain confidence in their own abilities with a knife.

c) rootstock selection

Aesculus could also be used to initiate a discussion on the merits and demerits of rootstock suitability and scion compatibility - as at that time *A. hippocastanum* was used almost exclusively as the rootstock.

d) production of seedling rootstocks

A paper is appended (of later date) which deals with this subject in detail.

e) production and selection of scions

The establishment and treatment of stock plants for the development of suitable scion material in the quantities required.

f) the significance of hygiene in preventing fungal infection or red spider infestation during the process of callusing and union formation.

As the vegetative propagation of clonal selections of *Aesculus* species by stem cuttings is difficult, the use of bench grafting or field budding and grafting has been the norm.

The Process

When bench grafting *Aesculus* the stocks used are dormant, one year old, bare rooted seedlings. The operation is carried out in February-March in order to allow a union to form and so allow a full growing season for the new plant to establish.

The grafting is carried out on the hypocotyl of the seedling as this ensures that the rootstock does not develop suckers.

Prior to the operation the rootstocks are washed and it is ensured that the hypocotyls are clean. Whether the taproot is pruned and to what length will be a function of how the next stage in the production process is designated.

The scions are selected from young trees that have been pruned to develop the desired type of growth. The shoots are selected from the lateral shoots, ie not those which would be regarded as leaders. This is determined by the fact that these shoots will be of a similar caliper to the rootstocks. Most subjects will thus produce suitable shoots between 18 and 25cm long when cut just at the junction with the previous season's growth, the terminal bud is left intact as it is unlikely to be a flower bud.

The caliper of the stock and the scion to be grafted should be selected to match as exactly as possible, so that when the joint is matched that the cambiums of both are immediately adjacent.

These notes accompany the line drawing attached

The scion is made, leaving the terminal bud intact so that a straight through leader is immediately present for the young plant. The main basal cut is made, obliquely, 2-3cm long, through the lowest pair of buds so that one bud remains on the side of the scion. Thus the scion will be about 15cm long.

The stock is then cut horizontally through the top of the hypocotyl, using sharp secateurs, so that the stem system is removed. A matching oblique cut is made into the stock but finishing after some 2.5cm and a short sloping cut is then made to meet the base of the first cut from the opposite side - thus developing the 'base' of the whip and so preparing the stock to receive the scion.

The scion can then be finished by making the basal cut from the opposite direction to match the slope of the short basal cut on the stock.

This then allows the two pieces to be put together snugly and with a sufficient rigidity and firmness that tying in can be achieved easily and without movement. That the correct length cuts have been made can be seen if there is a church window cut showing above the stock - this ensures that the cambiums are matching from as high as possible on both stock and scion.

The graft is secured using a thin elasticated rubber tie in a tight spiral under tension so that the union is fixed. The complete tied area is then sealed with a layer of paraffin wax in order prevent water loss.

The graft is then placed in a suitable environment for the union to develop - this usually implies that the temperature in the region of the union is at 20°C.

Callusing of the cut surfaces will be apparent through the tied region and the ties can be cut when this stage is reached.

Woody Plant Propagation Vegetative Seed Propagation

Some comments on Apomixis

Apomixis (or sometimes **agamospermy**) is a term used to describe the production of, otherwise normal, seeds by a vegetative process - an asexual process in which meiosis (reduction division) is not involved. This implies that the ovule is produced by mitotic divisions and produces a seed (in the relevant plants) with a 2n genetic complement and thus is a clone of the parent. However despite the above assertion seeds have also been shown to be produced by mitotic division of meiotically produced gametes.

This is an abnormal system and in woody plants is chiefly significant in the Family *Rosaceae* and generally the sub-family *Maloideae*. It does however occur fairly commonly in herbaceous genera - mostly in the *Asteraceae* and *Poaceae* and also in the *Rosaceae* where the Brambles (*Rubus*) have a very complex system of such species.

The practical significance relates to the fact that seedling production is an extremely cheap system for the vegetative (clonal) propagation of those species (and in some cases cultivars) which produce such seed. It avoids the necessity for (usually) budding or grafting and the consequent rootstock production.

To all intents and purposes the resulting embryo and food reserve develops in the normal fashion - the seed developing from the mitotic division of a cell in the nucellus to produce an otherwise normal embryo - at least in the subjects quoted here.

In plants relevant to these notes, the action of pollination on the stigma is often still required to stimulate embryo production - although the pollen tube does not complete its growth and no fertilization occurs.

Apomixis, as a process, did not arise just once but has developed from several different routes and sometimes in conjunction with normally produced seed so that a mixture of sexual and asexual seeds is produced. Understanding the detailed implications reveals a complex arrangement of origins and systems and it is probably best left to the boffins to determine what is what. From a practical horticultural view point it is best to accept the simplistic view described above

Why apomixis should have developed is obscure, however it is prevalent in plants which have developed some form of polyploidy and would otherwise not be able to produce viable pollen or ovules. Thus species arise which are completely apomictic and are effectively clones.

Genera in which apomixis is not uncommon and is the sole result of the seed production process:-

Malus

M. toringoides

?Blenheim Orange - a triploid - apomictic

Sorbus

Cotoneaster

C. horizontalis

Amelanchier

Aria

A raft of localized species which are completely apomictic, are polyploid

Crataegus

Rosa Pfanders

Rubus

Apomixis is also economically important in Citrus, Mango and Mangosteen - most importantly in the production of seedling rootstocks

Apomictically produced seedlings develop through the life phases in the normal pattern - developing both juvenile and mature characteristics in the normal succession.

**Practical Aspects of the Propagation of
Temperate Ornamental Woody Plants
from Seed**

Contents

1. Introduction
2. Preliminary Considerations - The Seed
3. Collection, Extraction, Assessment and Recording
4. Viability, Vigour and Longevity
5. Storage
6. Dormancy controls
7. Germination
8. Liner production

Appendices

1. Reduction treatments for seed coat conditions
2. Endogenous dormancy treatment by chilling
3. Removal of chemical inhibition by leaching
4. The maturation of Immature and Rudimentary Embryos
5. Specialised seed treatments
6. Recording data

Encyclopaedia of subjects

Gymnosperms A-Z
Cycadales
Ginkgoales
Coniferales
Angiosperms A-Z

Index of genera cited

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1.

Introduction

'Hardy Woody Plants from Seed' (Grower Books, 1979) dealt with this subject matter in the context of that time and particularly it reflected the level of practically applicable knowledge and the technology which was available. Horticultural and scientific knowledge, as well as the almost ubiquitous electronic distribution and retrieval of information, have moved on since that time and the sophistication of the techniques used in the nursery industry has developed considerably - however it is still often difficult to locate and then be able to interpret useful information for the seedling production of a particular woody plant and indeed to know whether the detail actually exists and in an accessible form.

The development and assembly of those notes (during the mid 1970s) had been prompted by the volatility of European exchange rates at that time; this had created a lack of reliability in the normal pattern of the European marketing of nursery stock. This meant that supplies of seedling material became unreliable both in quantity and quality as stock was diverted, by the producers, to more financially lucrative markets. Reliability of supply therefore would be fostered by the encouragement of a home grown production. Because this industry was virtually non-existent at that time in the UK (except for one or two pioneer firms and the Forestry industry) little useful information relevant to British conditions was available.

Today these updated notes are offered in response to the sheer number and diversity of potential subjects of hardy, ornamental woody plants which are now available and could reasonably be propagated from seed. This state of affairs results from the immense expansion of woody plant material that has been discovered, collected, introduced and has subsequently matured in cultivation, in the UK, since the Second World War. It also reflects the increasing sophistication and knowledge of the gardening public in the UK which seeks to acquire more exotic woody plants and therefore also the retail trade which seeks to satisfy this niche market.

As previously, these notes have been developed in the context of the relevant requirements of nurserymen, lecturers and students, other professionals and interested

amateurs, in the UK, who need to be able to produce seedlings of hardy ornamental woody plants in a productive and economic manner.

In nature the reproduction of woody plants by the production of seed is generally a highly efficient but, nevertheless, improbable process insofar as the number of successfully established offspring as a proportion of the seeds produced and dispersed is more often than not infinitesimally small.

The germination of the seeds of woody plants of both warm and cold temperate climates is often delayed by the development of (sometimes complicated) strategies and mechanisms to block germination - in broad terms these are referred to as 'Dormancy' controls. These systems have evolved to synchronise the appearance of the new plant (seedling) with the occurrence of the most favourable environmental conditions for the process of germination of the seed and to maximise the chances of successful establishment and survival of this seedling. The objective of the propagator, therefore, is to determine the nature of these mechanisms and strategies for any particular species. These can then be analysed, interpreted and evaluated so that reliable, accurate, effective and suitable practical techniques for overcoming, eliminating or avoiding them can be developed. Thus, as a result, protocols can then be created to develop and establish a sequence of suitable treatments in order to achieve germination and seedling production in the most reliable and productive manner, with a speedy and synchronised emergence and within an acceptable time scale.

This philosophy, however, does not imply that every single seed in a sample should germinate but may, in complex cases with difficult, variable or poorly understood dormancy factors involved, allow the germination of the greater proportion of seeds in the sample with the sacrifice of the remainder - in order to achieve an economic outcome in a reasonable time scale.

The nursery production of seedlings of woody plants in temperate climates is undertaken to produce a variety of end products. Effectively there are a number of distinct types of commercial producers, generally with a particular market emphasis. The scale of production is also variable insofar as the operations vary from the large (field) scale

and extensive to the, often, small scale and intensive. This, in general, tends to reflect the value of the end product, the sophistication of technique required and the necessity for an economic and productive return.

Traditionally, in the UK, the largest seedling producers, in terms of numbers produced, have been the forest tree nurseries. Generally they are producing a fairly limited inventory of timber species under extensive conditions. The system relies on the large scale production of a relatively cheap product; although at the premium end of the market the processes and systems have become, in recent years, considerably more sophisticated and intensive. This tends to be a specialist industry without diversification from the mainstream.

The extensive, field scale production of low and medium value seedling crops such as hedging plants, fruit tree rootstocks and rootstocks for the more common ornamental subjects has generally been the prerogative of the continental producer, often working in co-operatives for marketing purposes. Historically the scale of production has been sufficient, collectively, to supply the whole of the European market. Large scale production is an essential component of the business in order to maintain a uniformity of product and a competitive price. Despite this there are several very successful UK producers who are succeeding in this medium priced market place by relying on offering a quality product with scheduled delivery dates. There is also a market in this sector for the production of native species of known genetic provenance for conservation purposes.

Over recent decades there has been a significant increase in the seedling production of high value, ornamental woody subjects in the UK - which reflects the increased sophistication of the market place in this country for such material and the overall benign nature of the climate which allows such a wide spectrum of subjects to be grown. This climatic advantage provides, to the local producer as well, a benefit not available to the traditional Northern European producer. The market for individual subjects is generally small but the range is extraordinarily extensive so that economic production must depend on very high levels of individual productivity - which in turn depends on the development of effective protocols and the evolution of an

efficient and integrated system of production as well an understanding of how the market place operates.

Thirty five years ago (at the time of the production of Hardy Woody Plants from Seed) the emphasis on seedling production was associated with outdoor seedbeds and growing on for the season to produce a '1yr field grown' seedling. The pregermination treatments were also reliant, in most cases, on the necessary treatments being carried out by the same token - eg the chilling, to break cold temperature dormancy, being achieved by autumn sowing in outdoor seedbeds etc. However productivity was becoming variable as the prevalence of mild winters did not provide a sufficient effect for some species. At this time the artificial pre-treatment of seeds of ornamental woody subjects, in commerce, was still in its infancy and there was very little relevant or reliable information on such protocols. While the situation is far from satisfactory today - much more of the processes involved are understood and the detail of these is available.

The production of seedlings in outdoor seedbeds is not addressed in these notes as the process has not substantially changed in the intervening years and what was written then is largely still relevant.

Nowadays (post 2010) the production of the seedlings of ornamental subjects is considerably more sophisticated, successful and productive. It has advanced, at its most intense, to the use of controlled treatment conditions, effective timing and a programme of continuous artificial treatment (ie which is not dependent on the vagaries of the natural environment) leading to the production of the liner stage in a container. This necessarily requires a reasonably detailed knowledge and experience - as well as access to relevant sources of information in order to develop protocols which are reliable. It also implies the availability and operation of various specialist bits of 'kit' - such as incubators, refrigerators, structures for environmental protection etc.

The nature of production is now represented by a much more streamlined and controlled system and should resemble the systems seen in a bedding plant or young vegetable plant production unit than formerly. The diversity of the subject matter in the inventory of a modern hardy woody plant nursery's seedling production unit however creates an

additional issue. It is this latter area of the detailed knowledge which is, almost inevitably, still less than satisfactorily served and it is this area that these notes are intended, where possible, to address.

The range of subjects covered in this survey contains several taxa that would be regarded as warm temperate in their distribution and only marginally suitable for cultivation in the UK. However if the projections for climate warming are credible then it may well be that many of these will become more widely planted. It is also relevant that many of the present day plant explorers are seeking provenances of nominally warm temperate subjects at the cooler extremes of their distributions.

Today there are several suppliers of woody plant seeds who will provide seed which has been treated, especially to overcome dormancy controls, and which is effectively 'ready to go'. However the inventory is inevitably limited and there is still much to be said for the 'control' provided by self involvement - once an understanding of the processes involved have been achieved.

Although the approach in these notes has been based on a scientific appraisal of the information that is available from those plant physiologists working in the field of seed biology, it is essentially intended as a practical treatise and merely attempts to interpret this current status - which is inevitably always in a state of flux.

The descriptive material in these notes has been gleaned and derived from a variety of sources - these are primarily scientists, plantsmen/propagators as well as commercial and amenity practitioners. This information has then been incorporated into the knowledge accumulated from fifty years of personal experience.

Nowadays the all pervasive internet provides access to unprecedented quantities of literature and information on every aspect of this subject from modern plant taxonomy and the important plant relationships which this unfolds to the intimate details of the requirements for germination of a wide variety of subjects. It is because of this ready access and the fact that the approach is practical, that it has not been deemed necessary to include the literature citations.

The objective of this exercise, at its most intensive, is to develop a series of protocols, for each individual subject, so that the entire process from the identification of the source to the production of a liner seedling can be determined by the use of a production process blueprint in order to achieve an economic and productive outcome.

The chief difference in approach to the presentation of these notes in relation to specific recommendations, from previous presentations, is the importance which has been attached to the taxonomic relationships of plants. Over time evolution has seen the development of what are now classified as Families and the genera and species within these entities are likely to have developed similar conditions and strategies in relation to seed structure, seed physiology. dormancy and germination (although not necessarily exclusively). This will therefore provide an indication as to the likely protocols needed for the successful seedling production of those subjects for which there is no relevant information available.

These notes are intended to provide a basis for the producer of relatively small numbers of seedlings, of a wide variety of subjects, from small samples of seed. Hence there is no emphasis on 'kit' for collection, extraction and processing - as most operations will be tailored to the individual subject and will chiefly be by hand work or by the use of 'domestic', manually operated equipment.

It is recognised that there are also many other professionals, concerned with propagating and growing woody plants, who will need relevant information in order to succeed or to waste less time finding out the hard way! In addition there are always dedicated amateur collectors and growers who need information.

It is to this purpose that these notes are offered in order to assemble as much of the relevant information as can be currently gleaned but inevitably it exposes the limited capabilities and knowledge of the author.

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2.

Preliminary Considerations - The Seed

The seed itself is the basic raw material of the seedling production system and as such its qualities define the potential status of the end product. The implementation of the commercial practicalities of the production system will necessarily have an influence on the individual quality of the end product in terms of appearance, size and vigour but essentially, however, it is the genetic constitution and integrity of the seed which determines the commercial outcome. This is derived on the basis of a reliably determined identity and quality (ie fitness for purpose). The integrity and quality of the seed, as the raw material, is therefore paramount in the success of the operation.

Determining the production inventory

There are effectively two approaches to the commercial production of seedling ornamental woody plants in the context of these notes. The first is to operate a controlled inventory in which particular subjects are identified for an annual production schedule and for which there is a proven and substantial market place or, secondly, to be opportunistic - always being on the lookout for the unusual and often new subjects - and grow whatever comes to hand - as long as there is a potential (and preferably a premium) market available. In practice an amalgam of both is quite possible or indeed a business may well concentrate on the seedling production a particular genus or group of plants (eg Acers, conifers etc)

All of these approaches have their advantages. The ever increasing number and diversity of exotica which are maturing (and thus producing seeds) - as a result of material collected, introduced and planted, in the UK, in recent decades - makes any of these courses a reasonable speculation and has much to recommend it. In the last forty to fifty years there has been an unprecedented explosion in the variety of ornamental woody subjects which have been introduced to cultivation in the UK. Many of these have now come to maturity and - with many as yet still immature - their discovery, locally, will provide an ever increasing potential inventory.

Whatever the decision, the production levels for each particular subject will inevitably be relatively small

unless a specific market, where a national distribution network - usually within garden centre outlet system - can be accessed.

Sources of Seed

a) Seedhouses and seed collectors

There are, throughout the world, seedhouses supplying the seeds of woody plants aimed at either commercial or non-commercial customers. They supply various categories of material. In Europe, especially, there are several large seedhouses (often acting as wholesalers) which source from both home and world wide contacts and offer a comprehensive selection. Elsewhere there are many seedhouses offering material chiefly of native species - in Australia, New Zealand, Chile, India, Japan, South Africa and the USA - which, in general, offer a comprehensive range and an excellent service.

Nowadays there is no necessity to enumerate a list of these suppliers (as would have been the practice in the past), as access to the internet provides most of the information necessary and tends to be current in its application and status.

In general the more specialist is the inventory of the commercial supplier the more reliable will be the material and will allow the possibility of negotiation as to aspects of the collection procedure and season of dispatch. Inevitably this relationship will depend for its success on the level and value of the business transaction.

Although these suppliers are very useful in obtaining stocks there is no substitute for the collection, by the practitioner, of any subject which can, satisfactorily, be sourced locally. Such a situation can allow the determination of the identity and quality of the material and can control the timing of collection. This creates the potential for greater certainty and thus offers a much more reliable outcome. The local provenance also provides an indication of the performance of that particular species in the local environment and climate and that it is functionally suited to the area. These comments do not imply that the process will cost less money but simply that control of the sequence of events will start at an earlier stage.

There are intermediate possibilities between commercial sources and self collection - as it is possible to make useful contacts with professional collectors or other reliable personal contacts, both at home and abroad, who will identify, collect and dispatch particular species to order.

b) Self collection

Identification of the parent and genetic status of the seed

Whatever the starting point - the most important consideration is to determine and confirm, with as much certainty as is possible, the identity of the subject to be propagated. Not only in the context of one's reliability and responsibility as a supplier but also for determining the likely protocols for production.

Although there are many reliable and very competent commercial seedhouses dealing in plants from temperate climates, which supply seeds in excellent condition; it is still the most satisfactory starting point if the seeds can be collected by the propagator at a particular time that has been predetermined and that selection in relation to quality can be assessed.

In general, for any particular species, there is one normal defined gene pool and virtually all of the seedlings from a representative sample of parents will deliver typical specimens. However there are some species which have a very extensive geographical range and which vary, in their characteristics, quite considerably, through it - often responding in various characteristics to the local environment so that the gene pool has become locally specialised. This range nevertheless is often clinal in variation so that these changes within the species are not easily delineated although, often, particular extreme variants are given specific names viz *Acer saccharum* (the Sugar Maple) changing gradually into *Acer floridanum* in the south and becoming the 'Caddo Maple' in the farthest west of its distribution (a drought tolerant form in Oklahoma). Similarly *Acer grandidentatum* (the Canyon Maple) varies from a shrubby tree in Utah to the single stemmed upright 'Uvalde Maple' in the east of Texas - on the Edwards Plateau towards San Antonio - the variation responding to increased rainfall. In the UK this variation can be demonstrated for native Oaks where the smaller stature and thick leaved characteristics of the type from the Cornish Atlantic Rainforest ecosystem differs widely from the type

to be found in the drier East Midlands such as Sherwood Forest! As long as this sort of variation is accounted for in the assessment of the parent sample, and is recognised, it does not become an issue. Hence any description of the provenance of a sample is a useful guide to expectations.

Once the identification has been confirmed then the next consideration is to assess the available individuals which are producing seeds - in order to select the most suitable parent. More often than not, however, there will probably only be one seed bearing parent plant available - or with luck there may be several specimens which exhibit sufficiently similar characteristics to demonstrate a reasonable uniformity among the available donors. It will be useful to determine whether these potential parents are seedlings, or are of vegetative (clonal) origin, as this will govern the limits of the available gene pool and its potential for variation.

It is probable, therefore, that the most significant consideration up to this point has been to assess the likely genetic integrity of the parent plant(s) - insofar as the seed crop has been produced as a result of self pollination or cross pollination from another individual of the same species. This will help to ensure that the offspring will be, reliably, of the same basic genetic constitution and be reasonable representatives of the species. In the great majority of subjects it is likely that particular selection will not be necessary as all of the available plants will provide a relevant genetic constitution whether growing in an advantageous or less suitable position.

c) Stock beds and Seed orchards

If it is the intention to establish a reasonably fixed inventory, there is much to recommend the establishment of one's own source of seed - where this is feasible - by planting suitable stock and allowing it to reach seed bearing maturity. In practice this will only be suitable for subjects (chiefly shrubs) which will reach sexual maturity in a relatively short time. The possibility of hybridity however should not be overlooked.

The chief issue to be addressed will be the availability (and cost) of the land - for the space required is inevitably an extensive exercise.

Hybridity

In a situation where other relevant, related species are growing in the same area, such as in Gardens and Arboreta, the potential for cross pollination and the production of hybrid offspring should be allowed for and thus seed collection should be avoided, from such potential parents - unless there is some particular value accruing.

Apomixis

There are a few species of woody plants (especially in the *Rosaceae* - eg some of the species in *Cotoneaster*, *Sorbus* *Malus* and *Aria*) in which the seed is produced by a process described as apomixis or agamospermy - an unusual process in which the ovules are produced by mitotic cell division (ie there is no halving of the chromosome number) and not by the normally expected meiosis (reduction division). Although the flower may well be pollinated, pollen tube growth is prevented from reaching the ovary and fertilisation does not occur - however seed development is still stimulated and it is the mitotically developed ovule with the $2n$ chromosome number which develops to become an embryo and eventually an otherwise normal seed. Thus seeds with the same genetic complement as the parent are produced and, to all intents and purposes, the new generation are identical to the parent. This phenomenon has much to recommend it insofar as the chance of hybridity or other genetic variation is virtually eliminated from parental selection.

Some Factors influencing Seed Quality

Selection of the parent(s)

If there is an opportunity to collect seed from more than one parent plant then it will be prudent to make some assessment of the specimens in terms of their trueness to type and that they represent the species. There is some value in selecting seed from a single stand alone specimen as there is every opportunity to make this assessment of all the features. This is not to imply that other specimens growing in a more competitive arena will not be acceptable but simply that the assessment is less rounded and complete.

In the forestry industry there is much selection of elite individual trees in order to ensure the very best qualities

for timber production in particular environments. However, with ornamental plants, this is not significant unless selection is being made for a particular trait - such as flower colour (*Daphne mezereum*) or leaf characteristics (purple and/or dissect leaved *Acer palmatum*). There occurs, in some genera, the existence of undesirable traits - which more often than not relate to the quality of timber production but do detract ornamentally viz the development of straight stems, as opposed to spirally twisted stems in *Quercus robur* and *Castanea sativa*. Otherwise no selection of parent plants is needed.

A depauperate plant, even, is not to be ignored if it is simply growing in a very competitive situation - poor apparent status does not necessarily imply poor genetic constitution.

Parental influence on the Quantity of seed produced

When dealing with the collection of seeds from plants that have only recently matured (and hence have reached a phase for flower and thus seed production), it will be evident that the plant, at this early stage in the mature phase, is still producing vigorous vegetative growth and that the greater part of photosynthetic product is being used in this growth. Normally the level of seed production will be relatively sparse and the quality of any seeds produced - especially in terms of the amount of stored food reserve - may be low.

As the plant progresses further into the mature phase and reaches middle age, the amount of annual vegetative growth declines and seed production in both quantity and quality potentially improves. At this stage, vegetative extension growth has moderated considerably and the plant has reached the greater part of its ultimate height and spread. This increase and stabilisation of the growth pattern is accompanied by maximum leaf area (ie photosynthetic area to produce carbohydrate) and by an increased propensity to produce flowers. As a result of this combination of factors there will be the potential to produce high quality seeds until the senile phase approaches when there will probably be a flurry of heavy crops prior to death.

The established mature plant thus is diverting materials for the development of both the embryo and the food reserve to the seed and a good crop can be anticipated. However, especially in the UK, this theoretical level of seed

production may be modified by various environmental conditions in any particular year eg frost occurrence at flowering which may concurrently also determine the availability of suitable pollinators; low summer temperatures and the associated poor light levels - as well as the incidence of leaf pests and diseases.

The advent of 'middle age', in this context, is not easy to forecast for any particular species without some experience - for example, in Cornwall, *Cornus capitata* will flower and fruit prolifically from the age of four years whereas *Magnolia campbellii* will probably need from twenty to thirty years even to flower and a further period before fruit and viable seeds are produced with any regularity.

Currently there are many species, resulting from relatively recent collections, which are moving into early middle age and are producing reasonable crops of seed and in the near future will be producing good crops of seed (eg *Aesculus assamica*).

Season of collection

Normally it is anticipated that seeds will be collected just prior to dispersal when all of the biological processes involved with the development of the maturity of the seed will have been completed. At this stage the seed is mature and will be suitable for proceeding to germination or where relevant - storage. There are however a significant number of species of woody plants in which this is not necessarily the best strategy to adopt as the seed will have developed intransigent dormancy conditions by this stage. It is therefore prudent to collect the seeds at an earlier stage - when the seed has matured and is complete - so that particularly difficult seed coat conditions can be mitigated or even avoided.

Periodicity of seed production

It is a well documented fact that there are many tree species, especially, which exhibit a periodicity in the production of seed crops. The production of prolific seed crops will only occur at more or less regular intervals. Some knowledge and/or observation of this phenomenon is therefore important to the propagator in order to be able to gather sufficient crop in the 'on' years to account for the deficiency in the 'off' years by storage.

This more or less genetically controlled condition should not be confused with a failure to crop due to a particular prevailing environmental condition such as frost incidence - which may affect the initiation or development of the seed at flowering, pollination or fertilisation; poor summer light conditions etc.

The amount of seed produced annually by a particular plant is a function chiefly of the amount of food, excess to vegetative requirements, which the plant diverts to storage for seed production - this may dictate the level of seed/fruit production in any one year and will reflect the nature of the season - in terms of photosynthetic light reaching the leaves and creating a particular level of carbon assimilation. In those plants which do not accumulate sufficiently to produce crops annually, the response, in mature plants, will determine the frequency of seed production year on year. This is demonstrated by Beech which produces good mast years on infrequent occasions (five to seven years) or some subjects which will respond by biennial bearing. In the intervening years seed production may be absent or of poor quality or the production of unsustainable seeds without an embryo or sufficient food reserves.

Scope

It is quite possible, with the right enquiry and observation, to discover an extensive array of seed bearing species within a few miles of the production facility. It is always surprising how many subjects are growing locally and as collection and cultivating of new introduced material continues to expand this type of sourcing will undoubtedly intensify.

3.

Collection, Extraction, Assessment and Recording

Collection

As has already been emphasised, for those subjects that are available locally, the most satisfactory system of seedling production is one based on the collection of the seed 'in house'. This allows the confirmation of parental identity, an assessment of the quality of the crop and the potential to harvest the seed at a particular moment of maturity. This does not however preclude obtaining material from reliable correspondents with access to particular individual specimens and/or stands in cultivation or in the wild and who have the ability to transmit the material quickly and effectively and who are in a position to follow the designated protocols. Thus if the nursery is operating with an extensive catalogue grown in relatively small quantities and only small samples of seed are required annually - then self collection for much of the list (and hence known provenance) may accrue benefits.

In spite of this recommendation the economics of this mode of collection must be assessed in relation to the benefits when compared with commercial sourcing. For subjects that do not lose water readily or do not lose viability quickly or do not have dormancy issues then commercial sourcing will probably be a relevant resource.

The objective in the collection of seeds is to harvest high quality seeds in such a way that there is no detriment to the integrity and condition of the seed and its contents - so that the highest level of viability and condition is maintained.

It is not sensible to waste time and resources collecting poor or substandard samples of seed.

The collection of seeds (and/or fruits) requires a number of preliminaries to be considered:-

- a) designate the source and confirm an identification.
- b) assess the quality.
- c) obtain the necessary permissions to collect (if such are required or as a courtesy).
- d) gear up - ie assemble the required kit for collecting, labels, packets and containers, cool boxes for removing field heat and for transporting the sample.

- e) determine the quantity needed and assess whether this is available - this should be monitored through the season.
- f) schedule the collection when the seeds or fruits have reached the required stage of maturity so that they can be gathered easily or when the dormancy avoidance dictates or before the critters deem them palatable.

The actual collection will require some attention:-

- a) Collection when conditions are suitable
- b) Adopt suitable methods to avoid detriment to the seed or the parent tree or shrub.
- c) Wear any protective equipment - gloves, smog masks etc, when necessary, to avoid allergic reactions etc
- d) As even small quantities of (especially) big seeds or fruits are likely to 'heat up' as a result of their normal metabolic activity - the material should be packeted in 'small' units and it would be prudent to provide a cool box for temporary storage and transport in order to remove the 'field heat'.
- e) Collect as clean a sample as is feasible - remove leaves and other detritus as you go.

Extraction

The objective in the extraction, of a sample of seed from its surrounding fruit, is to avoid damage to or cause any detriment to the structure and integrity of the seed and its contents or to reduce the level of viability or to affect any dormancy conditions.

The extraction of seeds from the fruit is determined by one of the following processes:-

- a)) separation of the seed from the remainder of the fruit, in order to obtain a clean and unadulterated sample;
- b) separation of the seeds from multiseeded fruits into single entities;
- c) isolation of the seeds from the flesh or other materials constituting the fruit (which may contain germination inhibitors or harbour agencies which may be detrimental to the survival of the seed).

The process should be achieved

- a) with the minimum of damage to the physical integrity of the seed;
- b) with the retention of acceptable levels of quality;

- c) without altering the internal physiology of the seed and especially without enhancing any dormancy conditions or inducing secondary dormancy;
- d) without enhancing any seed coat condition associated with moisture permeability and
- e) without critically affecting the moisture content of the seed.

The actual methods of extraction are as disparate and diverse as the individual types of fruit themselves. It is possible to describe various generalised methods of seed extraction but it is to be emphasised that each sample should be dealt with and organised on an individual basis. The process should be monitored continuously in order to modify the action of equipment or the treatment process itself to suit each sample and that regular assessment is made of the status of the seed in order to maintain quality control and so produce a sample with the highest capacity to regenerate.

Drying

Those plants which liberate their seeds from the fruits simply as a result of drying - is a common process - and as water is withdrawn by the parent or is lost by the action of external agencies, the fruits mature to the point at which they open or release the seeds. It would appear that within rough parameters this process is sequential. The process will proceed as the fruits gradually dry, or the fruits may disintegrate or even explode - depending on their mode of dispersal. Fruits of this type therefore will generally be collected as they become fully mature and reach the point at which they are approaching the stage at which they will open to disperse the seeds.

In many species of plants the seeds are liberated from the fruit as a result of the withdrawal or loss of water from the fruit tissues until such time as a point of weakness is triggered and the seeds are gradually exposed or even explosively ejected. The time of collection however prior to this stage is often critical as drying of the fruits, using an artificial (hence external) source, will not necessarily produce the correct drying process (sequence) and the points of weakness will not be triggered and the fruits will remain stubbornly closed - *Ceanothus*, *Euonymus*, *Magnolia*.

The **cones of conifers**, in general (ie not those producing a fleshy fruit or serotinous cones), normally open and liberate their seeds as a result of a natural drying process. As harvested cones are necessarily collected before they open and liberate their seeds, the cones can be dried artificially in gentle, dry warmth when they will respond without difficulty and open successfully. On a large scale this activity can be undertaken in a suitable 'kiln' - in which the cones can be tumbled dried at no more than 60°C. This will achieve satisfactory results and a clean sample of seeds will be produced. If the cones are of the type which break up to liberate the seeds it will be necessary to fan the resulting mass to separate the seeds from the scales.

Serotinous cones can usually be opened by flaming them over a fire; however if they are particularly tightly closed and do not respond they should be soaked, then frozen and then thawed and dried. The seeds will then shake out once the scales open.

Fleshy Fruits

Fleshy fruits, of whatever construction (drupes, pomes, berries, arils etc), have generally evolved as a mode of dispersal for the seed and represent the various ways of attracting an animal vector by providing a food resource. The same strategy has developed in many other genera where the outer tissues of the seed have adapted for the same purpose once the fruit case has opened (eg *Euonymus*, *Magnolia*). The attraction to the vector is often enhanced by the development of colour which identifies the food resource and the stage of development in terms of palatability and food value. This type of strategy also provides for the possibility of an extensive distribution of the seeds especially with birds - which can cover large distances while the seed is still in the gut. Fruits and seeds of this type will, more often than not, contain seeds with a 'hard' seed coat condition - this provides the protection for the seed to avoid damage as it passes through the gut and the various digestive processes and if all has gone to plan the seed coat will have been degraded close the level allowing water permeability when it is eventually expelled. Artificial extraction does not achieve this degradation so that it is important that the process does not enhance the condition - which usually occurs when the seed is dried more than is necessary.

The process used for extraction of the seeds is to macerate and ferment the fleshy fruits in water under warm conditions until the seeds begin to separate from the flesh, at this stage mild agitation will cause the seeds to sink to the bottom of the container. The dross and liquor are decanted off and the seeds can then be rinsed clean and any adhering material gently rubbed away. Do not allow the process to go beyond the stage at which separation can be achieved - to avoid any detriment to the seeds. Finally wash the seeds with a small amount of dilute detergent and rinse again - this should remove any remaining potential issues such as residual fat which may affect water uptake by the seed or any flesh or skin which may contain germination inhibitors.

Assessment

Among the ancilliary considerations which may govern the suitability of a sample for collection are:-

- a) determination of biological problems such as infestation by insects etc and fungal infection
- b) the seed count is usually measured and expressed in two ways - 100grain weight or seeds per unit weight (ie per oz, per lb, per kg) - however it is important, for comparative purposes, to be aware of the status of the assessment of a particular seed lot in terms of whether the data provided is a function of the dry or fresh weight. This is a useful piece of information in that it gives a useful guide to the confirmation of identity, an indication of quality (potential vigour) insofar as it can be assessed against the known average. It also provides information as part of the seed sowing rate calculations and deriving quantities in the purchase of seed. This factor is commonly affected by the nature of the growing season.
- c) an approximate field assessment of the viability of the proposed sample.

Recording

The importance of recording all the relevant activities and conditions with dates and details concerning a seed lot is a *sine qua non* in the whole process of seed propagation. This provides the basis for the development of efficient and reliable systems for future reference and comparison in developing processes and protocols.

Some indication of this detail is presented in **Appendix 6**.

When growing woody plants from seed, at the species level, there is an expectation that the 'offspring will resemble the parent' - it is well known that some species will vary considerably (often clinally) and the taxonomic unit (rank) is then decided by the arcane deliberations of the taxonomist - hence the provenance of a seed sample is therefore of some importance.

4.

Viability, Vigour and Longevity

The Plant Propagator will be concerned with the germination of seed lots at various times, from varying sources and for particular intensive or extensive production systems and circumstances. On any one occasion and for any particular sample, however, it will be necessary to be aware of the potential productivity, how this is influenced and how it is maximised, over time, in production practice. When determining the sowing rates for a sample of seed, in order to achieve a predetermined density of seedling production, it is an essential part of the calculation to know what proportion of the sample is viable and thus potentially capable of developing into a seedling.

Viability

In assessing the value of a seed sample, the quality of the seed lot will not only be determined on the basis of genetic considerations and the size of the individual seeds (which reflects both the size of the embryo and the level of food reserve) but also on the fraction of live seeds present and the vigour that is expressed by these live seeds in the germination process.

What will chiefly concern the plant propagator, who seeks to produce a crop of seedlings, from a particular seed sample, will be the actual potential of the lot to produce seedlings not only in terms of the quantity but also of their quality. This potential will not only be a reflection of the number of apparently live seeds within the sample but will also reflect the condition of the structures and processes within the seed which determine the vigour of the process. The ideal is characterised by the presence of a normal, live embryo and a sufficient and available food reserve which can be readily mobilised to support the duration of the germination process until autonomy is achieved.

The term **Viability** is used to represent that portion of the seed sample (at the time that it is measured) which is alive and capable of producing a seedling - ie the number of viable seeds.

A viable seed is therefore one which has the potential to germinate and establish as a seedling, given the provision

of suitable conditions; and is thus one which is capable of producing both a sufficient root and shoot system and developing a sufficient photosynthetic apparatus to ensure continuing autonomy.

There will be many causes for the lack of viability in seeds - even those which, externally, appear to be sound.

The lack of viability of a seed may be attributable to:-

- a) the absence of an embryo,
- b) the presence of a malformed embryo,
- c) the lack of a sufficient food reserve,
- d) an inability to mobilise and/or use the food reserves,
- e) physical damage engendered by the collection, extraction and cleaning treatments,
- f) an attack by biological agencies causing degradation of the various structures and/or processes,
- g) the seed may have 'aged' to an irreversible state of deterioration which effectively does not allow the process of germination to proceed with sufficient vigour to be completed.

The potential viability of a seed lot is usually expressed as a percentage of the number of seeds present and reflects the proportion of the sample which is capable of a satisfactory germination. This figure however only represents the potential at the time that it is measured and is limited by the particular method of assessment.

The viability of a sample does not represent a constant state. It will inevitably be in a continuous state of decline - if for no other reason than the effects of the natural ageing processes. As is usual in the great majority of biological systems this process of decline - the losses due to the ageing processes and general biological losses due to other causes - does not occur at a constant rate, even given an optimal and stable environment, but follows the well documented pattern of a sigmoid curve.

As the viability of a seed lot is naturally declining over time there will inevitably be an interest in the rate of the time scale of this deterioration. However it is influenced by so many environmental factors which can accelerate or delay the rate that any assessment can be little more than a relative comparison.

Longevity

The term **Longevity** is used, in the context of seed viability, to describe the 'length of life' of a seed sample during which some useful capacity for germination is retained. It is however rarely defined in a measured way and is, in general, used in a relative or comparative fashion to determine the effect of storage conditions on maintaining viability.

In practice this period can vary from a few days (*Acer rubrum*, *Acer saccharinum*, many Willows and Poplars) to many years (many of the hard seeded *Leguminosae*).

Vigour

The measure of viability provides the overall picture of the live status of a seed lot but experience will indicate the potential this level will have on the rate and strength of seedling emergence during the germination process. This aspect is described as the **Vigour** of the seed lot.

When a seed is fresh and ready for dispersal there is (as would be anticipated) normally no deterioration in either the structure or the physiological processes - the maximum number of embryos are 'live' and the support systems (metabolic processes) are at maximum efficiency. When the germination process is delayed this causes, with the progress of time and subject to whatever the environmental conditions prevail, damage and deterioration of structures and processes.

Observations of the internal structures of a particular seed lot, over time, will reveal areas of necrotic tissue developing and eventually as these areas coalesce it will be evident that this must give rise to some level of impairment. However the crucial aspect of such deterioration, in relation to viability and vigour, is dependent on the exact location of this necrosis - if this condition is in the embryo itself the effects will usually be markedly deleterious whereas if they are present within the food reserve the effect will largely be as restrictions to the availability of the food reserve and hence the general vigour of the germination process.

Any deterioration in these parts and processes will slow, in some degree, embryo enlargement, seedling emergence,

rate of development and seedling establishment. This will be seen, as time elapses, as a depression in the rate of germination, an erratic emergence and a reduced capacity to establish as a seedling - consequently this, in turn, reflects the number of seedlings which survive or conversely the number of seedlings which germinate but fail to establish.

The accurate assessment of both viability and vigour of a seed lot for the determination of seedling establishment, for use under field conditions, is not an easy task. Germination tests measure the rates and levels of potential emergence by assessing the response under controlled and suitable environmental conditions but are only practicable once any limitations to germination have been removed. Artificial tests, using staining techniques or excised embryos have the advantage that any germination inhibition present is not relevant but it does require a considerable experience in the practical interpretation of the responses - in order to give a measure which is useful under field conditions. Obviously the more controlled is the proposed environment for germination, in the production process, then the more useful and applicable are the results from such artificial assessments and are more useful for use under practical nursery conditions.

The Practical Assessment of Viability

Effectively all the practicable methods and techniques used in the assessment of viability have some real disadvantage in either the accuracy of the process itself or in the evaluation of the results. This often reflects, in general, more the ability of the operator to interpret the outcomes than the process itself. Experience, as ever, is a very real necessity. However each technique has a niche in the overall spectrum of resource and has a place for particular purpose or context. The significant factor in all of these assessments is to be able to correct the apparent results to the actual figure that will be achieved under suitable conditions for germination - this measurement is sometimes described as the level of **Germinability**. This measurement eliminates seeds with apparently germinable embryos but which, for various reasons, do not produce any or suitable (deformed) seedlings.

The various techniques for the assessment of viability under nursery conditions can be categorised as:-

- a) Cutting Tests,
- b) Germination Tests,
- c) Excised Embryo test and
- d) Staining Techniques.

The **Cutting Test** is the simplest operation to carry out, as it relies on exposing the internal tissues of the seed to observation - and from this, by a visual assessment, the status and condition of the embryo and food reserves can be determined.

The operation is carried out on a randomly selected, relevant sized sample of the seed lot. The individual seeds are then cut in half in such a way that a representative cross section of the structures within the seed are exposed and it is possible to assess the status, presence and condition of the various parts of the seed. Although this operation can be carried out with the aid of low powered magnifying equipment, it is really only a satisfactory technique for use on seeds which are large enough to be viewed satisfactorily in this context - arbitrarily - it is difficult to be conclusive with seeds less than 2mm in diameter or length. This measure inevitably depends on the experience of the operator in determining the size and position of the areas of necrosis and then having the experience and ability to translate this into a practical application under field conditions.

The **Germination Test** provides a relatively more accurate assessment of the potential for germination which might be achieved under operational conditions. Seeds which are otherwise unencumbered can be subjected to reasonably constant and reproducible environmental conditions which are suitable for initiating and sustaining the process of germination. The results as measured by the seeds responses and these can then be evaluated.

This technique can be operated at varying levels of sophistication - from sowing the seeds in a suitable container using a relevant compost and placing it in a practical environment to the placement of the seed on a damp pad in a Petri dish and placing it in an incubator under definite and constant controlled conditions. The responses measured from such observations not only provide a picture of the proportion of seeds which actually germinate but also allow an assessment to be made of the rate and uniformity of seedling emergence. This gives an

indication of the vigour of the sample as well as the potential number available.

Inevitably this technique is only valid for seeds which are not dormant or have any other encumbrance to germination.

These observations give useful and real indications but their application will only be relevant if a correlation to the relative environmental sophistication of the actual level of the practical process can be determined.

The **Excised Embryo Test** is necessarily a more complex test to operate and requires the availability of some limited laboratory resource and the development of some expertise in being able to dissect out the embryo from within the seed without damage. This technique involves the removal of the embryo from its surrounding tissues and seed coats and its transference to a moist situation in a Petri dish or similar receptacle, where it can be suitably incubated and any responses assessed.

This operation allows seeds with an imposed dormancy due to seed coat condition to be assessed quite simply on the fact that embryo development will begin with the growth of the radicle.

For those seeds which have an endogenous embryo dormancy the radicle however will not develop but viability is potentially indicated by the greening of the cotyledons if light is available.

The use of **Staining Techniques** in determining the presence and pattern of living tissue within the seed (and conversely the presence and pattern of necrotic tissue) can be achieved using a range of vital staining agents. There are a number of such chemicals which will achieve useful results and which are assessed on a visual determination.

The most universally implemented of the staining techniques involves the use of 2,3,5 triphenyl tetrazolium chloride (TTC). This material will stain living tissue and thus allow an assessment of the status of the seed in terms of viability and vigour without the use of a great deal of sophisticated resource. However it will require the availability of simple laboratory facilities. This material will stain the 'living' tissue of the seed a bright pink and leave the necrotic tissue colourless.

This quick biochemical viability test can be applied to a seed sample and will give, with ongoing experience of the test, results which are comparable with the Germination Test. The test involves the use of this soluble, diffusible chemical which will stain living tissue deep pink and will leave necrotic (dead) tissue uncoloured.

The process involves imbibing the seed, cutting the seeds in half and then immersing them for a period of time in a solution of the chemical. The time needed for the take up of the stain varies with the species and will vary from a few hours to a couple of days. The seeds are then assessed under a low magnification, by dissection, to determine the presence and distribution of the necrotic areas. This in turn, with experience will give an indication of the viability and vigour of the sample.

An advantage of such a test for viability is that it allows an observation to be made on endogenously dormant seeds which cannot, otherwise, be measured by a Germination Test.

The assessment of viability, using staining tests such as this, is necessarily subjective and almost always suggests a higher viability potential than is actually achieved in practice using a germination test. An allowance therefore needs to be made to correct this discrepancy.

Some knowledge of the viability of a seed lot is however fundamental to any study concerned with the germination (and pre-treatment) of seeds - and is ultimately the significant basis for controlling the quality of seedling production.

5. Storage

An effective method for the storage of seeds is required to maintain a high level of viability, at the least, in the short term between harvest and sowing (or the treatments prior to sowing) during the course of a normal season; or may be necessary in the longer term, from year to year, in order to even out the availability of supply to take account of the vagaries of collection, seasonal influences or periodic cropping.

The object of such storage is to extend the longevity of a seed lot by maintaining the highest feasible level of viability for as long as possible. This is achieved by the provision of environmental conditions which have the effect of reducing the rate of deterioration within the lot.

Perhaps the most obvious consequence of this concept will be evident by attention to the sigmoid curve representing the 'normal' rate of deterioration within a lot. It is evident that the highest level of viability occurs at the top of the curve and hence the greatest potential for extending storage life (longevity) will be achieved when the seeds are subjected to suitable storage conditions at this stage ie the earliest possible moment after dispersal.

Viability is at its highest level immediately after dispersal. At this stage the seed lot is in prime condition and in normal circumstances there will be little or no deterioration of the structures or processes for a short period, after this viability will decrease in the anticipated pattern at whatever rate is the norm for the particular species. The effects of storage, therefore, in enhancing the longevity of the lot only begin with the viability at the time the process is begun - in other words this provides the base level of the process.

Storage of seed, to achieve an extension to the longevity of the seed lot, is achieved by modifying certain environmental conditions surrounding the seeds.

The most usual environmental factors which influence the successful enhancement of longevity are those which slow the metabolic processes, especially the rate of respiration of the seed, and which can be applied under practical circumstances. In practice three environmental factors are

relevant - temperature, moisture content and the gaseous constitution of the atmosphere.

One of the most commonly manipulated parameters in the storage of the seeds of woody plants, within the environment of the seed, is that of **temperature**. It is a well documented feature of biological processes that the rate of the process is responsive to temperature. Normally the colder the temperature is maintained - the slower will be the rate of reaction. Thus at a low temperature the rate of respiration is lower, food reserves are mobilised and consumed more slowly and the consequent ancillary processes are slower. Any reduction of temperature will enhance longevity but the most effective response is achieved at the lowest temperature that the seed will tolerate without damage.

Harrington, fifty years ago, in his critical observations on seed storage proposed a number of 'Rules of Thumb' or generalisations for successful storage. In relation to temperature he proposed that storage life could be doubled for every 10°F reduction in temperature that could be achieved.

Storage temperatures well below freezing (using liquid nitrogen and similar agencies) can be practiced but normally this requires a dedicated unit and such a facility is only usually available to large organisations, seed banks etc. It requires particular knowledge, critical technique, specialised equipment and experienced operators to achieve success.

Simply subjecting seeds to sub-zero temperatures in a freezer usually causes damage at the cellular level as the intercellular and then the intracellular water freezes; damage is normally caused during the differential movements of cell walls in the thawing process as ice crystals penetrate cell walls in the embryo and in the food reserves - it is most effective when the moisture content of the seed is low and this is often only feasible with seeds in which the food reserve is stored as carbohydrate.

In practice, for most woody plants of temperate provenance, a storage temperature of 2-3°C is adequate to achieve the level of longevity which is useful for the practical operator. At this level a normal household refrigerator can be manipulated to maintain such a temperature.

Historically the most favoured method of increasing the longevity of a seed lot is to reduce its **moisture content**. However, generally, the seeds to which this refers have been the seeds of major agricultural, crop plants in which the food reserve is stored as carbohydrate. Such seeds are more responsive and successful at reconstituting themselves after the drying process. Many species of woody plants store their food reserves in the form of proteins or lipids (as well as carbohydrates) and these materials do not lend themselves easily to rehydration.

The reduction in the water content of the seed effectively slows the metabolic processes of the seed by reducing the water, within the seed, which is available for enzymes and other biologically active chemicals to mobilise and activate the various processes within the metabolic system.

Drying is probably the most widely practiced technique for increasing the longevity of any particular seed sample. However the practice although used on a large scale is chiefly limited for the storage enhancement of many crop plants and these subjects, more often than not, store their food reserves as carbohydrates. Such seeds when dried can be rehydrated reasonably successfully without significant damage to tissue, allow the normal mobilisation of enzymes and the complete use of the food reserves.

This, however, does not necessarily apply to those seeds in which the food reserves of the seed are stored as protein or lipid. In these instances the dehydration of the materials to below a critical level effectively means that the storage materials become unavailable to the embryo and viability is lost rapidly. This reaction is associated with the nature of these particular materials - for once they have been dehydrated it is not possible to reconstitute them by rehydration as the water repellent characteristics of these materials effectively waterproofs them and so prevents their reconstitution back to their original status. This absence of water thus severely restricts the movement of enzymes and metabolic products so isolating the food reserves as the necessary energy resource and for practical purposes causes the loss of viability by embryo starvation.

These so-called 'intractable' seeds can be successfully stored if critical attention is given to the degree of the

drying process. However, unless evidence is available to the contrary, it is probable that storage should be conducted under water conserving conditions and maintaining the moisture status at which the seeds were dispersed from the parent plant. If marginal drying occurs during collection and/or the extraction process then re-wetting to reduce the possibility of moisture being lost from the food reserves to the seed coats provides a useful safety valve when the seeds are stored in an impermeable container.

When a minimum moisture content is cited as part of a recommendation for seed storage, care should be taken in ascertaining on what basis the calculation has been made as this parameter could be critical to survival. The difficulty is perhaps obvious but will depend on whether the calculation was determined as a factor (usually as a percentage) related to the fresh weight or dry weight. It will be evident that the mathematics of such an exercise could have quite a dramatic influence on the outcome of the storage process. For practical purposes the most satisfactory and reproducible results will be derived from measurements made on a dry weight basis - as fresh weights are very likely to be much more variable depending on the nature of the particular season - ie the moisture content is expressed as a percentage of the dry weight.

When storing seeds at a predetermined moisture content attention should be given to maintaining this status during the storage period. The seeds should be sealed in a water conserving container in order to isolate them from the vagaries of the atmospheric humidity of the storage environment - otherwise the moisture content of the seed may decline as it equilibrates with that of the atmosphere.

Harrington's Rule of Thumb in relation to the moisture content of the seeds during storage (effectively only for carbohydrate storage) is expressed as 'that for every reduction of 1% in moisture content of the seed, the storage life will be doubled' - experience however suggests that a figure on 2% is nearer the mark.

Intermediate type seeds - which store their food reserves as a mixture of carbohydrates and lipids or proteins -are more tolerant of drying but nevertheless the quality of the subsequent development will undoubtedly be affected.

The effects on the success of storage can be enhanced by combining these two parameters and so lengthening longevity.

Although rarely practiced, it would be quite possible to slow metabolic processes in the seed by reducing the availability of **oxygen** however this possibility should be treated with care as a wholesale removal of oxygen could induce an anaerobic response if the other parameters are not also involved.

References

- Harrington, JF (1960) 'Thumb Rules for Drying Seeds'; Crops and Soils **13**(1):16-17
Harrington, JF and JC Douglas (1971) 'Seed Storage'; Nat. Seed Corp., New Delhi, India

6. Dormancy

When a viable and quiescent seed is subjected to conditions suitable for germination and it does not respond, the seed is said to be dormant. This implies that there is present, in the make up of the seed and/or its coverings, a mechanism for preventing the process of germination from proceeding.

Although this situation presents an irksome problem for the propagator, the condition is an evolved strategy which the particular species has developed to enhance survival after germination or it may also reflect the need to spread germination over time. It has evolved to ensure that germination and establishment occurs when the most suitable environmental conditions for the survival of the seedling are available and conversely that germination is prevented when conditions are adverse. It may also delay germination spasmodically over a number of years in order to achieve success when suitable years occur. However it should not be overlooked that some seed coat conditions have evolved to protect the seed from digestion while passing through the gut of a predator/vector.

The propagator needs, therefore, to recognise and understand these limitations and, by investigation, create protocols to overcome them artificially and allow germination to proceed, as and when required and without constraint, in order to achieve the best productivity. In all of the ensuing descriptions the seed is understood to include any significant part of the fruit which may be relevant.

The evolution of dormancy controls has not been the simple development of a few standard variations which therefore can be treated with a precise and uniform set of treatments but has developed at various times and in a diversity of situations, with the resulting complex of present day scenarios. Inevitably however the practicalities of operation, in a nursery context, need to be relatively simple and fit into a manageable programme which is predicated on a few standard treatments, however - as has been indicated - the dormancy controls exhibited by individual species do not necessarily conform exactly to such uniform fixed parameters and it is necessary to be flexible when applying treatments at a species level.

In broad terms the factors making up the spectrum of dormancy controls, in the seeds of woody plants from temperate climates, can be attributed to a number of different conditions which can be categorised as:-

A) external conditions in which the seed coat or other parts of the fruit may

- a) prevent the uptake of water by the seed,
- b) restrict gaseous exchange or
- c) limit embryo expansion;

B) seeds with an immature or rudimentary embryo and

C) biochemical conditions which rely on the endogenous physiological inhibition of some essential reaction which controls a phase of the germination process.

Dormancy caused by the condition of the seed coat

The seed coat may be categorised as 'hard', 'tough' or 'waterproofed'. If seeds are sown and left to their own devices the seed coat will gradually (or in particular cases suddenly) be degraded in the soil until such time as it is possible for water to permeate and enter the seed and, thus, for it to imbibe. The great majority of species exhibiting this type of constraint to germination (dormancy) achieve the objective by preventing the uptake of water from the surrounding soil and so prevent the seed imbibing. There are a number of mechanisms which fall into this category:-

Hard seed coats

Many plants produce seeds which develop a hard seed coat - the commonest form of which is the production of a hard stone-like or shell-like condition. The effective method of reducing this to a water permeable condition varies from caustic digestion, through heat treatment, physical and biological degradation, to warm water soaking depending on the degree to which the 'hardness' (and hence impermeability to water) has been developed.

The reduction of the seed coat to a water permeable condition can be carried out by the digestion of the seed coat by caustic agents such as concentrated acids. However this is a hazardous enterprise even when quasi-laboratory facilities are available and should probably only be contemplated as a last resort. It is not only the potential danger to the operative which can be a problem but that the

determination of the end stage is not easy to monitor so that either the seed coat does not become fully digested or conversely it is too fully digested and the acid penetrates the seed so causing the loss of the sample. For the seeds of those species with a less intractable condition, degradation can be achieved by a relatively long term soak in a weak organic acid (eg 1% citric acid).

For the seed of those species which have a hard brittle or hard stony seed coat it is feasible to achieve a physical degradation of the seed coat, to a sufficient level for imbibition to occur, by cracking or physically degrading (abrading) the seed coat - this is the safest and probably the most effective method available.

Seeds of species, whose survival strategy is dominated by the occurrence of wild fires (the so-called fire ecology), have hard seed coats which protect and preserve the seed in the soil until the passage of fire. The seed coat of many species is hard, brittle and shell-like and will crack once a particular level of temperature, surrounding the seed in the soil, is reached. Other species have developed similar responses which depend on the temperature causing a differential expansion within the seed coat which causes the irreversible splitting of a hilar fissure or the dislodgement of a strophiolar plug. Once this stage has been achieved the seed will imbibe as soon as water becomes available and then proceed to germinate.

This latter strategy is a common feature of the seeds of woody plants from Mediterranean climate plant communities which are dominated by a fire ecology eg Mallee in Australia, Chaparral in California, Mattoral in Chile, Fynbos in South Africa and Maquis and Garrigos in Southern Europe.

It should be reiterated that because a seed has a hard seed coat that it is not necessarily a barrier to water permeability. Many seeds have developed a hard seed coat for protection of the seed while it is subjected to the digestive processes during passage through the gut but water uptake is still possible. Similarly the seed coat may be reduced by such passage and water permeability enhanced.

The practicalities of treatments for mitigating these conditions are dealt with in **Appendix 1**

Tough Seed Coats

The types of seed coat which constitute this category are quite varied in their constitution and construction but all are to some degree 'leathery' ie they are - when fully developed - pliable, tough and impermeable to water. They generally have a more or less constant and uniform consistency or sometimes have a reticulate structure. All are intractable - insofar as the removal of seed coat material, artificially, is difficult and often hazardous. Although it is possible to degrade them by digestion with acid or other caustic materials, the operation is usually difficult to administer and monitor adequately - especially those with a reticulate structure as the acid may not act uniformly through the seed coat and may suddenly penetrate through to the embryo. Although slower, the use of a 'natural' material which degrades the seed coat biologically is safer and can be operated effectively if not with great accuracy.

The practical aspects of artificially overcoming these types of dormancy are described in **Appendix 1**.

'Waterproofed' Seed coats

Although not of common occurrence there are several plants in which the seed is maintained in a quiescent state by a surface waterproofing which prevents the ingress of water. Materials such as waxes, fats and oils are the most commonly found agents. Often the condition is only short lived but should it need to be removed - hot water soaking is usually sufficient, if more robust action is required suitable organic solvents or detergents will be effective.

The practical aspects of artificially overcoming these types of dormancy are described in **Appendix 1**.

Immature (Underdeveloped) and Rudimentary Embryos

In many species of woody plants the process of germination is prevented, simply, because the embryo has not developed to a sufficiently mature stage, either morphologically and/or physiologically, for germination to occur when conditions are suitable. For germination to occur the embryo must have reached a state of 'maturity' at which it is capable of proceeding into the sequence of phases which constitute the process of germination.

This particular condition is seen in two manifestations:-

- a) as a rudimentary embryo in which the embryo exists only as an, more or less, undifferentiated mass of cells. This condition is normally found in parasitic plants but is seen occasionally in conventional, terrestrial subjects from Families of Angiosperms - especially those which produce 'microseeds' or 'dwarf seeds' (eg *Ericaceae*), but also includes primitive families (eg *Aquifoliaceae*);
- b) as an immature embryo in which the embryo has been partially or fully differentiated but has not reached a sufficient size or physiological status to be able to germinate. This condition is usually found in those Families which appear early in the evolutionary development of both Gymnosperms and Angiosperms, but not exclusively, - and includes the:- *Cycadaceae*, *Ginkgoaceae*, *Taxaceae*, and *Podocarpaceae*; *Adoxaceae*, *Araliaceae*, *Daphniphyllaceae*, *Escalloniaceae*, *Monimiaceae*, *Lardizabalaceae*, *Magnoliaceae*, *Oleaceae*, *Pittosporaceae* and *Winteraceae*.

The immature embryo condition can, in general, be mitigated by storing the imbibed seed in a suitable environment, at a 'warm' temperature, for a sufficient period to allow the maturation process to be completed. However there are examples where the maturation of the embryo occurs, optimally, at 'cool' temperatures (c5°C) eg *Sambucus*.

The practical aspects of this procedure are described in **Appendix 4**.

Physiological Dormancy Conditions

This type of dormancy control occurs within the seed itself and depends on the presence of particular chemicals which prevent or interrupt the normal patterns of metabolic activity and growth at this stage of development - the process of germination. These activities occur and are controlled at the molecular level by genetic keys which can work at various levels of intensity - an understanding of this series of mechanisms is beyond the compass of these notes (and their author!).

It is evident that the processes and reactions which are governing the growth and development of the embryo at the post imbibition phase, ie the start of germination, are determined by growth regulating substances - such as gibberellic acid - which engender cell division, cell enlargement and cell differentiation. Initially, after the process of imbibition is complete the activity of the growth regulating substances should begin and the embryo

should proceed to develop in a normal fashion. However in the seeds of those plants in which the embryo does not respond in the normal sequence of events - ie when environmental conditions are suitable and it fails to develop further - are described as being **endogenously dormant**.

This facet of seed biology is still imperfectly understood and the actual mechanisms which are creating this situation are not yet completely elucidated - at least as far as the lay person is concerned. There is currently therefore a void in the spectrum of this area of knowledge. Currently, it would appear, that the prevention of germination of the imbibed seed is caused by the presence of inhibitors which the seed has metabolised during the maturation process. The chief recognised agent being abscisic acid. Further activity then depends on the reduction of the level of the inhibitor with a corresponding increase in the production of the growth promoter (usually cited as a gibberellic acid).

It would appear that, at present this type of dormancy can be mitigated by the exposure of the imbibed seed to a period of cold temperature.

Embryo Dormancy overcome by Chilling

An endogenous dormancy condition which requires the imbibed embryo of the seed to be exposed to a period of 'cold' temperature is an evolved strategy developed in many woody plants - especially of temperate climates. It operates on the premise of preventing germination during the unsuitable conditions of winter and then promoting germination during the spring when environmental conditions are most suited for germination, the development of the seedling, seedling establishment and survival. Thus the seed is prevented from germinating before the onset of winter by a physiological (and genetic) mechanism, within the seed, which prevents germination - despite environmental conditions being suitable. The passage of winter provides the 'cold treatment' which releases this block to germination and thus allows the imbibed seed to germinate, when the environmental conditions are suitable, in the spring.

There are a number of practical implications within the process which need to be addressed by the propagator in order to simulate the natural process of chilling under

artificial conditions and so achieve an efficient and productive response:-

- a) the removal of all other naturally occurring inhibitions or constraints (dormancy conditions) which could prevent germination;
- b) that the seed is fully imbibed and therefore primed for the necessary physiological activity;
- c) that there are no other constraints within the process - such as any restriction on the availability of oxygen or the presence of inhibitors in other parts of the seed and
- d) the provision of a period of 'cold'.

Cold in this context is the sum of two parameters:-

- a) a temperature below the threshold at which the process will occur - ie the availability of a critical pathway, within the physiological activity of the seed, becoming available and
- b) the maintenance of this low level of temperature for a sufficient duration such that the constraint is eliminated and thus allows germination to occur.

The threshold temperature, below which the chilling process is effective, is a function of the environmental conditions under which the species has evolved and is particular and constant to that species.

Warm temperate species may well respond to the maintenance of cool temperatures which are below 7° or even 10°C; the same is true for many subarctic species which are effectively frozen during the winter and have to respond to the thaw period in the spring. Cold temperate species tend to respond in the range below 3°C to 5°C.

There is no advantage or disadvantage to the chilling process if the maintained temperature is lower than the threshold - as there is no cumulative effect with lower temperature (the degree-day concept). However, because of the practicalities of administering the cold at various thresholds, a constant 'low' temperature is operated, in a universal role. This accommodates the chilling threshold for the great majority of species in one facility. The temperature chosen should not be cold enough to cause physical damage to the seed and especially, in this context, temperatures below 0°C should be avoided. The freezing of intracellular and intercellular water could well be physically damaging as well as effectively pausing the physiological activity by removing the water from the

cell by freezing it into ice. In practice the cold temperature facility should be maintained at +/- 3 or 4°C as this will be below the required threshold for the chilling for most species.

The critical factor for the plant propagator in this process, then, is determining the length of time that is required for the chilling process to be completed and so allow the speediest and most synchronised germination to occur.

In most woody plants the optimum duration of this process is reasonably constant and does not vary within a species either within the sample or from year to year. Variations in the response times, reported in the literature, are generally created when another dormancy factor(s) has not been fully eliminated. If variations in response time are encountered then the shortest time will be the one which is the closest to being relevant.

The period of chilling that is required to eliminate the dormancy control is not concluded suddenly with the achievement of a complete process. When suitable conditions for germination are provided there is, once a minimum threshold chilling period has been achieved, a slow and erratic response if exposed to suitable conditions for germination. Then, with incremental additions of chilling, the process gradually unifies although germination in the early stages is still slow, erratic and incomplete. As the period of chilling increases the response time becomes gradually quicker, with a more uniform emergence and a greater proportion of the seeds responding - until the optimum period is reached when the block to germination has been completely removed. At this stage the response, during the process of germination, is quickest, with the closest synchronisation of emergence and with the maximum number of seedlings being produced - and further enhancement of the chilling period does not produce any improvement. It is at this stage that the period of chilling is designated and incorporated into a production protocol.

There is also some evidence to suggest that before the optimum period is achieved that germination only occurs in a much narrower range of temperature - ie in that period before the chilling process is completed.

Thus once these factors have been addressed and resolved it is then possible to derive a protocol to overcome this type of dormancy in any particular species.

In general terms species from warm temperate climates exhibiting this type of dormancy have high threshold temperatures and require only a short period of exposure to achieve the response. Species from cold temperate climates, as might be expected, have lower threshold temperatures and require longer periods of exposure to eliminate the condition. If this period is an unknown then it is helpful to have some knowledge of the type of the native climatic environment of the particular species so that pointers to likely outcomes could be proposed.

In line with many other biological processes concerned with germination the concept of chilling and its evolution, as a strategy in the germination and survival process, is not always as straight forward as it would appear - as there are varying levels at which the depth of the effect operates. In practice however those seeds which have an obligate chilling requirement are dealt with as above but there are some species in which the chilling merely enhances the speed and synchronicity of emergence compared with non-chilled seed which will emerge more erratically, more slowly and generally at lower levels of productivity.

The practical aspects of achieving the chilling process effectively, productively and efficiently are outlined in **Appendix 2**.

An Eccentric Dormancy Condition

There are inevitably areas of knowledge, which are concerned with 'dormant' embryos, which are unclear and often confusing for the layman to understand - especially in relation to traditional perceived wisdom and practice. One such concerns the perception that hard endocarps prevent imbibition and hence germination. Modern knowledge however indicates that more often than not (outside particular Families - eg *Fabaceae* and *Anacardiaceae*) the hard condition does not indicate impermeability and that the associated practice of warm stratification does not reduce the hard seed coat to create permeability - it is in fact always permeable. This period of warmth is required to 'mature' a physiological condition within the seed (the embryo of which otherwise is morphologically fully developed) which is blocking germination, once it is

mitigated the already imbibed embryo can be successfully chilled or treated.

With this insight it is thus possible to understand the difficulties which have been prevalent in determining the conditions required to create germination in certain taxa. Classic in this respect is probably the uncertain nature of the recommendations available for the germination in *Prunus*.

Chemical Inhibition

The prevention of germination induced by the presence of a chemical inhibitor(s) (probably abscisic acid) is a more widespread phenomenon than is generally appreciated.

This form of dormancy is fairly common in woody plants from desert and other arid communities where rainfall does not necessarily provide an adequate reservoir of water in the soil to allow germination and establishment of the seedling. Under such conditions the water soluble inhibitor acts as a gauging mechanism to determine rainfall (and/or flooding) and so measure the accrual of a sufficient reservoir of water in the soil to allow germination and establishment of the seedling to a survival threshold.

This response depends on the water solubility of the chemical and the passage of water through the seed coat to remove, by leaching, the chemical - such that when the chemical has been fully leached there should be a sufficient reservoir of water in the soil to support the process of germination through to establishment and hence potential survival.

Other chemical inhibition occurs in many woody subjects of cold temperate climates, once again involving the presence of abscisic acid in the pericarp or fruit. Leaching of the seed is also effective in these instances. It is also possible that external abscisic acid is also found in conjunction with endogenous abscisic acid induced dormancy requiring mitigation by a period of chilling and when not eliminated fully can create confusion in the length of the chilling process.

The practical arrangements to achieve satisfactory leaching is dealt with in **Appendix 3**.

Chemical enhancements for promoting germination

There are many species which are native to fire ecologies in which germination is promoted by particular chemical components produced in the process of burning the natural organic matter. These may be present in 'smoke' or may be the result of leaching from the residual charred material ('Charate'). The actual active components creating this effect are far from perfectly understood.

The treatment of seeds with other chemicals including potassium nitrate, gibberellic acids and kinetins is also used to promote germination in particular circumstances.

These situations are dealt with in **Appendix 5**.

Epicotyl Dormancy

The condition known as epicotyl (double) dormancy, although not uncommon in herbaceous plants - especially the *Liliaceae*, is not common among woody plants in general. It is typified by the emergence of the radical, from the imbibed seed, during the first warm period after dispersal; however the plumule requires a period of chilling before it will germinate when conditions are again suitable. This usually means that the seedbed is occupied for two growing seasons before the seedling is produced. Examples among woody plants that have adopted this strategy include:- *Chionanthus*, *Davidia* and some North American species of *Viburnum*. In some warm temperate and tropical species the plumule is not 'mature' and requires a period of warmth for maturation to occur and then proceed into the germination phase - the temperature for these two processes is not necessarily the same.

Multiple dormancy

It is not uncommon to find, among woody plants from temperate climates, the development, as a result of evolved strategies for survival, of more than one type of dormancy. This more complex picture is certainly more irksome for the plant propagator but it can be dealt with by eliminating the conditions in sequence in order to achieve germination. In nature this usually combines the need to spread germination over more than one year with avoiding the vagaries of winter survival.

In some species this entails, at the extreme, all three modes of dormancy and involves in order of elimination - a seed coat condition, an immature embryo and a chilling

requirement. The classic exponent of this state is the Common Ash of the British Isles - *Fraxinus excelsior*.

Dormancy packages

In several genera of woody plants - especially those which contain species which fulfil a pioneer role in plant succession - the seeds are often dispersed regularly or intermittently over the winter period. These seeds are often able to respond to the environment and time scale which is available by having, inherently, more than one dormancy control and only one of which needs to be satisfied and so allow germination at a suitable time (eg *Betula*).

Avoiding Dormancy

Dormancy control caused by intransigent, seed coat conditions can pose a number of vexing problems to the raiser of woody plants from seed. These conditions are conventionally overcome by the degradation of the seed coat by (more or less dangerous) caustic agents for swift results or quasi-natural methods which are relatively long term and difficult to develop accurately. Ideally the most successful outcome would be to be able to collect the seed before any of these conditions have developed in the maturation process of the seed/fruit.

Although it is currently not feasible to avoid endogenous dormancy conditions, it is however possible to avoid those dormancy conditions which are controlled by the condition of the seed coat. It is only in relatively recent years that it has become accepted that it is possible to harvest the seed as soon as it is complete, mature and before the seed coat condition has developed.

In the development of the seed, the cells of the fertilised embryo begin to divide to produce a food store and as this reaches adequate proportions it is used to provide the basic materials for the development of the embryo - which grows at its expense. Subsequently the conventional sites for the food store are differentiated and the seed is completed by the development of these food reserves. At this stage the endogenous dormancy controls are implemented and the seed begins to reduce its water content. As this phase reaches its conclusion the embryo finally matures and is isolated by the maturation of the surrounding membranes and encapsulating tissues. It is then that the seedcase and/or fruit begins its development and eventually develops

the condition which protects the seed against imbibition by providing an impermeable barrier to the ingress of water.

Even thirty years ago it was barely recognised and accepted that the collection of the seed, at the point of maturation and before the development of the impermeable seed coat, was feasible and could be undertaken without any potential damage. However the concept was not new and as long ago as 1945 van der Graf in the Netherlands published on this topic in relation to *Daphne mezereum*. Plants in as widely divergent genera and species as *Daphne mezereum*, *Acer campestre*, *Acer truncatum*, *Hamamelis mollis*, *Carpinus betulus* and *Viburnum lantana* have all been shown to respond to an adaptation of this technique.

7.

Germination

Germination describes the process by which an otherwise quiescent and viable embryo begins, and progresses through, the sequence of events which cause it to develop and establish as a new plant.

The aim of the plant propagator is to simulate nature, under controlled conditions, and attempt to convert the seed lot, via an understanding of this process, into a crop of seedlings.

The process of germination consists of a series of often complex and interrelated processes which, despite modern scientific and technological advances, is still imperfectly understood, at least, by the layman.

In the production of a crop of seedlings the aim of the plant propagator, in dealing with a particular lot of seed, is to induce germination in the most effective, efficient and productive manner feasible - ideally converting all the viable seeds into seedlings. This would normally be achieved by processing and treating the seeds in such a way as to cause germination in the shortest possible time with the closest synchronisation of emergence - together with the development and establishment of the highest proportion of viable seeds - a process which has been sophisticated to an advanced level by the bedding plant and vegetable young plant industries.

Germination occurs when a series of required, environmental factors coincide and are satisfactory for the activity to proceed. Viable seeds for which all of the environmental factors, necessary for germination, are provided and which fail to germinate are said to be dormant. Germination therefore can only be achieved productively when all other constraints and encumbrances have been completely eliminated. This will require an understanding of all these limitations and how they are most effectively eliminated with the least loss of viability.

For the process of germination to be initiated and develop adequately, the seed will require exposure to an environment in which there is:-

a) provision of a sufficient, non-limiting, and suitable water supply,

- b) an adequate and non-limiting atmosphere containing oxygen,
- c) a suitable temperature regime and
- d) light (or lack of it) if the seed is photosensitive and/or ultimately for photosynthetic activity.

Water and the process of Germination

In the process of seed maturation the seed tends to lose moisture and hence increase its dry weight. The extent to which this drying occurs varies according to the species and this in turn is often a reflection of the type of food reserve which is stored in the seed to support the process of germination. The germination sequence begins with the rehydration of the seed. For this activity to proceed the seed needs to be exposed to moisture. This rehydration starts with a process described as imbibition. Imbibition involves the uptake of water by the seed. Initially this uptake of water occurs as a non-biological reaction - an entirely physical process resulting from the colloidal adsorption of water by the matrix of the seed tissue. During this process the desiccated colloidal contents of the cells rehydrate. At this stage the water status is reversible (ie the seed can be redried) without detriment. This phase of the imbibition process occurs quite independently of any biological or metabolic activity. Seeds, as a result, may well swell to more than twice their original size. This reaction will occur even if the embryo is dead - provided that the contents and the structures of the seed have not deteriorated; indicating that this initial swelling is not an indicator of viability. This part of the imbibition phase is a relatively rapid activity - being completed in a matter of hours, if the surrounding moisture status is not limiting.

Once the seed has been rehydrated and the tissues have recovered their operational size, structure, shape and condition, the finer structures of the cells will also have become reconstituted or repaired and returned to as close to their functional mode as is feasible.

It is at this stage that the enzymatic activity and mobilisation of the food reserves and other resources begins. This is characterised by a continuing but slower uptake of water as a result of the osmotic gradients thus created. This phase of slower water uptake is described as the lag phase. When the effective moisture status of the seed has been restored, this first phase of germination

proper - the first, non-reversible, biological activity - follows quickly. It involves the initiation of those metabolic activities which promote cell enlargement and elongation. This happens, in the first instance, in the cells of the radicle and can cause sufficient growth for it to emerge through the seed coverings.

However if the seed is subject to an endogenous dormancy control this immediate post imbibition phase is delayed by the need to eliminate the inhibiting agency (or promoting the growth activity) before the processes concerned with cell enlargement and elongation are released. Indeed imbibed dormant seeds can be maintained indefinitely if not chilled or leached to break dormancy.

The cell enlargement and elongation phase, once initiated, is followed by the process of cell division and differentiation.

The root elongation and development stage follows, usually, after a delay (which varies from species to species), by the development of the epicotyl and further additional root development. During this phase cell division and cell differentiation occurs and is supported by energy and materials mobilised and derived from the food reserves. It is at this stage that the rate of water uptake begins to increase again. Often however the development of the root is extensive before any epicotyl extension occurs (a condition often encountered in species which experience arid soil situations).

Eventually the epicotyl (which may include the deployment of the cotyledons) then emerges and during the development of the plumule the leaves are deployed - at this stage the potential for carbon assimilation accrues.

The overriding feature in this sequence of events, which initiates and allows the unimpeded continuation of the process of germination, is the unrestricted availability of moisture so that the process is not limited by a lack of water or indeed a water tension. All of the metabolic activities will require water either as a raw material or as the medium for the reactions. Water is thus fundamental to a successful outcome.

Seeds will become imbibed by bringing them into contact with moisture, however this raises several practical issues

which relate to the efficiency of its uptake and this in turn will usually be related to the degree of contact with the water carrying medium. If the seed is immersed in soil or a similarly artificially constituted germination medium, the uptake of water is primarily across the points of contact between the seed and the particles of the medium and secondarily from the humid atmosphere. This emphasises the significance of the texture, particle size and structure of the materials used to create the medium and the importance of maintaining the medium at field capacity.

Imbibition can be achieved artificially by placing the seeds in, or on, moist paper or cloth or by exposing the seed to a saturated atmosphere, or by soaking (immersing in water). This provides a more controlled process and an opportunity to regulate the temperature more efficiently. However when soaking the seed there are a number of issues to be addressed, the most obvious is that of the time of exposure - in the first (colloidal uptake) phase of the imbibition process the activity is completely physical and the fact that access for oxygen is impaired is not significant - but once metabolic activity begins the requirement for oxygen will rise dramatically - hence soaking should be limited to the few hours necessary for this phase to be completed. Extended soaking may also cause flooding of the intracellular spaces and so impair oxygen access - potentially inducing anaerobic respiration; it may also significantly leach out various important solutes from the cell sap. Usually the first phase will be completed within twelve hours - assuming that the seeds have a completely water permeable seed covering. Once the second phase is initiated seeds should not be immersed but a suitable medium, which provides adequate moisture, aeration and effective contact should be provided.

Temperature - its implications and influences in Germination

Germination, however, although principally about water, is also a function of other environmental factors - most notably temperature.

Once the initial phase of imbibition has been completed (and it would appear that the rate of this activity is not temperature sensitive to any significant degree), the rate of germination becomes temperature responsive. Once the process moves into the biological phases the rate is determined by metabolic activity and development patterns.

In general increasing temperature therefore is reflected in an increased rate of the process of germination.

Germination proper, assuming that the seed has imbibed, will then begin once a threshold temperature is reached and then as temperature increases above this base level so will the rate of reaction. However although the base (threshold) temperature is not a fixed or constant feature to all species of a particular provenance it is more or less constant within a species. Indeed this threshold temperature for any one species will reflect part of the overall strategy for seedling development and survival. It will thus restrict germination to a particular window of opportunity within the overall ecological and environmental pattern of its normal habitat.

The rate of germination is then subsequently temperature driven once the threshold has been reached. Any increase in the rate of the process will then be a function of increasing temperature, within the normal biological limits - while somewhere in the intermediate range will be the optimal band which provides the greatest economic productivity. The response is typically that of a sigmoid curve.

The initial phase of imbibition and the rate at which it occurs, despite not being temperature sensitive, has nevertheless temperature related implications. The rehydration process at 'low' temperatures appears to cause injury to (or, at least, an impaired reconstitution of) certain cellular structures and membranes and this is later reflected in a reduced level of growth and performance of the seedling. At 'warm' temperatures the various membranes and structures are able to reconstitute and repair more efficiently and more completely and so exhibit a lower level of damage - this in turn permits a more constant and successful pattern of development and activity.

The determination of 'warm' in this context will be a variable parameter and will reflect the temperatures experienced in the natural environment of a particular subject and the various adaptations and responses of the species itself to ecologically developed strategies.

This concept has at least one important practical implication for the plant propagator who seeks to achieve maximum productivity. The temperature at which the seed is

imbibed will be more effective and less damaging to future performance if conducted at a warm temperature, even if the seeds are subsequently to be subjected to a chilling treatment. For once the membranes and structures have been successfully reconstituted by hydration they will remain effective and undamaged even when subjected to chilling temperatures.

Atmosphere - the influence of gases in germination

Germination occurs most effectively if, in the consumption of the food reserves of the seed, energy production is achieved as a result of aerobic respiration. Most complete use of the food reserves and the liberation of the greatest amount of energy is obtained as a result of aerobic respiration. This infers the necessity for a third environmental parameter for most effective germination - oxygen.

The maximum effective, respiratory activity therefore requires the unimpeded availability of oxygen. Any limitation to the availability of oxygen could, at the extreme, limit the efficiency of the process by initiating the far less efficient system of anaerobic respiration. This system liberates much less energy and results in the production and liberation of toxic end products such as alcohol. Although untreated seed coverings may play some part in affecting the development of partial pressure of the oxygen atmosphere within the seed, the most likely impediment to effective gaseous interchange will be waterlogging.

Variability in germination performance, within an otherwise satisfactorily treated seed lot could therefore be attributed to the variations between individual seeds, in their ability to continue an effective gaseous exchange between the seed and the atmosphere. Some seeds may well be affected more than others, having developed a greater degree of waterlogging in the same sample - as a result of soaking. This is often a reflection of the practical difficulties which are encountered under field conditions and which are less likely to be a problem with a more sophisticated application of technique and greater artificiality (control) within an integrated and monitored system.

Light and its relation to Germination.

Light is a much researched response activity, in relation to the control mechanisms of the germination of seeds, as there is a recognised and obvious vehicle for the response activity - the presence of phytochrome molecules within the seed. A positive response to light is part of an ecological strategy in providing the seed with an indication and a measure of available light thus giving a measure of the potential for seedling development and survival. Species with positively photosensitive seeds are not common among woody plants of temperate climates but knowledge of the potential is significant in the germination of the seeds of those particular species (eg *Betula* and the *Ericaceae*).

Some species of plants demonstrate a negative response to light - being inhibited by the presence of light and may be a mechanism to ensure that the seed is sufficiently deep in the soil for a satisfactory germination and establishment.

In practical terms the presence or absence of light is not a significant environmental feature for the germination of the majority of temperate woody plants. However for those species which are forest dwellers, especially, it can virtually act, for some species, as a dormancy control - insofar as the germination is inhibited until a clearing in the canopy lets through enough light for germination to proceed and so allow seedling development and establishment.

Light also has a significant role - post germination - once the photosynthetic apparatus is deployed and carbon assimilation is possible.

The pattern of epicotyl deployment in germination

In the physical process of embryo expansion and growth, there are potentially two patterns of response in relation to that part of the epicotyl which emerges and undertakes the first positive role in carbon assimilation. This characteristic describes the position adopted by the cotyledons at this time. In those plants in which the hypocotyl extends to promote the cotyledons above the ground to form, in effect, the first leaves of the plant, the sequence is described as epigeal. In those plants in which the cotyledons remain below ground and there is no extension of the hypocotyl, the cotyledons gradually give up their food store to promote the first true leaves above the ground so that these are the first photosynthetic

organs of the plant - this sequence is described as being hypogeal.

Ancilliary considerations associated with germination

Many plants depend, for their successful establishment and survival, on strategies associated with the development of symbiotic relationships. In temperate woody plants this is usually associated with the engagement of mycorrhizal associations or relationships with nitrogen fixing agents.

Mycorrhizal associations are of various types and complexity and exhibit various degrees of obligation. They are chiefly concerned with the efficiency of water and mineral absorption from the soil, by the roots, in which the fungal component receives elaborated foodstuffs from the plant in exchange.

Nitrogen fixing agents, which are usually either particular species of bacteria or blue-green algae, effectively act in the same symbiotic fashion.

As far as the plant propagator is concerned it is useful to have some knowledge of these relationships and to know how soon in the life cycle of the plant this relationship becomes an essential for realistic development rates.

When propagation is taking place in traditional open ground seedbeds this issue is rarely significant as substrate inoculation will occur from 'spore rain'. However when germination and seedling establishment is taking place under more controlled and sophisticated conditions then it may be necessary to inoculate the germination substrate with suitable agencies to ensure proper development.

Other considerations

The sequence of processes described here lead up to seedling establishment - the stage at which the leaves have become deployed and the new plant becomes a self supporting (autotrophic) individual and no longer needs to rely on the food reserves of the seed. Germination can be said to be complete when the seed has finally exhausted its food reserves.

Many seeds contain, not insignificant, quantities of nitrogen containing compounds in the form of amines, cyanogenic glycosides and alkaloids which in many cases represent an important available source of nitrogen in the

metabolic synthesis of protein. However these toxins may also represent a chemical defence system; which means by taste, appearance or poison; deters likely predators and enhances the survival of some of the seed production. It is well documented however that specific predators can overcome these mechanisms by the development of a modified metabolism which is capable of detoxifying the deterrent chemical.

Practicalities

As the seeds of ornamental woody plants are normally sown on a tray containing a compost as opposed to sowing directly into a plugs or other individual units - because of the potentially variable or even unreliable levels of germination success - unless the practically non viable or non-responsive seed is able to be separated and extracted - then there is a need to be able to separate the seedlings, soon after emergence, from the compost readily and without damage.

A compost composed of a high proportion of relevantly sized sharp grit and a suitably structured organic matter component - which will easily fall apart and separate from the seedling root system will allow a swift and easy transfer to a liner unit. This phase benefits from carrying out this particular operation before there is any substantial development of lateral roots - the presence of which will slow the transfer operation and potentially cause damage to the roots.

8.

Liner Production

The successful production of a crop of liners, derived from seed, continues with moving the seedling from the germination medium into the liner unit (pot, plug etc) with the minimum amount of damage to the seedling and especially its root system. A check to growth at this stage may set the seedling back quite dramatically.

The objective of the liner production phase is to achieve as uniform a crop of young plants as is reasonable and one which has produced the maximum amount of growth compatible with the maintenance of the typical characteristics of the particular species. To achieve a uniform crop, in a commercial situation, it may be necessary to be prepared to cull extremes unless they have particular value.

In a wholly controlled seedling production process the constitution and components of the germination medium have a relevance in the development of a rapid and efficient system of liner production. If an effective protocol has been derived for the pre-germination stage and the seed is sown with germination following on quickly - then it is probable that the seedlings can also be moved on into a liner unit in a relatively short time. The objective is to achieve a minimal disturbance of the root system of the seedling in the transfer and so create an efficient process and rapid establishment of the liner. Thus the sooner the seedling is moved on - ie before the root system has had a chance to develop much more than radicle elongation - the more is the likelihood of an uninterrupted development. The constitution of the germinating medium will reflect this and has been discussed previously.

In whatever liner production system is adopted, there are a number of factors which will not only determine the amount of growth produced by the plant, in this phase, but will also affect the quality and the ability to grow it on successfully in the production phase:-

- a) the liner container - individual size and shape and hence the handling system;
- b) the growing medium - physical, chemical and biological attributes and
- c) the growing environment and its management - whether open or protected; and the manipulation of temperature, water and light.

The detail of the container and the compost used in liner production has received much attention in recent years and this has resulted in the various proprietary materials which are now on the market. There is little relevance in discussing these in particular as they will undoubtedly be superseded and developed still further in the future.

The Container - the liner unit

When operating in a modern outfit with integrated systems of production and the need to use growing spaces and resources economically it would be prudent to adopt a specific modular handling system - which standardises the shape, size and number of the various liner units and the carrying module - so that a multiple module layout (ie in terms of the area and its shape - so that each carrying unit occupies x1, x2 etc of space in a particular shape) can be adopted and so maximising the use of the relevant space.

The size (volume) of the individual liner unit should be chosen from a limited range of containers (see above) and should be commensurate with, and allow for, the potential size of the particular plant at the end of the (liner production) season - given the specific growing environment - so that there is no check to growth and the development of a typical specimen will be anticipated.

The individual shape (ie the volumetric configuration) and the construction detail should be chosen to provide the most suitable conditions for root development and to suit the type of root system developed - as well as taking account of the typical shape and spread of the stem system. The major issues are to avoid the potential for root circling and to allow for the development associated with those subjects producing a tap root.

The Growing Medium

The actual constituents of a growing medium, suitable for containerised liner production, are not, in themselves, significant as long as the individual material or mixture provides the texture and physical attributes required for the desired level of plant growth - which are:-

a) the ability to maintain the relevant and required structure without deterioration over the anticipated 'life' of the medium;

- b) the ability to absorb, retain and release water without a significant pressure gradient;
- c) the ability to maintain a desirable air filled porosity ratio;
- d) the provision of suitable, textural surface conditions for the retention and availability of the required chemical materials needed as plant nutrients or to maintain a relevant pH;
- e) the provision of conditions for the development of any relevant biological agencies;
- f) that they do not contain or develop any phytotoxic or other growth inhibiting materials and
- g) have a textural compatibility with the growing medium to be used in the production phase or with open ground conditions - when the liner is moved on.

Thus the actual constituent, component materials of the medium are then determined by availability and cost; as well as, potentially, any 'green' considerations.

Although the nutrition of the seedling in the liner phase can be taken care of by the provision of slow release fertilisers it is probably more efficient and economic to provide this only at a base level at the start of this production phase and to provide ongoing nutrition as and when required by a process of liquid feeding which is tailored to the needs of the crop so providing a more constant, suitable and relevant pC status.

Most of the plants that will be grown in a general inventory of woody subjects will flourish within a reasonable range of pH values. However for those subjects which are adapted to conditions at more extreme levels it will be necessary to modify the pH value of the growing medium to suit the particular species. This is achieved either by using chemicals or more satisfactorily by choosing the physical components of the medium which have a natural pH attribute suited to the particular individual species.

Biological considerations - Symbiotic associations

It is now generally recognised that a very large number of woody plants will form a symbiotic relationship with a micro-organism(s) with some degree of dependence, intensity or reliance. These relationships usually enhance the supply of a particular nutrient and/or water from the micro-organism to the host - which in turn receives, in exchange, elaborated materials - normally in the form of

carbohydrates. This is part of an evolved (at least by the host) strategy to enhance the ability of an individual to compete and survive in an otherwise difficult environment - usually waterlogged, depauperate or deficient soils. In such a competitive situation the ability to obtain water and/or minerals efficiently and effectively or from an alternative source will give a particular species the edge in creating itself a successful niche.

The relevant symbiotic associations developed by woody plants are usually of two types - a) the fixation of atmospheric nitrogen by a micro-organism through a process which turns atmospheric nitrogen into a form in which it is available and useable by the host plant; this agent is housed in specialised root nodules developed by the host plant for the purpose and b) the development of an association with a fungus (or a range of fungi) which, in effect and in some degree, acts as a substitute for the root system of the host in accessing water and minerals.

Nitrogen Fixation

Nitrogen fixation is carried out by bacteria (described as diazotrophs), generally in anaerobic conditions, in the root nodule. Nitrogen from the atmosphere is combined with hydrogen (from water) by the enzyme nitrogenase using energy liberated from ATP as it is reduced to ADP. This results in the formation (usually) of an ammonium radical which is assimilated into glutamate and then transferred to the host plant.

The *Rhizobium*/Fabaceae symbiotic association

Nitrogen fixation by the (diazotrophic) bacterium *Rhizobium* occurs in specialised root nodules in the family Fabaceae. These bacteria, despite being involved in this very specialised symbiotic arrangement are also generally found as free living organisms in the soil. Hence in open ground seedbed conditions inoculation of the roots of a potential host is not a problem; however in situations where the subject is to be grown in an artificially constituted and 'sterile' compost it may be necessary to provide an inoculum.

Actinorhizal symbiotic arrangements

A similar arrangement is found in a number of other woody genera - (*inter alia* - *Alnus*, *Ceanothus*, *Cercocarpus*, *Comptonia*, *Eleagnus*, *Hippophae*, *Myrica* and *Shepherdia*) in which the nitrogen fixing (diazotrophic) organism is the

actinobacterium **Frankia**. This actinorrhizal association also occurs in root nodules on the host.

Mycorrhizal associations

Many plants will enhance their ability to compete for or to utilise resources more effectively as a result of creating a symbiotic relationship with particular fungi. These fungi will develop in conjunction with the root system of the host and will, in some degree, replace it in terms of the processes by which water and nutrients are accessed from the soil by the plant. These symbiotic relationships between fungi and the roots of higher plants are described as mycorrhiza (literally fungus roots).

The fungal mycelium, at the ultimate, may virtually completely replace the roots as the organs of water and mineral uptake from the soil - the fungus fulfilling this particular function and transferring these materials into the plant roots - the particular arrangements for transfer being dependent on the structural interrelationship. Broadly there are two types of arrangement - those in which the mycelium penetrates the root tissue and those in which the mycelium develops as a sheath around the surface of a specially modified root tip. In return for providing the plant with these raw materials the fungus extracts elaborated carbohydrates for supplementing its own energy resources.

Mycorrhizal associations are normally at their most effective, for the host plant, in demonstrating their benefits in nutrient deficient situations and especially those where phosphate deficiency is prevalent. Conversely where nutrients are readily available mycorrhizal development is often impaired and no additional growth increments will accrue from, or can be attributed to, the association.

Mycorrhizal associations not only provide the plant with an opportunity to improve the ability of the roots to obtain water and minerals more consistently but also provide the plant with a more penetrative and efficient system for the exploitation of the entire soil profile than can be provided by the roots alone. It provides the plant with the opportunity to forage more efficiently through the entire volume of soil. It also creates the scenario in which these fungal 'roots' are not only more efficient foragers but it also implies the ability to adapt by the rapid development

and redeployment of the mycelium into any particular area as a result of the changing patterns of water and mineral availability in the soil.

Those fungi which are capable of developing a mycorrhizal association are otherwise normally saprophytic and are part of the normal soil flora and ecosystem.

The necessity for any particular species of woody plant to develop a mycorrhizal association is variable - some species at the extreme, as has already been indicated, are obligate in their arrangements and have adapted the development and structure of their roots to the most efficient arrangement (eg *Pinus*) and if the seedling is not 'infected' with the potential symbiont it cannot grow and develop successfully. Other species can develop a facultative dependence and will develop the arrangements depending on the environmental circumstances and the availability of suitable symbionts; at the other extreme many plants have not evolved to need this arrangement and manage quite successfully without.

For those species which have a degree of dependence the capability for growth and development will be enhanced by an opportunity for the development of the association soon after the deployment of the radicle at germination. In the process of germinating seeds it is therefore prudent to expose the radicle to the necessary symbionts at an early stage in order to encourage the association as soon as the process is feasible and so enhance the potential for the enhancement of growth at the earliest opportunity.

Fungi are, in general, particularly adapted to soils with an acid reaction and tend to form associations with subjects growing in these environmental conditions. In these habitats however the converse may be true in that these plants are able to survive in these environments because they have the inherent facility to make a suitable mycorrhizal association and so compete successfully.

Nowadays with the routine use of sterile growing media in the germination of seedlings and in the liner production phase, and the provision of protected environments, the provision of an inoculum is needed to ensure the required status is achieved. As the relevant fungi are saprophytic under natural conditions it is necessary that the growing medium has an adequate organic matter content to ensure the

rapid proliferation of the mycelium to a sufficient level throughout the profile as the seedling root system is developing. In 'open' growing situations the growing medium will be subject to the normal levels of 'spore rain' and inoculation will occur naturally.

This account of mycorrhizal association is not intended as a description of mycorrhiza themselves - as their study is in itself a complex and difficult discipline to understand; however the emphasis here is on the fact that, for many species, this arrangement is an integral part of successful seedling production. In these cases they are an essential and beneficial component of the process, and therefore a necessary provision within the overall pattern of husbandry.

The particular relationships between fungi and host are complex but it is evident that there is, in general, little specificity between the two components. There is a very large range of fungi which are capable of developing such an association and the host may embark on an association with several different species of fungi at the same time - as long ago as 1896 Hartig recognised 400 species of fungi forming symbiotic arrangements with the European Beech (*Fagus sylvatica*). In woody plants, in general, there are few specific host/fungal relationships; it is therefore only necessary to provide an adequate range of fungi to ensure success.

The Growing Environment

The growing environment provided for the development of the seedling during its establishment and growth to the stage of being a suitable liner plant is a function of:-

- a) **Light** - many plants are adapted for seedling growth to occur within the forest floor or in other habitats where full light is limited as a result of the shading created by mature plants. In order to make the most use of the season of available light, the seedlings of many deciduous plants do not abscise their leaves until well after the adults of most canopy species have shed their foliage. It is also quite possible that because of this adaptation that exposure to full light - especially 'the noon day' sun - may produce tissue damage (scorching) during the main season of growth. Thus the early and mid-season growing will be best undertaken in a shaded environment.
- b) **Temperature** - within reasonable limits, the growing temperature should approximate to the 'natural' growing

conditions for the particular plant and so avoid atypical growth induced by too high a temperature. Few plants produce seedlings which are able to resist freezing conditions - it is therefore relevant to provide frost protection for the seedlings - as even at marginal levels it will be a check to optimal growth rates.

c) **Water and humidity**

Apart from the competition for light the seedling is also subject to competition for water and this can be a factor in limiting growth rates under natural conditions. As the various plant species are adapted to varying degrees of water stress the optimal conditions for growth are necessarily difficult to describe in general. In practice it is easier to vary the texture of the growing medium and so alter the water holding capacity than to alter an irrigation programme. Optimal growth conditions will be achieved the greater is the length of time that the soil is as close to field capacity as is reasonable and water stress is minimised. Hence the watering regime should be tailored to this status. Similarly the humidity of the atmosphere will vary according to the needs of the individual plant and the growing environment should be tailored with that in mind. The maintained humidity may also influence the incidence of various pests and diseases such as Red Spider Mite and downy mildews.

Pests and Diseases

One of the inevitabilities of growing a high density of large numbers of a crop, under some level of artificial conditions, will be the occurrence of both general and specific pests and diseases. Particular attention should be made to this element of growing and the necessary measures for control put in place. The maintenance of high levels of hygiene in the growing environment to reduce potential occurrence is a *non-sequitur*. The prime consideration will, however, be the provision of those relevant conditions which preclude occurrence and thus maintain an environment which will not encourage infection or infestation. Where general, non-specific problems are likely to become an issue it would be prudent to maintain biological control materials or even the maintenance of companion plants which create an uncongenial environment.

However if such organisms do appear it may be necessary to resort to chemical controls but this should always be used in such fashion that it takes account of any side effects - such as the depression of mycorrhizal activity.

Weeds

If a 'clean', ie weed free, site is maintained the ingress of spores or seeds is much depleted and the odd occurrence can be removed before it becomes troublesome.

Mosses and liverworts - sources of infection within the site should be eliminated so that spores cannot access the growing areas and the irrigation regime should be tailored to prevent the surface of the compost from becoming too wet and so provide the conditions for rapid development

Ubiquitous ephemeral weeds - eg annual meadow grass and hoary bitter cress - although it is difficult to deal with these sorts of weeds in open situations the maintenance of clean conditions within structures should eliminate any primary source of local seed production.

Weaning

The final part of the development of any crop of liners will be the weaning of the crop from any protected environment to 'outside conditions' which then allows an unfettered move into the production phase.

Facilities

The facilities required for the production of a crop of seedling liners will reflect the type of crops to be grown - especially in relation to their optimal light and temperature requirements and this will necessarily require the provision of structures such as shade tunnels, poly tunnels, combination (hybrid) tunnels, glasshouses and possibly frames - as well as the necessity for outside growing space.

Water

Although the provision of a source of water for irrigation will be a necessity, attention should be paid to the water strategy for the whole nursery. This includes the collection or impounding of (rain) water, the impounding of drainage and run off water, recycling and the necessary treatment procedures to maintain and ensure a clean supply. Water is becoming an increasingly expensive commodity and effective and economic use is an essential component of the nursery practice.

Appendix 1

Reduction Treatments for Seed Coat Conditions

Dormancy in seeds with intractable seed coats (which prevent the seed from imbibing) creates a problem for the woody plant propagator. Seeds with such a condition will require one or more of the following procedures to prepare the seed to a stage at which the seed coat is sufficiently degraded that it will become permeable to water and so imbibe. It can then proceed into the next relevant stage of the germination process - which may be germination itself or may be the mitigation of an endogenous dormancy control or the maturation of an immature embryo.

These seed coat conditions have evolved as a strategy to prevent the seed from germinating and establishing as a seedling under adverse environmental conditions or to protect the seed in its passage through a digestive tract of an animal while it is dispersed or to spread germination over a number of years by the variability in the rate of decomposition. The procedures, which are indicated here, are for the treatment of the mature, fully ripened seed.

It may be possible to avoid the conditions by an analytical understanding of the maturation process and then collecting the seed when it is fully mature (ie when the embryo and food reserves are complete) but before the seed coat begins the maturation (hardening) process.

Not all plants which produce seeds, appearing to have a hard seed coat, actually have intractable conditions which prevent the uptake of water - although dry storage may well subsequently induce an impermeable state - a secondary dormancy. Many subjects have developed a 'hard' seed coat simply to protect the seed proper, as part of a fruit, in its passage through the digestive tract of an animal (eg the drupes of *Prunus*, the pomes of *Crataegus*, the hips of *Rosa*, the arils of *Taxus* and *Podocarpus* etc). The strategy is to entice the animal to eat the fruit with its valuable food and hence energy rich content in order to achieve dispersal of the seed; similarly the fat-rich outer, seed coat of the various *Magnolia* species achieves the same end. In all of these seeds the coat protects against the action of the digestive juices during the fairly rapid passage of the seed through the gut but does not subsequently generally prevent imbibition - in many cases the fruit has

laxative properties which aid this process by easing the activity.

Thus in some instances this hard seed coat is part of a strategy where an animal eats the fruit, digests its 'reward' and the passage through the gut actually degrades the hard seed coat condition sufficiently for imbibition to follow quickly once it is liberated and finds itself in damp soil (eg *Daphne*).

The objective for the plant propagator is to develop a protocol for the reduction of the intractable seed coat to a stage at which it will readily imbibe. This needs to be achieved in such a fashion that a uniform response is engendered in the sample and that there is no damage internally to the seed itself.

Types of seed coat condition

It is not easy to categorise seed coat conditions with any accuracy as each plant has evolved for its own particular condition and the response, structure and mechanism is unique to that species (or probably genus). However many plants, especially when they are closely related or live in similar environments, have obviously evolved very similar protections and can therefore be treated in very similar fashion. Nevertheless there is no universal basis to this mechanism so that mitigation strategies have to be tailored individually.

Intractable seed coat conditions can be described as 'hard' - in which the protection is shell-like or stone-like; 'tough' - in which the coat is described as fibrous, leathery etc; or the condition may be intermediate or possibly more than one type is encountered in layers surrounding the seed (eg *Tilia*, *Hamamelis*).

Additionally there are a number of species in which the seeds have what is basically a permeable seed coat but this is waterproofed by the presence on, or in, the surface of the seed of a water repellent material such as lipids.

In order to overcome such seed coat conditions a variety of techniques are available - depending on the nature of the individual problem. The various techniques can be classified quite simply as physical, chemical or biological.

Methods to overcome seed coat conditions

a) Physical methods

1. Hot water soak

In the very simplest condition the seed coat exists as a structure that will eventually allow the passage of water if it is soaked in water for long enough. The seeds of many species develop seed coats, which are marginally resistant to water uptake but once they are dried they are substantially resistant and so prevent water access to the embryo for imbibition. However once they are exposed to continuously damp conditions the seed coat gradually softens and water will access the seed. An artificially provided warm water soak, which starts with hot water and the maintenance of warm conditions, and gradually cooling over a period of several days, will normally be sufficient to achieve the required level of penetration. The time necessary to achieve this will be a reflection of how dry the seed case has been allowed to become. The treatment will be most usefully conducted with about four volumes of hot water being poured onto one volume of seed.

Where possible it would be prudent to collect the seed as early as is feasible so that the development of the 'hardening' is kept to a minimum - so that the period of soaking is also reduced to a minimum.

2. Scarification

This technique is most effective for the degradation of those seed coats which are hard and shell-like or stone-like. This usually occurs when the seed is fully mature and dry, and has become fairly brittle. The process depends on reducing the seed coat until it is breached in one place to a level at which water can permeate - it is not necessary to reduce the whole of the seed coat.

If the seed is big enough to handle individually (eg *Gymnocladus dioicus*) it is quite possible to chip the coat of the seed - preferably without cutting into the seed itself.

If the seed coat is brittle it may be possible to break or crack the seed coat sufficiently by pressing the seed between boards. For those seeds which are of regular shape and in which the sample is relatively uniform in size it would be possible to achieve the same outcome by passing the seed through critically set rollers.

If these methods are not practical because of size, quantity or structure then seed coat reduction using sand or other abrasive materials is feasible. The use of two sandpaper boards and rubbing the seeds between them or lining a jar with sandpaper and shaking until a sufficient reduction is achieved will eventually succeed, although this can be tedious to work.

It is possible to ascertain that the seed coat reduction has been achieved by immersing a sample of the seed in water for a few hours when the seeds will visibly swell as they imbibe.

Seeds which have a hard seed coat - but which water can access when a strophilar plug is dislodged can be treated simply by bouncing the seeds vigorously in a solid container until the plug is disengaged.

3. Heat

Many species, especially from Mediterranean climate biomes, exist in a fire ecology system. These species depend for their survival on being able to germinate and compete in an area which has had the vegetation destroyed by the passage of wild fire. Seeds which have lain dormant, over many years, in the soil are induced to germinate by rains following this pattern. The protective coat of the seed (which allows survival for many years in the soil and is able to resist the normal decomposing agencies) is modified by exposure to heat at a sufficient level that it causes the coat to crack or for a strophilar plug to be sprung (by differential expansion) or by the splitting of a hilar fissure (which is irreversibly opened by seed coat expansion). In nature only a fraction of the seed present in the soil gets the right temperature - seeds near the surface may be overheated and killed then there is a layer in which viability is maintained and the necessary action is achieved and below this the level of heat penetration is not sufficient to cause any activity. Thus whatever the intensity of the fire some seeds will receive the correct treatment.

Artificially the temperature treatment of seed samples can be carried out by pouring hot (boiling) water onto the seeds, however it is quite feasible that the duration of the requisite temperature is not maintained for long enough and no result ensues.

The alternative is to use dry heat which can be controlled more satisfactorily both in terms of level and duration. The seed is extended in about four times the volume of dry sand and placed in a suitably sized metal tray, it is then transferred to a preheated oven at 100°C (+/-10°C), normally a period of four to five minutes will achieve the desired result, however a longer period will not usually harm the seed and so considerable leeway is available.

b) Chemical methods

3. Digestion by caustic inorganic substances

The use of inorganic caustic materials, such as concentrated acids and strong alkalis, to degrade seed coats can be effective but, in general, it is a dangerous procedure and requires expert knowledge in the handling of the materials, access to the proper equipment and facilities - and in these days of 'Health and Safety' an unwelcome bureaucratic paper trail! It should only be contemplated in the last resort.

4. Digestion using organic acids

For those species where seed coats which will respond to less drastic action than the foregoing - less caustic materials such as organic acid will degrade seed coats albeit as a slower response. The best documented material, and the one used reasonably extensively is Citric acid; it is used at an aqueous concentration of 1% (10,000ppm) as a soak for (usually) between four and six days. The seed is soaked in about four times the volume of the dilute acid.

c) Biological methods

5. Digestion

There are many species of woody plants which develop intractable seed coat conditions which are described as 'tough' - as opposed to 'hard'. The texture of the outer coat of these seeds develops a structure which is normally, more or less, peculiar to a species or genus and is described variously as amorphous or fibrous or leathery or reticulate etc. These seeds do not respond easily to treatment with caustic materials as often the outer surface chars and prevents further action or the structure is not uniform and the action penetrates 'thinner' areas quickly and destroys the embryo.

Tough seed coats can therefore be dealt with by using a biological digestion which approximates to what happens under natural conditions. For quickest action it as well to

collect the seeds while they are still green, soak them for a few hours to top up their water status and then commence the treatment immediately - as this will arrest the further development of the seed coat.

A measured quantity (by number or weight) of seed is mixed with about four times the volume of a damp, organic substrate such as peat or a suitable substitute with a satisfactory air filled porosity. This is then inoculated with a nominal amount of proprietary compost accelerator (which will induce a quicker decomposition of the organic seed coat material). This mixture is then placed in suitably sized polythene bag (zip lock type) and incubated in a warm environment (30°C). The bags should be monitored on a weekly basis, shaken to maintain an even atmosphere and moisture content - if the material appears to be drying then add moisture to maintain the water status. The seeds will imbibe and swell once the treatment has been completed. This type of treatment is necessarily less exact than some but experience will allow a reasonable estimate to be made of the likely periods needed for a successful outcome and a standardised procedure with reasonably accurate parameters can be developed.

Other Impermeable conditions

A short term protection against the uptake of water by the seed is provided by a water repellent material on, or in, the surface of the seed coat. These are usually waxes, fats or oils and under natural conditions are relatively quickly removed in the soil, by natural agencies, so that imbibition does not occur until dictated by the plant's strategy for successful germination.

In many of the species however it is just as likely that the protection is provided to maintain the water status of the seed itself until such time as it gets into the soil.

Lipids of these types are readily extracted by using a hot water soak and flushing two or three times or by organic solvents such as alcohols, acetone etc.

In some species associated with a fire ecology the seed is surrounded by a thick, dense layer of waxy material which protects the seed until the passage of fire when effectively the material melts and frees the way for water to permeate when it is available.

In California it is often the practice when small seeds, such as *Dendromecon* and *Romneya*, are to be treated that the seed is sown by mixing with a dry compost and then placing in an earthenware container, covering with excelsior and igniting - thus simulating natural conditions - however only the seeds in the stratum of compost receiving the right temperature will be successfully treated (see above). The seed can then be left in the container and, when watered, will quickly germinate.

Appendix 2

Endogenous Dormancy Control

Seed treatment by chilling

Those seeds with an endogenous dormancy control, which is mitigated by a period of cold temperature (chilling), constitute a fair proportion of the species from cold temperate climates.

This is an evolved strategy in which the embryo is prevented from germinating, during the autumn and winter, by the presence, within (or adjacent to) the embryo, of an inhibitor which prevents any further physiological activity associated with development and growth. This inhibitor is eliminated and/or neutralised and/or replaced by promoters during this winter exposure of the imbibed seed to a specific period of cold so that germination will occur as soon as environmental conditions are satisfactory for it to proceed.

For the process to be successful and to be achieved artificially with exactitude, it is important that all other constraints to germination associated with seed coat conditions and other chemical inhibition have been completely removed from the seeds.

The accurate assessment of the period required for chilling to eliminate the dormancy condition is an important step in determining the protocols for a complete blueprint in the seedling production for a particular species.

The practicalities revolve around ensuring that the seed receives a suitable and sufficient cold treatment (chill).

Prior to the commencement of chilling it is an imperative that the seeds are fully imbibed - as any backlog of moisture required by the seed to complete imbibition, once the chilling process has commenced, will distort the time scales.

Initially therefore the seeds will require a warm water soak for several hours to ensure complete imbibition. A warm water, rather than a cold water, soak ensures not only that imbibition occurs effectively and quickly but that certain microstructures within the cells reconstitute more efficiently at higher temperatures. It has been shown that the level of imbibition required to allow the chilling

process to achieve is marginally less than the level required for the initiation of germination. Hence it is possible to prime the seeds by chilling at this critical level of imbibition and then holding (ie store) them without further water uptake until they are required for germination. However this process requires much inquiry and measurement and is only feasible for large scale operation and is thus limited to commercial seedsmen who wish to sell a 'primed' product.

The seeds are then ready for chilling and this treatment should begin without allowing the seed to dry.

When the prepared seeds are to be subjected to the cold temperature treatment it will be prudent to determine how this will be achieved. The seeds will need to be able to maintain their water status and have a satisfactory surrounding atmosphere so that there will be a normal and adequate pattern of gaseous exchange for metabolic activity. It is important that oxygen is not limiting as an absence or a low level of availability will induce anaerobic respiration within the seed with the anticipated deleterious results.

The seeds are mixed with a suitable inert and more or less sterile, extending medium which will hold sufficient water, will maintain sufficient contact with the seed and will achieve a satisfactory and continuing level of 'air filled porosity' - such that the required metabolic processes can proceed normally and without constraint.

Conventionally a mixture of equal parts by volume of damp, sieved peat and coarse sand or sharp grit (up to 2-3mm) provide the right conditions, although materials like vermiculite and perlite have been successful - choice is a function of seed size and the materials available.

The sieved peat is dampened until, on squeezing a handful, it is just possible to cause a drop of water to be emitted. The components are mixed thoroughly to create an even consistency. The determination of what constitutes a 'volume' of damp peat is a bit of a moveable feast - as peat can be compacted to significant levels. It is therefore necessary to determine this amount ('volume') by trial and error (ie what suits the particular materials and process within the operation) and in order to establish the

consistency of the working unit for use in any particular circumstances.

As long as the physical conditions are satisfied and there is no other chemical or biological problem, the actual constituents are not, in themselves, critical.

The seed sample is then extended with four times the volume of this medium.

As it may well be that in subsequent operations the seeds will not be separated from the medium it will be prudent to treat a measured unit quantity of seeds - either by weight or by number to facilitate this subsequent procedure. This measured quantity of seeds may well be the quantity needed to sow a container or a particular area of seedbed.

For this reason it is advantageous to treat the sample in small units and a container such as a polythene zip-lock type bag is particularly useful. A label should be placed inside the bag carrying relevant details and identification as well as on the outside - to ensure continued individual identification and treatment.

The cold temperature is provided by transferring to a refrigerator which has been set to maintain a temperature of 3°C (+/-1°C) - as a temperature at this low level is likely to satisfy the requirements of the great proportion of species to be treated.

Once the sample has been bagged and placed in a refrigerator, for the cold treatment, it will be important to monitor progress regularly. At least once a week the bags should be opened to check water status and allow gaseous exchange. Shaking will also prevent any uneven compaction of the medium and so eliminate any variation, within the sample, in water uptake or gaseous exchange. Hence it is wise not to stack the bags but to have sufficient shelves and place only one layer per shelf.

Such a procedure will also allow a visual assessment of progress - as some species will germinate (at least to the radicle emergence stage) at low temperatures once the condition is mitigated.

Once the chilling period has been completed, the seed is ready to enter the germination phase and will need a higher

temperature for a speedy, uniform and effective result. Usually the practice has been to sow the seed onto a suitable compost in a relevant container and place on a bottom heat of 18-20°C. However it is more energy efficient to achieve this stage in an incubator and then sow the seeds a day or so before the anticipated germination date. The same conditions for monitoring and managing the packets of seeds apply as are suggested for the chilling procedure.

Appendix 3

Elimination of Chemical dormancy controls by Leaching

There are many species of woody plants in which dormancy is engendered by the presence of a growth inhibitor, such as abscisic acid, in the fruit and/or the pericarp surrounding the seed. With maturity of the fruit this can then permeate the seed - effectively creating a distortion in the initial phases of the chilling process. Fortunately this chemical is freely soluble in water and can be removed fairly efficiently by leaching.

Leaching can be achieved by soaking the seeds and then washing or by flushing them in warm water for several iterations. This chemical is often an unexpected and unrecognised presence, albeit in small quantities, but nevertheless needs to be recognised and removed as a matter of course. It will delay the chilling process until it is eliminated - thus distorting the period needed for the chilling procedure.

This sort of inhibition probably accounts for the very variable time scales, which appear in the literature, for the chilling requirement of the seeds of such divergent species as apple, many Roses and *Mahonia aquifolium*.

There are many woody plants of arid environments in which the seeds contain a chemical which effectively acts as a rain gauge. Precipitation, in a location with limited rainfall, is often not sufficient for the completion of germination and seedling establishment. The plant has therefore evolved for the seed to contain a particular amount of chemical that is not completely leached until there is a sufficient reservoir in the soil to support the full process. Leaching will normally be effective for these subjects.

Appendix 4.

The Maturation of Underdeveloped Embryos

A few species of woody plants produce seeds which, at the time of dispersal, do not have a mature embryo. This will therefore require this immature embryo to be provided with the necessary conditions to develop and mature to a condition at which the various processes leading to germination can proceed.

The immaturity of an embryo, in a seed at the time that it is dispersed, may vary from an amorphous aggregation of cells through stages of morphological differentiation to the final physiological maturation. These stages of development lead to the production of the mature embryo which is capable of processing into the germination or pregermination phase which ensues.

Whatever the stage of maturity of the embryo - it is necessary to treat the seed to bring the embryo to full maturity in order to proceed.

The first requirement will be to imbibe the seed and this may require any impermeable seed coat condition to be eliminated as a first step. Once this has been achieved the seed should be imbibed with a warm water soak - for about twelve hours - so that the seed contents are reconstituted with the minimum of detriment to the tissues.

Once this has been achieved it will be necessary to store the seed over a requisite period of time in order to allow the embryo to reach full maturity. This length of time will reflect the degree of immaturity of the embryo and the temperature at which the storage is maintained.

The storage environment must of necessity provide conditions which will allow the maintenance of the viability of the embryo, hence the water status of the seed will have to be maintained and a suitable atmosphere provided. This is usually achieved by using compatible materials (such as are described for chilling the seed in dormancy breaking) and packaging and labelling in the same way.

A storage temperature in the range of 20-30°C will normally achieve an effective result - higher temperatures may lead to the food storage materials (especially if they consist

of fats, waxes and oils) in the seed becoming rancid and lower temperatures will necessarily cause a much slower response - with the possibility that there will be some losses in the sample by an attenuated ageing process.

Appendix 5

Specialised Seed Treatments

Inevitably, in such a variable process as seed germination, there is still much that is imperfectly understood. There are, evidently, other than 'normal' cues which stimulate germination and often appear in unusual or particular environmental situations or geographical locations. There is also the possibility of sidestepping dormancy by the use of chemicals.

1. Promotion of germination by the use of 'chemicals'

a) Gibberellic Acid is a known growth promoter and it is not unreasonably postulated that it is the material which promotes seed germination. As any inhibitor present is eliminated there is an increase in Gibberellic Acid - ie GA increases as ABA is reduced.

Hence it would be reasonable to suppose that a GA soak might enhance germination by overcoming such dormancy issues. The picture is complicated by the number of varieties of GAs which occur in plants, GA3 - commonest used.

b) Other chemical treatments which have been shown to be effective in promoting germination in particular circumstances are:- soaks with (*inter alia*) Kinetin and Potassium nitrate.

2. Promotion of germination by the 'by products' of fire

As germination is potentially stimulated or cued by fire in those plants from 'fire ecology' environments it is logical to assess the impact of fire. Primarily the effect is usually simply one of heat degrading an impermeable seed coat by one of the many processes available. Secondly the effect may be by the action of the chemical residues of fire - ie 'smoke', 'charate'.

[Burn dry woody and green material from the species or related plants in a drum and pipe the smoke into a plastic tent containing the sown seeds, leave in situ for a couple of hours ie a 'smoke' treatment - or burn related woody material on top of a sown seed container (not plastic - it will probably melt!) and then place under mist or similar

and allow the 'charate' to be leached into the compost and, hence, the seed.

It is now possible buy 'discs' of extract which are placed in water and the water then used to soak (imbibe) the seeds.

3. Australian provenance

There are many genera of Australian plants which can prove difficult to germinate and which do not respond to the 'normal' or 'conventional' approaches to the issue. Perhaps this is not surprising as the continent has been isolated for so long that alternative solutions to the development of dormancy have been evolved.

All of the above treatments are in a state of flux as researchers around the world delve into these mysteries. It therefore behoves the practitioner to investigate via the internet the current position.

Appendix 6

Records

The efficient development of effective protocols for seedling production will be the result of the accumulation and aggregation of basic knowledge combined with the practical experience gained from operating the various systems over time. For this to be effective it is important to maintain records in a detailed, coherent and recoverable fashion so that this experience can be verified from a primary source which, in turn, is derived from the immediate context of the operating conditions at a particular site. This will allow the development of reliable protocols for use within the constraints of that particular establishment.

The primary records are most usefully maintained on the basis of each individual seed lot. This implies an ability to maintain a chronological record of all the events and details pertinent to a particular sample. This, in turn, will require that each lot can be identified by a numerical and/or alphabetical code or other detail (eg bar coding) which allows the quick referral of information to this particular log. Nowadays, with the development of ever improving and more efficient and sophisticated systems and databases, computerised record keeping becomes relatively easy - once the parameters of the database have been established and an understanding of the possibilities has been achieved.

It is not the intention to present sample record pages as the abilities of any particular operation and the amount of information recorded will depend on the time available - after all the object of the exercise is to produce seedlings - not to store data! Thus the following notes are presented as a guide to allow an operator to be aware of all the various parameters which might affect the outcome and provide an overall view of all the variables which might affect the development of a protocol.

Nevertheless the more information that can be recorded - however trivial - may turn out to be significant. Remember that with modern digital photography - images are easily produced and one picture can take the place of 'a thousand words'! The current, ever accelerating, development of information technology equipment can allow hand held, mobile, digital 'pieces of kit' (with phenomenal abilities

and memory) to be carried and that this will allow records to be made in the 'field'.

All individual records of detail should be preceded by a date.

a) Seed lot recognition code

The most significant initial task is to assign each seed lot an individual identification code (see above) that will be used to monitor it throughout its presence in the system of production.

b) Identification

The name by which a seed lot is accessed should be recorded but the record should also allow for subsequent correction if later information demonstrates that the initial nomenclature was erroneous - either as a result of mistaken identification or as a result of taxonomic changes.

c) Source

External origin

Commercial

Seedhouse

origin - name of supplier

cost

invoice no.

name (identification) as used

lot number

quantity - weight or count

(image)

any other information provided eg provenance

Other supplier or collector

relevant information as above

Self collection

weather conditions

status/condition of the sample

location - GPS

(image)

other relevant information

d) Extraction

details of methods and techniques used

- this is usually relevant only to a species or group of species

e) Seed description and count

(close-up image)

unit count - 100 grain weight or

no. per (relevant) 100gm, Kg, oz, lb

viability

method of assessment

measure

(This feature is often a diagnostic feature in confirming the identification of the subject)

f) Storage

container

water content

temperature

other relevant details

g) Pregermination treatment

Dry seed - seed coat degradation,

scarification

heat treatment

Seed coat digestion

material

duration

rinse

Seed imbibition

period

temperature

Warm stratification

constituents of the medium and proportions

ratios of seed to medium

additives

container

temperature - provision and duration

unit size

monitoring

Chilling

constituents of the medium and proportions

ratios of seed to medium

container

temperature - provision and duration

unit size

monitoring

h) Sowing

container
medium - constituents and proportions, inc additives
density - broadcast or station sown
covering
watering
temperature

i) Germination

emergence - daily records
any relevant descriptions or peculiarities

j) Transfer to liner production

seedling quality
compost details
container
environment

Having collected the data - it is now important to use it -
ie correlate, analyse and develop protocols and year on
year refine one's processes and protocols.

A-Z
Gymnosperms

a) Introduction

b) Cycadales

c) Ginkgoales

d) Coniferales

Taxaceae

Cephalotaxaceae

Podocarpaceae

Araucariaceae

Sciadopityaceae

Cupressaceae

Pinaceae

Gymnosperms - Introduction

The Gymnosperms represent a recognisable group of plants with particular botanical affinities - most fundamentally all produce 'naked' seeds - from flowers which develop into structures which are described as cones. They appear in evolutionary terms after the Ferns and before the Angiosperms. Their classification into Orders and Families has been the subject of much debate over the last couple of decades but recent advances in DNA analysis and its interpretation have clarified most of the relationships and in consequence many surprising and unexpected realignments of taxonomic units have been created. The importance of this in taxonomic terms does not directly concern these notes (except in terms of nomenclature) but the real affinities and relationships of genera and species do have relevance in seedling production - insofar as close relationships are likely to have evolved down similar avenues in terms of both anatomical and morphological development and physiological responses. These developments will have been influenced by the environmental and ecological conditions preceding, surrounding and affecting germination during the evolutionary process.

The Gymnosperms consist of four Orders - the most significant and numerous being the **Coniferales**; in addition are the **Gingkoales** - represented nowadays only by **Gingko biloba**, the primitive **Cycadales** and the **Gnetales**.

The affinities of the plants in their Families are relevant to the plant propagator as they may well provide clues to potential similarities in relation to seedling production, seed structure and composition, seed handling, dormancy conditions of the seed, the environment for germination and seedling development. These similarities may provide indications for the handling and treatment of less well known subjects where direct information is lacking - as closely related subjects are likely to have developed similar characteristics. In this respect a tendency to the storage of oily food reserves, immature embryo conditions, hard seed coats and endogenous dormancy all appear to have evolved in closely related patterns.

The seeds of conifers are relatively simple in structure - the embryo is carried vertically in the seed usually with the radicle close to the base. The embryo is embedded in, and supported by, the endosperm. These food reserves are

more often than not high in fats and oils - which has implications for the provision of storage conditions (*loc cit*) of the seeds. Usually the cotyledons are numerous but this is not invariably the case and in some genera - especially at the more primitive end of the spectrum - there may be only two or three.

In general the presence of a morphologically immature embryo condition in this group of plants is uncommon but it seems to occur more frequently earlier in the evolutionary tree rather than later *viz* *Gingko* and *Taxus*. Its mitigation however is just time consuming and simply requires the provision of warm conditions for the imbibed seed to mature. Elsewhere among the conifers the presence of an immature embryo, although requiring the same conditions for mitigation, is much more marginal and is often a function of physiology rather than morphology.

A few species have developed genuinely impermeable seed coat conditions but in the great majority of cases this is a hard seed coat rather than a tough condition and can usually be mitigated by an extended warm water soak. Seeds with such a condition, even marginally, also tend to enhance the condition in dry storage. Although the hard seed coat condition is not common among conifers it does occur as a protective strategy in those genera where the seeds are dispersed in a fruit which is attractive as a food source to mammals or birds (*eg Taxus* and *Juniperus*). Thus the 'hard' coat provides protection for the seed while in passage through the gut - by the time the seed has passed through the gut and is expelled in the faeces, the seed coat has become degraded and is usually no longer impermeable and the process proceeds to chilling or germination without the encumbrance. In the absence of a suitable pet bird or mammal to undertake the activity, these species will require a suitable protocol to eliminate the condition artificially.

The seeds of conifers are not, in general, subject to an endogenous embryo dormancy condition which requires a period of chilling for mitigation. However there is, among several species from cold temperate climates, the presence of such a control in the seed. This control is not definite or constant and can vary in its intensity from year to year, sample to sample and indeed can vary within a sample. It is usually not sufficient to prevent germination within a sample - and this may occur without chilling but the

germination process will usually be slow, erratic and incomplete.

The variation in this situation occurs, it would appear, because the agency causing the encumbrance develops fairly haphazardly in the endosperm and/or the seed coverings. This can be demonstrated by excising the embryos and finding that they will germinate without delay. The presence of this block to germination can be mitigated by, usually, a fairly short period of chilling. The presence of this block to germination is part of the evolved ecological strategy for encouraging germination to occur during an advantageous window of opportunity - as many of the seeds of such species are shed over a reasonably long period from the autumn to early spring and it is feasible that any deep seated condition would not be satisfied.

An effective dormancy is also developed by the seeds of many species (which do not necessarily exhibit endogenous embryo dormancy) by the requirement for a high threshold temperature for germination - for while low temperatures persist germination of the imbibed seed is effectively prevented and emergence is delayed until there are suitable conditions for development and survival of the seedling.

In general conifers from warm temperate, subtropical and tropical provenances do not exhibit any constraints to the germination process; however species from temperate, cold temperate and subarctic climates often have developed strategies for preventing germination at unsuitable seasons so that germination is promoted at the best possible time for survival of the seedling.

Many species of conifer are native on soil types with a poor nutrient status - especially phosphorus - and have adapted to succeed and compete under these conditions by developing mycorrhizal associations. When propagating species with this necessary requirement - especially under protected conditions (where natural inoculation by spore rain is potentially impaired) - it will be prudent to provide a relevant inoculum to the growing medium.

The conifers represent an important group of ornamental plants and although the great proportion are variants which are propagated by vegetative means - many of the species (which are ornamental or of interest in their own right) are readily and economically produced from seed.

Cycadales

The classification of the Cycads is much discussed - as to whether there is one all embracing Family - the **Cycadaceae** - or the three families shown below. Currently over three hundred species, in eleven genera, are recognised - although it is believed there are many species as yet to be identified, as many species are very narrowly endemic and probably have not yet been discovered or recognised.

The Cycads

Family	Genus	Species	Distribution
Cycadaceae	<i>Cycas</i>	105	Old World
Stangeriaceae	<i>Stangeria</i>	1	Southern Africa
	<i>Bowenia</i>	2	Queensland
Zamiaceae	<i>Dioon</i>	13	Central America
	<i>Encephalartos</i>	65	South East Africa
	<i>Macrozamia</i>	41	Australia
	<i>Lepidozamia</i>	2	Australia
	<i>Ceratozamia</i>	26	Central America
	<i>Microcycas</i>	1	Cuba
	<i>Chigua</i>	2	Colombia
	<i>Zamia</i>	65	New World

The Cycads are primitive, cone bearing, members of the *Gymnospermae* and antedate the conifers in evolutionary terms. The surviving examples are relics of a once dominant, world wide group of plants. Nowadays they are limited to specific and defined habitats around the world - principally in the tropics and sub-tropics but with some outliers at the fringes and which survive in warm temperate climates and can be grown in the mildest niches in the British Isles. They are chiefly plants of humid conditions but some - especially those with a temperate distribution are xerophytic. These interesting plants are rarely common even in their native habitats and in most cases they are becoming rare and endangered - as man despoils their environment or collects them and moves them to cultivation. The great majority of species are slow growing and can live to great age.

These higher, seed producing plants are unusual in that the seed is fully developed in size before pollination and fertilisation occurs. All the species are dioecious and

pollination is by wind - although the process can be induced artificially.

Once the ovule has been fertilised further development is steady, continuous and inexorable - provided that the seed is not damaged. To this end the seed has a hard seed coat, which protects it and insulates it against the vagaries of its environment. Thus, despite many written recommendations to crack, scarify or hot water treat the seeds - they should be left as collected and extracted. The developing embryo does not need any additional water. The creation of a permeable seed coat, artificially, merely allows the possibility of drying with the consequent deterioration of the endosperm and/or the ingress of rotting agencies.

There is no quiescent stage - as in higher seed producing plants - and the embryo continues developing into the germination phase regardless of environmental conditions - it does not need the stimulation of warmth or moisture to achieve progress. Structurally the seed carries a large and extensive endosperm in which the embryo is enclosed. This provides support for the developing seedling for some considerable time - even after germination and the deployment of photosynthetically active leaves.

When the seed is shed from the cone it is drupaceous in structure; it is covered in a dryish, brightly coloured flesh which is attractive as a food source to various birds and animals. It is thus an effective agency in ensuring dispersal. The hard seed coat is therefore also a protection against abrasion by teeth, bills etc and then passage through the gut and the digestive processes.

At the moment of dispersal the embryo is undifferentiated but it will then continue to develop, often taking six to seven months to mature to a stage at which germination and radicle emergence will occur.

For crop production the cones are collected as they reach a stage at which the seeds can be separated from the cone scales. They are extracted from the flesh by soaking in warm water for a few days; this causes the flesh to soften and ferment. This degraded tissue is then rubbed free and the detritus and floating, non-viable seeds can be decanted off. The seeds are washed clean to remove any further adhering flesh (which may provide a substrate for

potentially rotting organisms) and then surface dried for ease of handling.

As the seed coat is hard and the developmental processes are not sensitive to the environment - except perhaps low temperatures; no benefit accrues from sowing the seeds until just prior to the stage at which the seed coat cracks and the hypocotyledonary tube emerges.

The seeds are therefore stored after surface sterilisation (to prevent the development of rots), extended in some moist vermiculite at a temperature of c25°C for the required period (usually several months) until the cracking is visible. Sometime prior to this it would be prudent to float the seeds again to separate any previously undetected non-viable material.

The cracking seed is sown by pressing it into the medium - usually sand, vermiculite, perlite etc - to leave about two thirds of the seed exposed. It is then subjected to a humid environment and warmth (25°C+). If the 'radicle' (which is in fact a tube made up of two tightly adpressed cotyledons) has emerged it can be angled down towards the medium. The radicle proper will then emerge from the tube and can be recognised by its small, dry, brown tip. As the radicle enters the soil it swells to form a tuberous tap root with numerous lateral roots. After six weeks or so, when the tap root is well established, the first leaves emerge by splitting the cotyledonary tube. At this stage the seedlings are lifted and potted individually.

The cotyledons continue to derive nutrients from the endosperm until well after germination and this supplements the requirements of the seedling for a considerable period: thus the seed should not be separated from the seedling, as it may well remain in place and be useful for as much as two years.

If a warm environment is maintained, germination is remarkably synchronised. Inevitably a more accurate assessment of the storage time for maturation will be made if the seed is obtained as soon after the dispersal phase as possible.

In general Cycads are high value crops - largely because they take several years to reach a maturity at which a

complete crown of leaves is developed. The juvenile leaves differ from the adult leaves, often quite significantly.

The seeds are in general scarce and/or expensive to buy in.

Ginkgoales

Ginkgoaceae

Ginkgo

This monotypic genus is the only survivor of a once widespread and dominant Family of ancient plants - they derive from the early evolution of the *Gymnospermae*. It represents an early phase in the evolutionary development of woody flowering plants. It is an evolutionary anachronism to have survived to the present time.

The Maidenhair Tree (***Ginkgo biloba***) from China, although rare in its native habitat (indeed if it is recognisable and still exists), is nevertheless a very ornamental tree and a great survivor of ecological changes and man-made disaster. It develops into a tall, long-lived, deciduous tree with a characteristically upright central leader and readily recognisable fish-tail shaped leaves. The leaves turn to brilliant shades of yellow in the autumn.

The species is dioecious and the flowers are produced in early spring just before bud burst and pollination is by wind. The female trees develop the autumn maturing fruits in the one season. The fruits consist of a single-seeded drupe-like structure - about 30mm long and 25mm broad. When ripe the flesh is particularly evil-smelling with an acrid clinging odour which owes much to the presence of compounds of butyric acid - for this reason it is prudent to plant only male flowering trees in amenity situations. Such selections are inevitably propagated vegetatively and although cuttings can be rooted successfully, they grow slowly. Propagation is therefore usually achieved by grafting and for this purpose seedlings will be needed as understocks.

The seeds are extracted from the fruits by maceration, fermentation in warm water and then rubbing (wear rubber gloves to avoid contamination with the smell) - the dross can be decanted off leaving the seeds to be washed in detergent, then rinsed and surface dried.

Storage of the seed can be achieved under water conserving conditions, at low temperature - when acceptable levels of viability can be retained for several months. Longevity is, in general, therefore only short term - a few months at

best. Storage at warm temperature causes a rapid deterioration of viability as the oily food reserves quickly become rancid.

The seeds are individually about 25mm long, ovoid and somewhat flattened in one plane with a lengthwise suture around the broadest axis; the ends are slightly pointed. The seed coat is made of a thin, hard, horny material which although not impermeable to water, does protect the seed from physical damage especially in the gut of any animal which may have the ability to eat the fruit. The seeds are a creamy-beige colour when fresh. The seeds are variable in size from lot to lot which, in general reflects the warmth and suitability of the particular growing season which the parent tree experiences. The soundness of the seed is also a reflection of the season - the suitability for pollination in the spring and the nature of the growing season for food reserve production. In warm locations seed production is normally prolific and of high quality.

Germination is initially delayed by the presence of a partially differentiated, immature embryo and subsequently by a low level chilling requirement. The degree of embryo maturity at the time of seed dispersal is a function of the temperatures experienced during the late summer - consequently the level of embryo development at dispersal determines the length of time needed to mature the embryo. This is therefore not a constant feature. To achieve maturation of any lot, whatever its status, warm storage of the imbibed seed is therefore set at 56 days in excess of 15°C - regardless of the initial level of immaturity.

Although a few seeds will germinate if sown and maintained at a warm temperature over the long term, a successful and reasonably synchronised emergence, in an acceptable time scale, can only be achieved if the seed is subjected to an adequate chilling regime: the most effective treatment is achieved with a period of storage of the imbibed seed at 5°C or less for 42 days - but even so the response may still not be completely uniform.

The most effective method for dealing with the cleaned seed sample is to:-

- a) soak the seed for 18 to 24 hours in warm water to ensure full imbibition;
- b) extend the sample in four times its volume of moist vermiculite in a suitable bag or container;

- c) store at $<15^{\circ}\text{C}$ for 56 days;
- d) transfer to refrigeration, for chilling, at $>5^{\circ}\text{C}$ for 42 days and then
- e) transfer to incubation at 20°C .

The sample should then be regularly monitored and when it can be seen that the seed coat is splitting and the radicle is beginning to emerge, the seeds can be sown individually one to a liner container - as each seed is ready. This treatment provides the most reliable system for achieving as uniform emergence as possible. The seed should be sown on its 'keeled' side to give the best orientation for efficient and swift emergence.

The seedlings are not frost tolerant.

Coniferales

Taxaceae

This family, which until recently had been regarded as a separate Order (*Taxales*) within the *Gymnospermae*, has, as a result of the assessment of the evidence provided by modern DNA analysis, been reassigned into the *Coniferales* as there are not sufficient differences to justify the separation - despite the significant morphological distinctions.

The Family is typified by being dioecious and by the development of the fruit as a single seeded, fleshy aril with the seed containing an immature embryo.

The ***Taxaceae*** contains five genera - ***Taxus*** (an important and widespread genus of cultivated trees and shrubs); ***Torreya*** (a small genus of similar looking trees and shrubs - not widely cultivated in the UK climate) and the little known ***Amentotaxus*** (four species in China - one of them hardy), ***Pseudotaxus*** (one hardy species in China but not normally found in cultivation) and ***Austrotaxus*** (one species found in New Caledonia).

Taxus

The Yews (***Taxus***) constitute a geographically widespread group of plants with a circumpolar distribution in the Northern Hemisphere. The taxonomists have treated them variously as eight species - each with a fairly distinct geographical niche - to one all encompassing species - *Taxus baccata*. They are evergreen bushes to small, dense, spreading trees with non-resinous wood.

The flowers are produced in the early spring and the fruits mature in the late summer to autumn of the same year. The fruit is a scarlet, fleshy, upright, cup-like aril containing a single seed. These should be picked by hand before they are taken by birds - which take them quickly once they are palatable.

The seeds are extracted by macerating the fruits, fermenting the resultant material in warm water for a few days, rubbing them to disengage the flesh and then decanting off the dross, any floating seeds and the liquid. The extracted seeds (which will fall to the bottom of the

container) should be thoroughly washed to clean them and are then surface dried.

Storage under water conserving conditions at cool temperature will maintain good viability for five or six years. The seed is protected by a bony seed coat which is hard and brittle but not impermeable to water - it is there chiefly to protect the seed in its passage through the gut of a bird and subsequently in the soil, protecting it against the ubiquitous rotting agencies while the various embryo maturation and dormancy breaking sequences are satisfied. These occur over a considerable time scale. Internally, at dispersal, the seed contains a minute, rudimentary embryo which is embedded in a copious, white, oily endosperm.

The embryo maturation process in Yews is very lengthy and, it would appear, cannot be hastened - merely raising the temperature above the required threshold does not significantly increase the rate of activity. There is little accurate information available on the time needed to mature the embryo (as traditionally the seeds were sown in open ground seedbeds and left to their own devices until a crop emerged) but provided that the seed is fully imbibed at the beginning of the treatment, then a period of 180 days at a temperature above 15°C appears to be sufficient, importantly very warm temperatures should be avoided as the oily food reserve is prone to turn rancid.

Once the embryo has developed to its full size it then requires a period of chilling to overcome an endogenous dormancy - the periods quoted for this activity vary dramatically from a high figure of 120 days downwards to 60 days; the high figures suggest that the combinations practiced did not complete the maturation processes and that these were completed during the chilling period. As such an extreme for the duration of the chilling sequence does not occur in any other group of Gymnosperms, it seems unlikely that such a lengthy period is needed - the available evidence suggests that if the maturation phase has been fully completed then a period of the order of 56 days at below 3°C should prove sufficient.

The treatment of Yew seeds is therefore a tedious and lengthy procedure, the time scale from collection - through extraction - pre-treatments both warm and cold - to sowing for germination will occupy a period of between eight and

nine months. Thus as germination cannot definitely be achieved until the second spring after dispersal it would be prudent to allow for generous over runs in the warm and cold treatment phases in order to ensure that all encumbrances are completely removed. This will allow sowing to take place so that germination can occur early in the year as day length is extending and so provide a long growing season for seedling development. There is no particular benefit in paring down the treatment phases unless critical observations suggest a time scale for germination in the first spring is feasible.

Although there are many recommendations for the treatment of 'naked' seeds - the treatment of these roundish, bony seeds (c6mm in diameter) is best undertaken by extending in moist vermiculite in the prescribed fashion; this will at least reduce the possibility of 'heating up' during the warm phase - although this is unlikely to kill the seed it could upset the programme or cause rancidity of the food reserves.

Torreya

The 'Plum Yews' (***Torreya***) are a small genus of geographically local, evergreen bushes or small trees which closely resemble the Yews, however they are readily distinguished by their fruits which are relatively large - about 25mm in length.

The genus is usually recognised as containing six species and these are native to North America and North Eastern Asia in various warm temperate climates - *T. californicum* from the extreme South West of the USA; *T. taxifolium* from Florida, *T. nucifera* from Japan and *T. grandis* from China - are the most significant and all are remarkably similar to each other.

The plants produce their flowers in the spring and the fruits develop over two growing seasons and are ripe in the early part of the second autumn. The drupe-like arils have a fleshy - if somewhat dry - outer coat which dries out gradually turning from green to purple or brownish purple and then splits into a series of longitudinal fibres.

The seeds are extracted by rubbing off the fibres which generally come away quite easily to leave a beige coloured, egg shaped seed, about 25 mm in length, more or less

flattened in one plane and pointed at both ends. The seed coat is thick and internally is folded and very irregular - encroaching into the endosperm. It is not impermeable to water. The seed contains a minute, rudimentary embryo in a thick, oily, white endosperm. Storage of the extracted seed is successful - under water conserving conditions at cool temperature - will give a longevity of several years.

The embryo is significantly immature and mirrors its close relatives, the Yews, in this respect. It will require a long period of warm storage of the imbibed seed to bring to a mature enough condition to move into the next phase of activity. It is probable that it will also require 180 days at above 15°C - also avoiding the development of too high a temperature to avoid rancidity of the food reserves.

After embryo maturation, germination is further delayed by the need for a marginal period of chilling to break an endogenous dormancy. This can be achieved by stratifying the seeds for 28 days below 5°C.

These Plum Yews are unusual in that the cotyledons remain trapped in the seed case at emergence and it is the first true leaves which appear from the germination substrate.

The remaining genera in this Family are little known in terms of their propagation from seed. They are unlikely to fruit in the UK and as such it will be necessary to import seed for the purpose. They will almost certainly have an immature embryo condition which will require maturation by warm stratification, Reference to their climatic provenance will determine if there is likely to be a need for chilling - albeit chilling may occur at a relatively high threshold temperature.

Successful growth of the seedlings of all species will eventually depend on the formation of a mycorrhizal association and this is of the vesicular-arbuscular type. It will be necessary to be aware of this and make whatever arrangements are relevant to the production process.

Coniferales

Cephalotaxaceae

The taxonomic position of this family of conifers has been much confused during recent years as it shows many affinities with the Yews (*Taxaceae*) - which it resembles morphologically - but because of the very distinct seed and fruit formation it has for long been retained as a separate entity in the *Coniferales* - but now that the *Taxaceae* are accepted as conifers many authorities suggest it should be merged with the *Taxaceae*. It is in this early part of the evolution of this branch of the *Coniferales* that the relevant DNA analysis and assessment does not yet seem to have resolved all the relationships fully. However from the point of view of the propagator, because the seed production is distinct it is more relevant to treat it separately.

This family consists of the single genus ***Cephalotaxus*** (although some authorities include ***Amentotaxus*** in this family and yet others include ***Torreya***). The genus is also ill-defined insofar as there is disagreement as to which taxa are constituted as species and which are delegated as variants - at the most diverse interpretation eleven species are recognised. As in *Taxus* there is a school of thought which includes all the relevant 'hardy' species from the Asiatic mainland (*C. fortunei*, *C. harringtonia*, *C. koreana* and *C. sinensis*) in one catch-all species. These species are then recognised as geoclimatic variants. The propagator however will pick a name and verify as far as is possible that the seed sample represents the provenance and entity desired.

The genus *Cephalotaxus* consists of evergreen, densely foliated, much branched, small trees and shrubs which are found in Eastern Asia - the hardier species occur chiefly in China, Korea and Japan. The plants are to all intents and purposes dioecious.

The male cones shed their pollen in the early spring and pollination is by wind. The female cones are found on the newest shoots - one to three together and the cones and seeds take two years to mature. The cone consists of one to a few ovuliferous scales with each scale carrying two seeds - only one of which matures. As the fruit matures the scale develops into a fleshy, often colourful, aril which

surrounds the seed and encloses it. Thus the fruit consists of a stem with a few 'olive looking' drupe-like seeds. The drupes are 2-3cm long and are taken by birds and mammals. The seed itself is acorn shaped and is surrounded by a hard seed coat which protects it in the passage through the gut.

At dispersal the embryo is immature and the imbibed seed requires a period of warm stratification to mature the embryo. The same practical procedures to achieve a successful germination, as are recommended for the Taxaceae, should be applied. The seedling has two cotyledons.

The seeds are big enough to be handled individually and can, consequently, be sown in individual containers if so required. A speedy germination will be achieved at 18-20°C.

Eventually the seedlings of all the relevant species need to develop a mycorrhizal association in order to achieve optimal growth. The relevant fungi are of the vesicular-arbuscular type. This relationship should therefore be accounted for during the production process.

As these plants grow as understorey plants in open forest they are adapted to shade and humid conditions consequently they are unsuited to arid conditions or to exposure to full sun.

Coniferales

Podocarpaceae

This family of evergreen conifers is probably the least settled in its taxonomic clarity in spite of the modern availability of DNA analysis and expert assessment. The determination of relationships and hence the naming of genera and species is still somewhat confused - at least to the layman. In the past the all-embracing genera of *Podocarpus* and *Dacrydium* covered a lot of sins but at least they provided a place to hide and provided recognisable names! In recent decades the family has been much revised and there has been much 'splitting' and as many as twenty generic names have appeared. Fortunately most of the genera and species found in this family are natives to warmer climates than that experienced in the British Isles, are not suitable for cultivation here and so do not concern these notes.

Although this family constitutes the third largest family in the *Coniferales*, it is hardly known by growers in Europe and the temperate Northern Hemisphere largely because it is fundamentally a Southern Hemisphere group of plants - the centre of diversity being in Australasia - it does however range into Africa, the western side of South America and above the equator to China and Japan and the great majority of the genera and species have distributions in tropical and sub-tropical climates. Because of this unfamiliarity and access to habitat, the family has largely been ignored by European and North American taxonomists. However there are several species which do have a distribution in temperate climates - especially in the temperate rain forest areas of South America and New Zealand and these provide some notable ornamental subjects for milder climatic areas in the British Isles.

The Family is diverse in morphology and ecology. The structure of the fruits however is fairly constant and, superficially at least, shows a close relationship with the Yews (*Taxaceae*) - usually they consist of a few seeds carried on fleshy, often colourful scales.

The following list of genera seems to provide the best shot at the current (2012) state of play:- ***Acmopyle*, *Afrocarpus*, *Dacrycarpus*, *Dacrydium*, *Falcatifolium*, *Halocarpus*, *Lagarostrobos*, *Lepidothamnus*, *Manoao*, *Microcachrys*,**

Microstrobis, **Nageia**, **Podocarpus**, **Prumnopitys** (to include **Sundacarpus**), **Retrophyllum**, **Saxegothea** and **Parasitaxus** (which is unusual insofar as it is the only known parasitic plant in the *Coniferales* - it is native to New Caledonia and parasitizes other podocarps). **Phyllocladus** has proved difficult for the taxonomists to categorise as it sits uncomfortably in this Family and is fairly distinct from other podocarps - it is thus sometimes accorded its own family by some taxonomists.

Relatively few of this family are satisfactorily cultivated in temperate climatic conditions but nevertheless those that are suitable provide a number of ornamental trees and shrubs.

In general there is little detail recorded on the conditions required for germination in this family and little if any critical work has been undertaken. Seed of any relevant species is rarely available in the British Isles either because of the unsuitability of the climate or most probably because there is rarely more than one specimen of a particular species in any collection - and as many of the genera are dioecious - there is no chance of reproduction!

All the Podocarps make an obligatory mycorrhizal association and this is of the vesicular-arbuscular type. Most of the genera produce a fleshy fruit which is dispersed by frugivorous birds and consequently the seeds are usually protected for passage through the gut of the bird by a hard seed coat - which may then present a problem for the propagator.

The genus **Microcachrys** is monotypic and is represented by *M. tetragona* - an endemic of Tasmania having a limited distribution to the Western Ranges. The plant is a virtually prostrate growing, evergreen shrub with whipcord like foliage and branchlets on which the leaves are carried in four ranks.

The plants are monoecious with the male and female cones being produced on separate branches. The female flowers have numerous fertile scales - between 20 and 28 - each of which has the potential to develop one seed. These then become enclosed in a red fleshy aril and the whole fruit develops and resembles a small mulberry about 6 to 8mm long.

The seeds are extracted from the ripe arils by maceration in warm water followed by a period of fermentation until the seeds fall and the dross and liquor can be decanted off. The seeds have a hard seed coat which must be made permeable - usually by an extended warm water soak.

The seeds benefit from a brief chill (28 days at below 5°C) in order to synchronise and speed germination.

The monotypic genus ***Saxegothea*** (*S. conspicua*) is a South American native - where it is found in dense temperate rainforest on the lower slopes of the southern Andes in both Chile and Argentina - in association with *Nothofagus dombeyi* and *Fitzroya cupressoides*. It is a slow growing tree of yew-like appearance and habit - growing into a conical tree to 11 or 12m - but sometimes much taller. It however shows only limited tolerance of cold conditions, despite its southern provenance, and is therefore only suitable for the milder climatic niches of the UK - it does reasonably well in Devon and Cornwall. It was introduced by William Lobb in 1847 - for Messrs Veitch of Exeter - so it is perhaps not surprising that the largest and oldest specimens are found in the far South West.

The trees are monoecious, the male flowers are produced in the leaf axils near the tips of the branchlets and the female flowers are solitary and terminal on different branches. The female cones mature by the first autumn after the spring pollination and consist of flattish, triangular, pointed, overlapping, fleshy scales - which overall present an irregularly globose outline. The cones are 15 to 20mm long with the fleshy grooved scales carrying two seeds each - an individual cone will develop between 6 and 12 seeds.

The seeds are hard shelled, ovate, about 3mm long and glossy brown. There is little definitive information on the regeneration characteristics of this species - most plants sold in the UK, up until the last decade or two, have been propagated vegetatively from cuttings but these take many years before they develop a dominant leader and as they are slow growing anyway the problem is compounded. With the increase in interest in Chilean flora, of recent years, it has been possible to obtain seed commercially and various seed collecting expeditions have also been successful.

Germination will initially depend on the imbibition of the seed and this will depend on developing the permeability of the seed coat. This can be achieved either by an extended warm water soak or by a reasonable period of warm, moist stratification - this latter procedure may be more effective as it is not clear whether the embryo in this species is fully mature at dispersal. After this process the sample will benefit from a short chill (28 days at below 5°C) which will synchronise and speed germination when it is subjected to conventional temperatures.

Despite its recent decimation, the genus ***Podocarpus*** is still a very large genus with an extensive geographical distribution in the Southern Hemisphere and up into Eastern Asia. A few of the species however are suitable for cultivation in the British Isles but generally only in the favoured climatic niches of the South and West. There are rarely sufficient numbers to allow the production of seed.

Pollination is in the spring - the cylindrical male cones are found along the branches - and in *P. totara*, at least, the pollen is ejected vertically, from the ripe cones, in a concentrated cloud in the first part of the morning as temperatures rise - quite a spectacular sight in its own right. The female cones occur usually terminally on the branches, they consist of 2 to 4 scales only one of which develops a seed and the remainder together with the top of the stalk fuse and develop as a brightly coloured, fleshy, edible structure much like an aril.

The fruits are picked when soft and ripe and are then macerated in warm water and allowed to ferment until the seeds will separate and sink to the bottom of the container when the liquid and dross can be decanted off.

The seed is an oval, nut-like structure with a thin, fleshy outer seed coat and a hard bony inner seed coat. The hard seed coat certainly prevents imbibition of the seed until such time that it is sufficiently degraded to become water permeable. This can be achieved by an extended warm water soak if the seed is fresh or an adequate period of warm, moist stratification which would also complete any embryo immaturity present.

The hardness of the seed coat could well vary from species to species as often a particular bird is responsible for taking the seed and so dispersing it - and the hardness of

the seed coat has evolved to achieve a satisfactory passage through the activities of this particular gut without damage but still degrading to the point of water permeability.

There does not appear to be, in general, any encumbrance to germination requiring mitigation by a period of chilling for the great majority of the genus but this should not be ruled out in a species at the extremes of temperate climate distribution, such as *P. macrophyllus* in the north and in the south it certainly benefits the speed and synchronisation of emergence (35 days at below 5°C) in the New Zealand, *Podocarpus totara*.

As seed is usually difficult to find it is necessary to import seeds and it would be prudent to purchase from a supplier with access to fresh material or a collector.

Good sized specimens - some of them over one hundred years old - of the following species can be found in the South West of England (and similar climatic niches elsewhere in the British Isles):- *Podocarpus salignus* (Chile), *P. macrophyllus* (China and Japan), *P. totara* (New Zealand) and *P. nubigenus* (Chile) but seed production is, to all intents and purposes, non-existent. *Podocarpus alpinus* (Tasmania) and *P. nivalis* (New Zealand) are both hardy, montane species - as low growing, evergreen bushes and grow satisfactorily in all but the coldest parts of the British Isles.

The genus ***Prumnopitys*** is currently confirmed as separate from *Podocarpus* and now includes what used to be called *Podocarpus andinus* which has become *Prumnopitys andina*. It is a montane species from Southern Chile with a high alpine distribution, it can develop into an evergreen tree 12 to 15m tall. It is reasonably hardy and fairly widely cultivated in the UK. The trees are usually dioecious but are sometimes monoecious. It is most easily distinguished by the aggregation of one to several single seeded fleshy scales fusing to form a fruit which resembles a small damson or bullace. The fruits are dispersed by birds and the seed is hard coated. This species is from Southern Chile and germination is enhanced by chilling the imbibed seed for 35 days at below 5°C, after the seed coat has been reduced.

The old portmanteau genus of **Dacrydium** has been severely split and of those species which could possibly be cultivated in the British Isles *D. bidwillii* (the Mountain Pine of New Zealand) has become **Halocarpus bidwillii**; *D. franklinii* (the Huon Pine of Tasmania) is now **Lagarostrobos franklinii**; and *D. laxifolium* (the Mountain Rimu of New Zealand and the smallest and lowest growing known conifer) is designated **Lepidothamnus laxifolius** - while *D. cupressinum* (the Rimu of New Zealand) remains in **Dacrydium**.

These genera are largely defined (and thus separated from *Dacrydium*) on the basis of the arrangements of the structures within the female cone but all are similar to *Podocarpus* in that they produce fleshy fruits which are dispersed by birds and have a hard (horny) seed coat. This implies a similar approach to achieving germination.

The genus **Phyllocladus** is included within the *Podocarpaceae* but is regarded by many taxonomists as sufficiently distinct to be attributed to its own family.

Phyllocladus species are evergreen trees and shrubs which are native to Tasmania, New Zealand, the Philippines and Borneo. They are readily identified by their leaves being reduced to small scales with the branchlets flattened into broad leaf-like structures - the phylloclades. The genus currently contains eight species - principally in New Zealand.

The plants are dioecious or monoecious and the flowers are carried on the margins of the phylloclades. The female cones are very small and consist of single erect seed carried on a single short fleshy scale - in some species there are several together in a cone-like body. The seeds are oval, nut-like (to 8 or 10mm long) and relatively large, at least twice as large as the swollen scale and resembling an acorn in its cup.

The fruits are picked individually and macerated in warm water to separate from the fleshy scale - leaving to ferment if necessary to achieve separation and for the seeds to fall to the bottom of the container.

The seeds are relatively hard seeded but can be made permeable with a warm water soak. No further treatment is needed to effect germination.

Coniferales

Araucariaceae

This evergreen, decorative family of conifers is found principally in the Southern Hemisphere. It is a relatively early development in the evolution of conifers and, although during the Jurassic was widespread and diverse, is now only represented by three surviving genera - **Agathis**, **Araucaria** and the very recently discovered **Wollemia** in Australia. The trees are generally large timber trees with whorls of branches developing on a single upright bole. The seeds are produced in large cones which only have one seed per scale - in some species these are individually very large and have a food reserve which is predominantly waxy. There are no endogenous or seed coat blocks to dormancy.

The genus **Agathis** consists of sixteen species, all of which are subtropical and tropical in distribution from Fiji through the Philippines to the Malay Peninsula - the most cold tolerant is the Kauri Pine (*Agathis australis*) from the very north of New Zealand - but it is not hardy enough to survive for long in temperate climates - even in the far south west of the UK.

They are tall, evergreen, very resinous trees with massive columnar trunks and whorls of horizontal branches - usually losing shape and grace as they mature and become large and aged. All the species are sought after timber trees.

Some of the more cool tolerant species could be grown in warm temperate areas but production would depend on importing seed. Seed is produced abundantly but much of it is not sound - however this cannot be separated readily by flotation as much sound seed also floats - it is therefore necessary to pick over the sample by eye. There are no apparent blocks to germination and seed emergence is rapid and uniform if the medium is maintained at c25°C and moist. Because of the thin seed coat imbibition is rapid and efficient - and emergence is thus tightly synchronised. The only proviso is not to sow the seeds too deeply as the hypocotyl is weak and is unable to push through any significant depth of compost (1cm).

The genus **Araucaria** is also chiefly subtropical and tropical in distribution and in the present time is found in Chile and Argentina, Australia and New Zealand, and the

adjacent Pacific Islands - despite its virtually global distribution in the Jurassic and Triassic. However one species - *A. araucana* (the Monkey Puzzle tree or the Chilean Pine) - is cold tolerant and occupies particular niches in the high regions of the Southern Andes in both Chile and Argentina - where it is found as a dominant tree in the high forests and where it is associated with the Southern Beech (*Nothofagus obliqua*). This region, although having a cold temperate climate, is also subject to wildfire and the tree will sprout from epicormic shoots if killed out above. All the species are tall regular shaped trees and have single, strong, upright trunks and symmetrical crowns. The branches are produced in the characteristic whorls. They are native of climates with more than 1250mm of rainfall *per annum* and occur on well drained soils.

The species are normally monoecious but the cold temperate species can be dioecious. The flowers are produced in the spring and the cones mature after two or even three years. The cones are large, almost spherical to pineapple shaped and can weigh several pounds; they are initially green but as they dry and ripen they become dark tan coloured. The cones disintegrate on the tree to liberate the seeds but sometimes the whole cone falls and smashes on impact. There is little dispersal of the seed by wind - it would appear that they are generally moved by birds or animals.

The large three dimensional seeds, shaped rather like a WW II bomb, have rudimentary wings; they are carried one per scale to which it adheres initially. The seeds can be picked up from the ground or the harvested ripe cones can be dried for a short period when they will disintegrate and the seeds can be hand picked. These large seeds have a thin seed coat and an endosperm consisting of lipids; thus ordinary dry storage sees a fairly rapid deterioration in viability levels. Good viability levels however can be maintained if the fresh seed is kept in cold storage at c3°C under moisture conserving conditions. This will give a longevity of three or four years. The seeds are elongate, to 30 to 35 mm long in some species and contain a large well developed embryo which is almost as long as the seed - it has two cotyledons.

None of the species exhibit any dormancy controls and the germination of all species will be rapid (c21 days) and

uniform if the seeds are kept moist and subjected to a warm temperature of 20 to 25°C.

The only other crucial feature for the production of good quality seedlings, during the germination process, is to sow these large seeds 'the right way up' (ie with the correct polarity). The seeds should be sown point downwards so that the orientation of the radicle and plumule within the embryo provides the correct juxtaposition for the components of the seedling at emergence, this produces an immediately upright seedling which will grow faster (it doesn't have 'to waste time' in tropic growth to correct the polarity). As the seeds are large and produce a substantially sized seedling at germination, the seeds are best sown individually in suitable sized containers.

Although all the species of *Araucaria* are important timber trees in their natural habitats, the following species are useful as ornamental trees in temperate and warm temperate climates - *A. heterophylla* (the Norfolk Island Pine - which is very wind and salt tolerant), *A. bidwillii* (the Bunya Bunya from Eastern Australia), *A. columnaris* (the Cook or New Caledonian Pine) and *A. cunninghamii* (the Colonial Pine). These species are sometimes offered in the UK as container grown trees for cultivation in conservatories.

Wollemia nobilis was only recently discovered in an inaccessible gorge in the Wollemi National Park in New South Wales - it is apparently a very narrow endemic to this area where less than 200 trees of all ages were found. It has been widely propagated and distributed in order to protect it in its native habitat. Eventually seeds will no doubt be distributed commercially and one day mature specimens in cultivation will produce seeds.

Coniferales

Sciadopityaceae

The genus ***Sciadopitys*** is the only member of this Family of conifers - it is another so-called 'living fossil' and its nearest relatives are found in the fossil record going back 230 million years.

The only living representative of the genus is the Japanese Umbrella Pine - *Sciadopitys verticillata*. It is a very slow growing evergreen, compact, but nevertheless upright, conical tree which can reach 25m tall in favoured localities. It is usually 'foliated' down to the ground with pairs of dark green structures in whorls - which are not leaves but cladodes and which resemble the spokes of an umbrella.

The flowers are produced at the ends of the branchlets in spring - both sexes on the same tree. The cones are oblong to ovoid and about 6-10cm long and 3-5cm broad; they ripen in the second season after pollination. There are normally between 5 and 9 seeds on each of the fertile scales. They are compressed and narrowly winged to 1+cm long.

The seeds are extracted by collecting the cones before they open on the tree in the autumn and then gently dried until the scales open and the seeds can be shaken free. The seeds can be stored under cool, water conserving conditions when viability will be retained at reasonable levels for a year.

The seed coat is hard and impermeable - sufficiently hard to require degradation before imbibition will occur and the germination process can proceed; however this is further delayed by an endogenous physiological dormancy which requires a chilling treatment before a uniform and synchronised emergence will be achieved.

The hard seed coat condition can be reduced by warm (20+°C) stratification for 63 days - it would also be possible to degrade the seed coat using a soak in 1% citric acid solution for 48 to 72 hours.

The chilling requirement can be satisfied by treating the seeds at below 5°C for 42 days. Germination can then be achieved at 16 to 20°C. If the chilling requirement is not

provided some of the seeds will eventually germinate - a 50% crop emerging after 75 days at 20°C.

The seedlings are extremely slow growing in the initial years and it may take five or six years before a handleable seedling for growing on is attained. It is possible that this slowness may represent an unknown environmental factor - such as the absence of a relevant mycorrhizal association.

Coniferales

Cupressaceae

This family of Conifers is now the largest in terms of the number of genera included (many of which are regarded as monotypic) but it is only about the third largest in terms of the number of species. This family now includes, as a result of the modern assessment of DNA patterns, those genera which were previously assigned to the **Taxodiaceae** - except for *Sciadopitys* which is now assigned to its own family. It has a world wide distribution.

The taxonomic positions and content of the genera included in this family, because of this modern approach, is still a significant area of debate and the nomenclature is still in a state of flux - as the various authorities make their determinations on the basis of what they think are the important DNA associations and arrangements. However it is now apparent that the **Taxodiaceae** nest within the **Cupressaceae** and that it is to be regarded as one big happy family! As far as the propagator is concerned however this is only relevant in relation to the identification of a potential parent and the necessity to be accurate in nomenclature - at least at the genus and species level. This activity has also involved the reassignment and renaming of several important species. It therefore behoves the propagator to determine, with as much clarity as is possible, what is the current name for a particular subject together with any relevant synonyms.

Currently (2012) the consensus appears to suggest that the following seven sub-families are recognised and that these contain the listed genera which might be grown in a temperate climate:-

Cunninghamioideae - *Cunninghamia*;

Taiwanoideae - *Taiwania*;

Athrotaxidoideae - *Athrotaxus*;

Sequoioideae - *Sequoia*, *Sequoiadendron*, *Metasequoia*;

Taxodioideae - *Taxodium*, *Glyptostrobus*, *Cryptomeria*;

Callitroideae - *Callitris*, *Actinostrobus*, *Neocallitropsis*, *Widdringtonia*, *Diselma*, *Fitzroya*, *Austrocedrus*, *Libocedrus*, *Pilgerodendron*, *Papuacedrus*;

Cupressoideae - *Thuja*, *Thujopsis*, *Chamaecyparis* (includes *Foikenia*), *Calocedrus*, *Tetraclinis*, *Microbiota*,

Platycladus, *Cupressus* (includes *Xanthocyparis* and *Callitropsis*), *Juniperus*.

The following five, sparsely represented, sub-families constitute the previously recognised ***Taxodiaceae*** and virtually all are survivors of, or are limited evolutionary descendants of, a much wider spectrum of ancient species - with a wider distribution and dominance than their current geographic status suggests.

Cunninghamioideae

The single genus ***Cunninghamia*** constitutes this sub-family and consists of two or possibly three species of evergreen trees and shrubs. It has a limited distribution in parts of southern China and Taiwan. The foliage has considerable similarities with *Araucaria*.

The plants are monoecious and the flowers of both sexes are initiated and develop during the autumn but do not open until the spring when they are wind pollinated. The female flowers are sub-terminal while the male flowers are produced at the tips of the branchlets.

The cones develop during the summer season and ripen in the autumn. They are rounded to ovoid in shape, about 40 mm long and wide - often several together. Individually they consist of several leathery scales each of which carries three seeds. The cones ripen and open on the tree, shedding the seeds throughout the winter. The spent cones persist and remain on the tree for several months into the next year. Each cone contains about 30 to 40 scales.

The seeds are hard, thin and elliptical - about 4 to 5mm long - and are surrounded by a papery wing. They are similar to those of *Sequoia*.

The germination of a seed sample is hastened and unified by a marginal period of pre-treatment by chilling. Exposing the imbibed seed to a temperature of less than 7°C for 21 days is normally sufficient.

Taiwanoideae

The genus ***Taiwania*** contains one, possibly two, species (depending on the taxonomic treatment) of very tall evergreen, densely foliated trees which in outline resemble

Cryptomeria but with foliage very similar to *Athrotaxis*. *Taiwania cryptomerioides* is found in Taiwan and adjacent southern China and Burma (Myanmar) - although here the variant is sometimes designated *T. flousiana*.

The cones are much like those of *Cunninghamia* - about 15mm long and 10mm wide and ovoid to cylindrical in shape. The middle 12 to 15 scales are generally fertile and each scale carries two seeds. These seeds are oblong. About 4mm long and are encircled by a membranous wing.

Little information is available on the germination characteristics of the seeds but it is reasonable to suppose that the imbibed seed will respond to a marginal chilling of 21/28 days at below 7°C in order to unify germination.

Athrotaxioideae

The single genus ***Athrotaxis*** is the only genus assigned to this sub-family and contains possibly three species (depending on the taxonomic treatment). These are narrowly endemic in the uplands of Tasmania at considerable elevations (around 1000m). They are reasonably hardy and will succeed in the milder, moister regions of the British Isles - *Athrotaxis latifolia* has exceeded 15m tall in Cornwall. The genus, in appearance, resembles both *Cryptomeria* and *Sequoia*.

The trees are monoecious with the sexes developing on separate branches. The cones are globose, slightly tapered at the base and swollen towards the top. Each consists of 18 to 20 tightly packed scales which are woody and wedge shaped with each ending in a spine like process. The cones are held vertically upright on a central axis. The cones in general resemble those of *Cryptomeria* and mature in the one season. The seeds are small, thin and oblong with two, narrow, opposite wings - much like a *Sequoia* seed.

The cones are picked just before they are ripe and when gently dried and then shaken the scales will have opened sufficiently to release the seeds - these separate readily and so produce a clean sample.

Although the imbibed seeds will germinate without pre-treatment the process can be speeded up and unified by

subjecting the imbibed seeds to a chilling period of 21/28 days at below 5°C.

Sequoioideae

This sub-family contains three monotypic genera - ***Sequoia***, ***Sequoiadendron*** and ***Metasequoia*** - all of which have value as ornamental subjects - albeit as potentially large to very large, single stemmed, erect trees. They all have a limited and narrow endemic distribution although the last does not now probably occur truly wild. They are all extensively cultivated in the British Isles where conditions are suitable.

The Coast Redwood (***Sequoia sempervirens***) of the Pacific slopes of the Western USA has been widely planted in the UK and succeeds where high winds are not a problem. This tree grows in a very restrictive habitat associated with the summer fog belts on the coastal ranges from mid-California north to the Oregon border. It grows in dense forests - each tree becoming a huge evergreen specimen with a slender trunk, when it is young, and given space, it is a shapely pyramidal to conical tree of graceful habit with downward sweeping branches and shiny deep green foliage. In virgin stands there are groves of trees in excess of 100m tall and over 3500 years old.

The small and insignificant flowers are produced from November to March on separate branches of the same tree and although pollination occurs then by wind, actual fertilisation does not occur until May. The cones are pendulous and ripen by September-October to a red-brown colour. They are smallish, oblong in shape and 20-30mm long by 20 mm wide; they consist of several hard, tightly packed, leathery scales - each carrying up to seven seeds, each cone will probably yield about sixty seeds.

The seeds are small - scarcely 2mm across, flattish, light reddish brown with a small spongy wing on each side of a central dark tan coloured seed. The quality is usually poor - often viability is as low as 15%.

The seeds can be readily extracted by gently drying the cones to open the scales and then shaking or tumbling. Storage by maintaining the seeds at the moisture content at which they were collected at cool temperatures will maintain the viability for several years.

There are no dormancy issues and the germination of imbibed, viable seeds at warm temperatures (20-25°C) will be quick and uniform - usually in 20 days or so. The seedlings develop with two cotyledons.

The genus ***Sequoiadendron*** is narrowly endemic to California. The single species - the Giant Redwood, Wellingtonia or Big Tree of California - *S. giganteum* - occurs in a very limited belt on the lower slopes of the Sierra Nevada in California (especially the famous Yosemite National Park). It was introduced commercially by William Lobb for the Veitch nursery in 1853 and the squabbles associated with its naming at that time are legendary!

It is a huge evergreen tree with a single erect bole which can reach 80 to 100m tall and with immense girth. In its native habitat it has reached tremendous age (some specimens being 3000 years old). The branches sweep down to the ground carrying their persistent Cryptomeria-like foliage and with its thick, soft, corky bark it is instantly recognisable.

The tree is monoecious and the small flowers are produced in April to May and pollination is by wind - fertilisation is then delayed until August - despite the development of the cone. The embryo remains as a few cells only, over the winter and then seed development occurs throughout the following summer when both the seeds and the cone are completed and mature. The cones, which are oval in shape 60-70mm long by 30-35mm broad, mature to a faded reddish brown colour. They are borne singly on the ends of the shoot and remain attached to the tree for many years with the seeds retained inside. The cones dry gradually and open slowly - so liberating the seeds over a considerable time.

Young cones can be picked in September-October and gently dried. This action will cause the cones to open and the seeds can be easily released by gently tumbling the cones. The seeds are 3 to 6mm long and compressed to about a thickness of 1mm, the wings are laterally united so that they virtually surround the seed.

Germination is markedly inhibited by an endogenous dormancy control. This condition can readily be eliminated by chilling the imbibed seed at 3°C for 35 days. Even after

chilling the seeds will only germinate in a temperature range of 16 to 21°C.

The deciduous, monotypic genus ***Metasequoia*** represented by *M. glyptostrobioides* is another plant which has been described as a living fossil and its discovery in the late 1940s in China and its subsequent 'escape' to the West in front of Mao's Long March advance is also the stuff of legend.

It is a tall, erect, single stemmed tree. Because of its relatively recent introduction there have been few mature fruiting trees available but now 70 years on there is no shortage of coning trees (it does produce cones and seed quite successfully at a young age) and seed can be located readily. The tree is monoecious, flowers in the spring and is wind pollinated. The cones are small and pendulous, egg-shaped with thick fleshy scales which eventually dry as they ripen in the first autumn gradually opening to release the seeds. The seeds are 6mm long, flat and obovate in shape, carrying two broad, paper thin, pale wings which are more or less convergent and surround the seed.

The cones should be collected at or about leaf fall - before they open, they are gently dried to release the seeds, which will probably need to be cleaned by picking over and removing the cone debris.

The seeds will germinate readily when exposed to suitable warm conditions and no dormancy blocks are apparent.

Taxodioideae

This sub-family contains three genera - ***Cryptomeria***, ***Glyptostrobus*** and ***Taxodium***

The monotypic genus ***Cryptomeria*** is represented by the species *C. japonica* - the Japanese Cedar or Sugi. It is native to the cold temperate climatic regions of China and Japan and grows into a stately, picturesque, upright, single-boled tree to 35 to 45m tall. It is grown for timber, shelter and ornament and because of the variability many ornamental forms have been selected - most of which are slow growing and/or juvenile foliaged and/or have a contorted habit - and are much used in gardening practice in the Japanese traditions.

The trees are monoecious and flower in the spring with the cones ripening in the late summer to early autumn of the same season. The mature cones remain on the tree, opening slowly and releasing the seeds over a long period. The cones are picked when ripe, which is evidenced by the development of a red-brown colour. They are globular (15 to 20mm in diameter) and consist of 20 to 30 woody scales radiating from a central axis. The seeds are extracted by gentle drying to open the scales when the seeds can readily be shaken free - producing a very clean sample.

The seed are dark brown, more or less flattened and of an elongated triangular shape - about 4-6mm long x 3mm wide - with each edge having a rudimentary wing. Viable seeds contain a relatively large embryo. Seed production is prolific but a large proportion of them are not viable.

The seeds can be stored satisfactorily for two years if maintained dry and cool.

Germination of virtually all samples of seed is prevented by the development, within the seed, of a reasonably deep physiological dormancy which is mitigated by a period of chilling. This problem can be overcome by exposing the imbibed seed to a temperature below 3°C for 56 days.

Viable seeds will germinate, after such treatment, without significant delay when provided with a temperature of 15 to 20°C. However the problem of assessing the viability of such small seeds with a high void rate makes the calculation of sowing rates difficult. So the sample is best sown thickly and pricked off - as soon as germination occurs.

The monotypic, deciduous genus ***Glyptostrobus*** is represented by the species *G. pensilis* and is closely allied to and is not dissimilar to the genus *Taxodium* - even to developing the same type of 'knee formations' on the roots under relevant environmental circumstances. The species is native to the warmer climatic areas of Southern China although it is possible that it no longer occurs wild. It does not succeed in the UK - except in the very mildest places and is thus rare in cultivation.

The cones are pear shaped about 20mm long with a long stem. The terminally winged seeds are about 5-6mm long and are thin coated; they show no barriers to germination once

suitable conditions for germination are available although germination does not occur below a temperature of 16°C.

The deciduous, Swamp Cypresses (***Taxodium***) from the South Eastern USA and Mexico are closely related to *Glyptostrobus*.

They are variously described as three species or as one species (*Taxodium distichum*) with a series of three geographical variants. They are tall, deciduous, upright, ornamental trees of relatively lightweight structure with a tapering slender trunk. They are particularly adapted to a damp, swampy habitat and on sites where they are regularly inundated they develop unusual aerial roots known as 'knees' - which project above the ground.

The trees are monoecious and flower in March-April as the leaves expand. Pollination is by wind and the cones mature in the late autumn to early winter of the same year. Two or three cones are, typically, developed in a group towards the ends of the branchlets. They are globose to polyhedral in shape to 30mm+ in diameter, are of a somewhat resinous consistency and ripen from green to purple in colour. They consist of a few four sided scales, each carrying two irregularly triangular, tough coated, woody seeds. On ripening the scales break away from the cone and liberate the seeds. Each cone will produce between 18 and 30 seeds.

The cones are collected just as they begin to open on the tree and are gently air dried, they are then crushed to extract the seeds. It is then necessary to separate the seeds from the detritus and because of their shape and structure this is a tedious task.

Cool storage under moisture conserving conditions will give a reasonable shelf life of a year or so.

Imbibition is initially delayed by the impermeability to water created by the thick woody seed coat but fresh seed which has been dried as little as possible will respond to a warm water soak of 48 to 72 hours. The literature has several *ad hoc* recommendations to improve the permeability of dried seed but probably the most effective would be a soak in a 1% solution of citric acid for 48 hours.

Once the seed has imbibed it requires a period of chilling before germination can be induced. There are many fanciful

recommendations in the literature which suggest periods of as much as 90 days - these are almost certainly due to the fact that the seed coat had not been made fully permeable prior to the chilling treatment. This species will usually respond to chilling at less than 5°C for 42 (even possibly 35) days. Germination is then best at 16 to 20°C

Cypresses

The following genera represent what used to be regarded as the *Cupressaceae*. This group of conifers has a world wide distribution and, in general, develop as upright single-stemmed, conical trees which are clothed to the ground.

In general they produce large quantities of seed, but this prolific production is usually associated with a high proportion of non-viable seeds. The cones are remarkably similar throughout the range and typically are small and round (more precisely polyhedral). The seeds are usually small, dry and winged. Most of the species from cold temperate climates exhibit a marginal dormancy condition which is eliminated by a period of chilling.

Callitrioideae

This sub-family contains a series of ten genera which are not much found in cultivation in the UK because they are not as competitive ornamentally and/or are less (or not) hardy and/or are best adapted to arid environments - most obviously the Australasian ***Callitris***, the narrowly endemic ***Actinostrobus*** from Western Australia, the African ***Widdringtonia*** and ***Neocallitropsis*** from New Caledonia. All of these are not suitable for cultivation out of doors in the UK and are therefore not described here. These four genera are all closely related and germination of the seeds does not appear to be affected by any dormancy conditions.

The old portmanteau genus of *Libocedrus* (which once was home to a varied, disparate and not very similar group of species in the *Cupressaceae*) has now been carved up and, as a result of modern DNA assessments, has been scheduled into a series of genera which are often monotypic. In this sub-family are located ***Austrocedrus*** (*A. chilensis*), ***Libocedrus*** (4 species), (the non-hardy ***Papuacedrus***) and ***Pilgerodendron*** (*P. uviferum*). ***Calocedrus*** has now been transferred to the sub-family *Cupressoideae* with its associated species - the most relevant being *C. decurrens*.

All of these genera are basically limited to a warm temperate or sub-tropical distribution but those which border on the cooler margins can be grown in warmer moister niches of the British Isles. Although germination of these species will be achieved without pre-treatment, a speedy and synchronised emergence will occur if the imbibed seed is chilled for 35 days below 5°C and then subjected to above 18°C for germination - however for the successful germination of *Austrocedrus* the chilling requirement is effectively mandatory.

The remaining two genera *Fitzroya* and *Diselma* are closely related and are the only two with a cold temperate distribution.

Diselma archeri is a monotypic genus from Tasmania. It is an evergreen bush or small tree and is rarely seen in cultivation. It would appear that it can be raised without problem - germination is said to be straightforward.

The monotypic genus *Fitzroya* is one of the most interesting of conifers insofar as it is the largest and potentially the oldest conifer in the Southern Hemisphere. It is found on both flanks of the southern Andes in Chile and Argentina where it is native to the region of temperate rain forest. In its native habitat it can reach immense size - on a par with *Sequoiadendron* - and specimens of 3500 years old are known. In cultivation in the UK it is quite rare and is only suited to sheltered moist environments. It was first introduced by William Lobb in 1849 for Veitch and again it was later sent back by Richard Pearce for the same employers. There are still some specimens of this vintage extent - most notably at Killerton.

It shows considerable variation in its sexual expression - various trees being dioecious, monoecious or even rarely hermaphrodite. The flowers are pollinated in the spring and the cones mature in the autumn of the same season - however as female trees will cone without pollination and fertilisation, it is likely that any seeds will not be viable - in the UK it is rare to find other than a single specimen at any one site so that even when sexually mature there will be no potential partner extant - if there was - Murphy's Law ordains that they would be of the same sex!

The cones consist of nine scales arranged in three whorls, the scales of the lowest whorl are minute and sterile, the middle whorl is normally empty but can produce the odd seed and the upper whorl of scales which are the largest and bear two to six, two or three winged seeds. The cone is woody and 6 to 8mm in diameter and terminates in a resin producing body which produces a fragrant smell.

The cones open readily when ripe and should be collected just before this stage as the colour changes from green to brown. They open with air drying and the scales flare out and the seeds can be shaken out easily to produce a clean sample.

The seeds are long, narrow and flat - about 4mm long - with usually two, broad half moon shaped wings. Much of a sample is non-viable.

Viable seeds do not exhibit any particular problems with germination although very limited experience does suggest that a short chill will synchronise and speed emergence.

Cupressoideae

Microbiota is a monotypic (*M. decussata*) genus from the Far East of Western Siberia in North East Asia, it is a small, low growing, spreading, evergreen shrub. It is mainly used as a ground cover plant in dry, depauperate hostile environments. In its native habitat it is reported that it rarely exceeds 50cm high.

The plants are monoecious and the cones are the smallest among the conifers - only some 2 to 3mm long. They are produced in the one season after pollination in the spring - they ripen from green to brown. They consist of four scales arranged in two opposite pairs. The seeds are roundish to oval and are not winged. Usually there is only one seed per cone.

Germination is unified by chilling - a period of 42 days at below 5°C is adequate.

Perhaps the most striking realignment, produced as a result of the DNA assessment in this part of the family, is the confirmation that the Chinese Arborvitae - most commonly known as *Thuja orientalis* - is (as had already been widely suspected) more closely related to *Microbiota* and

Tetraclinis than *Thuja* and is now finally separated into the genus ***Platycladus***.

Platycladus orientalis is a relatively small, slow growing tree often with a number of trunks from the base.

The species is monoecious. The flowers develop in the early part of the year and pollination occurs in March to April. The male cones are small - 2 to 3mm long and yellowish green. The female cones are produced terminally on the shoots and develop in one season, dehiscing in the autumn. They are fleshy and pale greenish blue when immature and red brown when mature. They consist of six sometimes eight scales - the middle four are fertile; the proximal pair carry two seeds each and the distal pair one each. The scales are fairly thick and woody when mature and if picked before dispersal, the scales spread wide and dehisce readily, when air dried, to liberate the seeds. The seeds are virtually wingless about 3 to 4mm across.

Germination is synchronised by a short period of chilling (35 days at below 5°C) but dormancy is also achieved by the seed requiring a relatively high temperature to initiate germination (optimally between 18 and 20°C).

Tetraclinis is a monotypic genus - *T. auriculata* which is native to the Western half of North Africa, Malta and sparsely in southern Spain. It grows into a conical, erect, evergreen tree to 12 to 15m tall and is a particularly valuable, ornamental conifer for the hot dry extremes of a Mediterranean climate area.

It is monoecious and the cones are produced solitarily on the tips of the branchlets in the spring. The cones ripen in about eight months when they become brown, they are broadly globular, 10 to 15mm in diameter and consist of four tough thick scales arranged in opposite pairs. The outer pair are sterile and the inner, narrow pair are fertile and carry two or three seeds each.

The cones should be collected just before dehiscence and then dried at reasonably high temperature (35 to 40°C) when the cones will dehisce and liberate the seeds. Viability is not normally high.

The seeds are about 6mm long, 2mm wide and oval with a broad papery wing on each side.

There are no particular blocks to germination although best results for a speedy and synchronised germination are achieved at temperatures above 18 to 20°C.

Calocedrus is one of the genera which have been devolved from the once all encompassing *Libocedrus* - which had become a portmanteau name for a fairly disparate collection of cypress type conifers.

This genus has, as a result of DNA assessments, finally been separated out and consists of the Californian Incense Cedar (*C. decurrens*) and the Chinese *C. macrolepis* (from Southern Yunnan) together with its two sub-tropical relations (?variants) *C. formosana* and *C. rupestris*. Only *C. decurrens* is suitable for cultivation in a cold temperate climate and is, in fact, much hardier than its Mediterranean climate provenance would suggest.

The Incense Cedar (*C. decurrens*) tends to grow, in the UK, as an erect, columnar tree to well over 30m tall - although on the West Coast of the USA it eventually develops a spreading crown. It has striking dark green foliage.

The female flowers are produced during the spring on the tips of the branches - pollination is followed by fertilisation and the cones mature in the same autumn. The trees are monoecious and seem to self fertilise without difficulty.

The cones are oblong-conical in shape about 25mm long and consist of six narrow, long, overlapping scales which open to disperse the seeds in the late autumn. The seeds are flattened with a substantial wing and are carried one pair to each of the two fertile middle scales - one with a large wing and one with a small wing - the actual seed being about 6mm long.

The cones should be hand picked in the autumn just before dispersal - when they will readily open with conventional air drying. When they are tumbled the seeds fall out easily and a good clean sample is produced.

Seed stored, without further drying, at cool temperatures will maintain viability for several years.

Virtually all samples of the seed of *C. decurrens* show a marginal dormancy condition which is eliminated by chilling. A chilling treatment of 35 days at below 7°C will unify the germination response. Rapid germination requires a temperature of above 16°C.

The genus ***Cupressus*** is a widespread group of tall evergreen trees. They occur principally in the warm temperate climates of the Northern Hemisphere fringing to the cold temperate range. There are more than twenty species which are divided into the New World Cypresses - many to several species (depending on the taxonomic treatment) usually with restricted distributions - and the Old World Cypresses - with a relatively few species ranging over quite large areas through the north of Africa and Southern Europe through to South East Asia; in addition what used to be called *Chamaecyparis nootkatensis* is now included in this genus. They are in general decorative subjects and would be more widely grown as ornamentals but for the occurrence of the microfungal disease, *Coryneum cardinale*, which disfigures (usually causing large brown blotches) and then ultimately kills the tree. Fortunately the disease has not, so far, become particularly virulent in the climate of the UK.

The trees are monoecious with the male and female flowers being produced in the autumn and pollination occurring over the winter; the cones then mature over eighteen months and ripen in the later part (July onwards) of the second summer. The mature cones are some 25 to 30mm in diameter, woody to leathery in texture and globular (polyhedral); the scales open at the sutures after drying to liberate the seeds. In those species which are native to ecological niches which are regenerated by wildfire many of the cones are serotinous (remain closed) until opened by the passage of a significant degree of heat - although these cones will remain on the tree for several years the viability of the enclosed seeds is not maintained for more than a few years. All the species are prolific cone producers.

The cones are collected, during the late summer just prior to opening. The cones do not open easily with artificial drying but if the cones are frozen for two days and are then subjected to a drying environment at 30 to 35°C the cones will open and the seed is readily shaken free. Each cone will have the potential to yield between 12 and 15 seeds - depending on the species and pollination success.

The quality of the seed, in terms of viability, is almost invariably low but existing viability can be maintained for a few years at cool temperatures.

Although germination of the seeds of all species will occur without any pre-treatment, a period of chilling will both speed and synchronise emergence. Storage of the imbibed seeds for 35 days at below 5°C will achieve the required effect.

The seeds of *C. nootkatensis* often develop a marginal, hard seed coat condition which can prevent imbibition - this can be mitigated by a warm water soak for 48 hours prior to chilling.

Cypress seeds have, in general, a considerable propensity to develop fungal infections and it would be prudent to consider dressing the seeds with a fungicide but this should be undertaken with care - bearing in mind the probable need for the seedlings to develop a mycorrhizal association.

The Junipers (*Juniperus*) are a large and widely distributed genus of evergreen conifers varying from procumbent shrubby alpine and montane types to tall, erect, single stemmed forest trees. They are chiefly found in the sub-tropical and temperate climates of the Northern Hemisphere but are found below the Equator in Africa. The number of species currently tends to be under review - as the determination of what constitutes species and subspecific rank is argued through - but somewhere between 50 and 70 is the current range!

They are generally a highly ornamental group which lend themselves to intensive cultivation. Many species tend to be variable and have given rise to an enormous selection of ornamental forms - these are inevitably vegetatively propagated.

The fruit of this genus is unusual and is distinct among the conifers insofar as it is effectively a berry - the flesh of which is a source of various useful oils and chemical products and in the case of *J. communis* provides the flavour to gin (Geneva)!

The plants flower in the spring and as the cones mature the scales become fleshy and coalesce to form an indehiscent berry-like fruit containing one to four seeds. According to the species, the plants are dioecious or monoecious and the fruits take one, two or even three seasons to ripen to maturity. The seeds are taken and dispersed by frugivorous birds. The berries are usually blue, black or red-brown (the colour is species specific) when ripe and are covered in a waxy pruinose bloom. Depending on the period taken to maturity, fruits of the previous seasons occur on the same branch.

The fruits should be picked as soon as they are ripe - before they are taken by birds. The seeds are extracted by soaking the seeds for a few days in warm water, then macerating and leaving to ferment until the pulp floats off and the seeds fall to the bottom of the container. Some species have an oily flesh which repels water and militates against successful fermentation; such seeds should be soaked in brine for two or three days when the flesh will begin to separate. It is important to persevere with the cleaning of the seeds as any residual flesh may still contain a germination inhibitor.

The seeds are protected by an impermeable hard seed coat - this has evolved to protect the seed in its passage through the digestive tract of the bird - although, as a result of this progress, the coat is massively degraded and in nature there is not much further degradation required before the seed can imbibe.

As the fruits are of different vintages on the same branch and ripening rates are variable, it is necessary, for ease of preparation, to pick the fruits by hand - selecting only the berries in the relevant condition.

After extraction and washing to provide clean seeds, they are surface dried, air dried for a couple of days and then they are stored, under moisture conserving conditions, at cool temperatures - this maintains viability for several years. Commercial samples of seed are often offered as dried berries but the treatment is the same beginning with an extended warm water soak.

Most samples of seed, in common with so many of the Cypresses, usually show a high proportion of non-viable

seeds - this is normally associated with a failure to develop an endosperm.

This genus exhibits some of the most comprehensive dormancy controls found among the conifers, a significant range of species show the development of a hard seed coat and/or an embryo dormancy requiring a period of chilling for its elimination; some species also produce germination inhibitors in the flesh of the fruits. The degree of dormancy control also varies within a species - where it occurs over a considerable range of climatic experience. There can be less chilling and often greater hardseededness in warmer provenances. The picture is also complicated by the possibility of the embryo being immature at dispersal.

In order to be reasonably certain of achieving a reasonable degree of success in a prescribed treatment sequence - the relevant phases of the following defined sequence should be applied. If no relevant data is available then use the treatments outlined:-

- a) extraction of the seed from the fleshy fruit - ensuring the production of a properly cleaned sample;
- b) reduction of a hard seed coat to a permeable condition - depending on the degree of hardseededness - either by a prolonged warm water soak or digestion with a 4 to 6 day soak in 1% citric acid solution;
- c) the maturation of the embryo by warm stratification of the imbibed seed sample at 22°C for 42 days;
- d) a chilling treatment of 70 days at below 3°C;
- e) the provision of a germination environment of at least 16°C.

The literature suggests that most temperate species have the same sequence of controls but vary in the period required to overcome the individual dormancy condition - however as usual some periods quoted seem to be extraordinarily long and outside their natural environmental parameters which suggests that the previous treatment was not completed adequately.

The following species are known to exhibit significant levels of hardseededness - *J. chinensis*, *J. communis*, *J. horizontalis*, *J. occidentalis*, *J. osteosperma*, *J. pinchotii* and *J. scopulorum*, while *J. ashei*, *J. deppeana*, *J. monosperma* and *J. virginiana* do not. Most of the species from cold temperate distributions can be expected to require a chilling treatment to break the endogenous dormancy and

species from warm temperate regions may still require chilling at below 7°C for 28 or 35 days.

The genus ***Chamaecyparis*** consists of tall, erect, conical, evergreen Cypresses which are normally clothed to the ground in flat dense foliage. They constitute a very ornamental series of species - which is typified by the Port Orford Cedar or Lawson's Cypress (*C. lawsoniana*) - in which virtually all the species show a fair degree of variability in size, habit and foliage colour. There are six species in the genus and these occur on the far Western side of the United States (*C. lawsoniana* and *C. thyoides*) and Eastern Asia (*C. obtusa* and *C. pisifera* from Japan, *C. (Fokienia) hodginsii* from Eastern China and the less hardy *C. formosensis* from Taiwan). They are all important as timber trees and as ornamentals. (*C. nootkatensis* has been realigned in *Cupressus*).

Because of their ability to remain clothed to the ground they are widely used as hedging plants - *C. lawsoniana* especially. The considerable variability in size, shape and leaf colour, which occurs in this species, has given rise to many vegetatively propagated variants but it has also been possible by judicious selection to determine parent trees which will produce a population of seedlings with particular coloured foliage.

The flowers are produced in the spring on the tips of the branches, both sexes on the same tree. The cones are small, spherical (polyhedral) to about 12mm in diameter. They mature in the late summer to early autumn of the same year - they consist of 6 to 12 scales - each scale with a potential to produce 5 seeds.

The cones should be hand picked just before they begin to open and are gently dried at about 30°C - the scales will then open at the sutures and the seeds can be shaken out. Each cone will normally yield between 20 and 30 seeds. The seeds are small, flat and winged and naturally are dispersed by the wind over the course of the winter. If the cones do not open readily - as often happens with *C. thyoides* - the scales can be induced by soaking the cones, draining and then freezing them and then returning them to the drying process.

Storage at low temperatures under water conserving conditions will preserve viability for several years. The

quality of the seed is intrinsically low - normally below 70% and often as low as 45%.

Germination will occur without subjecting the seed to any pre-treatment but under these conditions is usually erratic and over an attenuated period. A unified and synchronised emergence with a rapid response can be induced if the imbibed seeds are stratified at 5°C for 35 days. The less hardy *C. formosensis* does not need to be chilled and a satisfactory emergence will be achieved if the germination temperature is maintained in the range of 18 to 20°C.

Thuja - the Arborvitae are a widely cultivated, but small, genus of tall, ornamental evergreen trees, which although producing useful timber, are extensively used in temperate climates as a hedging plant and because of their variability are clonally reproduced to create a wide spectrum of decorative cultivars varying in shape, size and foliage colour.

There are five species (the previously designated *T. orientalis* is now shown, as a result of DNA observations, not to be closely related and is placed in the separate genus **Platycladus**). Two species (*T. occidentalis* and *T. plicata*) are found in North America and three species (*T. koraiensis*, *T. standishii* and *T. sutchuensis*) are distributed in Eastern Asia.

The trees are monoecious and the male and female flowers are borne on separate branches or twigs they develop in the autumn but pollination does not occur until the following spring. The female cones mature by the autumn of the same year. The cones are ovoid - about 10 to 15mm in length and are made up of relatively few scales (3 to 10 but 12 in *T. plicata*). During the summer the cone gradually turns colour from green through yellow and buff to cinnamon and finally brown - the overlapping scales become thin, flexible and leathery. Usually only about two or three pairs of scales are fertile and each carries up to three seeds underneath. The seeds are winged with a pair of thin lateral wings.

In the two North American species - *T. plicata* and *T. occidentalis* - the seeds are about 6mm long, flat and round - consisting of lateral wings surrounding an elongated centrally sited seed.

Once the cones are mature - ie they have just turned from cinnamon to brown - they should be picked and then air dried. The cones will then open readily and the seeds will shake free, producing a clean sample. Drying should not be continued for any longer than is necessary to separate the seeds, as they lose viability if they dry more than marginally. In common with so many cypresses the habit of prolific seed production is accompanied by a low viability. Storage under cool water conserving conditions will prolong existing viability for considerable periods.

If the seeds are sown without pre-treatment the germination response can be quite variable - as even marginal drying seems to cause erratic and attenuated emergence; however pre-treatment with a period of chilling (for 35 days at below 5°C) will synchronise and speed germination at temperatures in excess of 16°C.

The monotypic genus ***Thujopsis*** is represented by *T. dolobrata* - a Far Eastern species from Japan. It is rarely grown from seed as it such a variable plant in terms of size and habit.

The cones are globose in shape, upright on the branches and about 15mm in diameter. They are composed of 8 to 10 thick, fleshy scales - the top and bottom of which are sterile and dry to a hard leathery consistency. The seeds are carried four or five to a scale, they are fat and oblong with two narrow wings. The cones open readily on drying and the seeds can be shaken free.

No pre-treatment is normally required for a satisfactory germination.

Coniferales

Pinaceae

This family of conifers; includes the genera ***Pinus***, ***Picea***, ***Abies***, ***Keteleeria***, ***Cedrus***, ***Larix***, ***Pseudolarix***, ***Pseudotsuga*** and ***Tsuga***. These have much in common insofar as they all produce their seeds in dry 'woody' or 'leathery' cones. They all develop winged seeds and the food reserve in the endosperm is stored as fats or oils to a greater degree. It is also the normal pattern for the seeds of most species as a whole to exhibit, in some degree, an endogenous dormancy condition which requires the seeds to be exposed to a period of chilling to speed, unify and synchronise emergence at germination. ***Cathaya*** and ***Nothotsuga*** also belong here but, as they are 'not in cultivation', they are discounted for lack of information.

The interest in conifers as decorative shrubs and trees has been a feature of ornamental horticulture in the UK for well over two hundred years and this group contains many stately and shapely trees with many decorative characteristics. The benign nature and subtle variations of the climate in the UK also allows the cultivation of an extraordinary range of these species, from around the world, and most of these can be found reasonably locally and growing in a mature condition (and therefore, in general, cone bearing). This provides the opportunity to collect seed locally and manage the entire production process in such a way that high quality seedling production is achieved.

The seeds of virtually all of the temperate species within these genera of conifers are unusual in that they exhibit an endogenous embryo dormancy (caused by the presence of inhibitors in the endosperm - as excised embryos germinate without hindrance). Usually this effect is at a fairly low level and is often one that is not constant within the sample or even from year to year. Chilling of the imbibed seed, for c42 days at c3°C, prior to sowing will normally be sufficient to unify germination and synchronise emergence. This level of treatment (although the need may be considerably less) appears to be enough to overcome this variable constraint in all species and lots and satisfactorily prime all the viable seeds within a sample. Although it is possible, in many instances, to obtain satisfactory results by chilling the naked seed it is more

reliable to stratify the seed, within a suitable medium, in the conventional way.

To achieve the chilling requirement by stratification it will be prudent to use materials that are of a relevant size and texture so that the seeds can be separated if required. Many species of Silver Firs and Pines, for example, have relatively large seeds and for high value, ornamental production can be handled individually and station sown.

Pinoideae

This monogeneric sub-family contains only the Pines (***Pinus***). It is a large genus of 90 to 115 species - the number indeterminate as the species seem to be regularly 'lumped' or 'split'. They are natives of the Northern Hemisphere with a circumpolar distribution from the Arctic tree line to the tropics - although at tropical latitudes they usually occur at altitudes with sub tropical or warm temperate climates. They are the largest and most diverse genus of conifers varying from tall, erect trees (*P. lambertiana* and *P. coulteri*) to short multi-stemmed shrubs (*P. mugo* and *P. pumila*). They also contain some of the oldest individual trees alive today (*P. aristata* and *P. longaeva*). Many are important timber producing trees. Many of the species are highly ornamental trees and are used as specimen trees in relevant situations. The five needle pines, as a group, for example, contain a significant number of decorative species with long needles, a bright green foliage colour and a graceful habit - however several of these are not particularly hardy and are only suitable for mild areas of the UK. Some species have a very extensive geographic range (eg *P. sylvestris*) while others have a very local and endemic occurrence (eg the Pinyon pines of the Mexican canyons, *P. torreyana* and *P. canariensis*). About forty species are native to the United States.

The Pines are typified by their thin, generally long, needle-like leaves which occur in sheathed bunches (fascicles) containing one to five leaves (one of the diagnostic features for a species); the resinous wood and the resinous, more or less round, woody cones.

The male and female flowers are produced, on the same tree, in May/June and pollination occurs at that time. The female

flowers are produced in the crown of the tree and the male flowers lower down. The ovules in the female flowers are not fertilised until the following spring and they then develop into the familiar cones and produce seeds - the process of maturation is then completed by the autumn; however in a few species (eg *P. leiophylla* and *P. pinea*) this does not occur until the following autumn. The cones are, in general rounded in shape but may be elongated. They consist of well developed, spirally arranged woody scales which fit together tightly and these normally open readily on drying (unless they are serotinous). The cone scales open to shed the seeds during the late autumn and early winter. The spectrum of size of cones is considerable from the huge cones of *P. coulteri* to the tiny cones of *P. mugo*. A number of species are described as 'closed cone pines' (ie serotinous) and these respond to a particular scenario to liberate the seeds. In the case of species from Mediterranean climates especially (eg *P. nigra* and *P. radiata*) the cones remain on the trees for many years - often decades and require the flash heat of a wildfire to liberate the seeds. Other species from hostile environments (eg *P. cembra*) shed the complete closed cone which either eventually rots on the ground or is torn apart by animals seeking the seeds.

Coning in most species of Pines does not occur until the tree is well into maturity and the cones tend then to be produced high up on the tree. Collection is consequently difficult (David Douglas collected cones in the wild by shooting them off the tree!). The variation in quality of the trees in pine species can be quite substantial so that it is advisable to select 'good' specimens as parents in order to achieve a reasonable proportion of acceptable seedlings.

For those species in which the cones open conventionally it will be necessary to collect them just before the cone scales open in the late autumn to early winter and extract the seeds by drying them gently in warmth and shaking out the seeds - commercially this is carried out in a 'kiln'. It is as well to keep the drying to the minimum required for liberation as excessive drying may enhance or develop a hard seed coat condition. Closed cone pines can be dealt with by smashing them or inducing the relevant species to open with a short exposure to extreme heat - eg plunging them in boiling water for a couple of minutes.

Those species which produce serotinous cones are natives of ecological niches dependent on fire for regeneration - the cones are opened by the application of flash heat provided by a wild fire. Cones of the following species fall into this category in some degree - *P. attenuata*, *P. contorta latifolia*, *P. muricata*, *P. pungens*, *P. radiata* and *P. serotina*. In all species the seeds are liberated readily and promptly from an opening cone.

The seeds are winged - albeit in some of the species with large seeds the wing is rudimentary. The seeds vary in size from the large *P. (cembroides) monophylla* @ c2K per kg, through *P. cembra* @ c4K per kg to the small - *P. mugo* @ c150K per kg. The seeds of Pines tend to have a harder seed coat than that found in the preceding families. De-winging is only useful if large quantities of seed are to be processed. The seeds of Pines store their food reserves more generally as fats than as oils and dry storage thus tends to be marginally less damaging. However the harder seed coat also helps to conserve moisture and so the storage of seeds by conserving the moisture content at dispersal and maintaining them at c3°C is still the best option.

Some species develop a hard seed coat which will prevent imbibition if not treated. This is especially true of the seeds of large seeded species such as *P. cembra* and *P. pinea* - prolonged soaking in warm water will usually be effective but short term, warm stratification with an added compost activator is also a workable treatment.

In a few species it is possible to detect the presence of an immature embryo condition - this is almost invariably marginal and can readily be mitigated by a period of warm stratification. This condition may well be physiological rather than morphological but nevertheless it needs to be treated in order to unify the germination response. *Pinus cembra*, *P. koraiensis*, *P. parviflora* and *P. sibirica* should all be treated as falling into this category.

Although this genus of conifers will, in general, germinate without further treatment they undoubtedly benefit from a period of chilling. A period of 35 days at c3°C will unify and synchronise germination. Those species which produce large seeds - eg *P. cembra*, the Pinyons (the *P. cembroides* group), *P. pinea*, *P. bungeana* and *P. gerardiana* can be station sown. The largest seeds are probably those of *P.*

maximartinezii. Species with a warm temperate distribution, however, do not appear to develop any type of chilling requirement.

Several of these species which produce a nut-type seed appear to have a tough and impermeable seed coat - in the great majority of such species the problem is mitigated by an extended warm water soak to ensure water penetration and imbibition. If the seeds have had any extended dry storage the problem becomes enhanced and the degradation of the seed coat will have to be achieved by a period of warm stratification (preferably this is enhanced with the addition of a biological agent such as Garotta). An alternative technique is to soak the seeds in a 1% solution of citric acid for four days. The following pines fall into this category - *P. albicaulis*, *P. armandii*, *P. bungeana*, *P. cembra*, the *P. cembroides* group of species, *P. coulteri*, *P. flexilis*, *P. gerardiana*, *P. koraiensis*, *P. parviflora*, *P. peuce*, *P. pinea*, *P. pumila*, *P. sabiniana*, *P. sibirica*, *P. strobiformis* and *P. torreyana*.

Piccoideae

This sub-family contains only the genus ***Picea***, the Spruces. This genus chiefly consists of tall, upright, conical to cylindrical, generally quick growing, decorative trees. They produce their branches in whorls and these have dense green, grey-green or bluish foliage. There are about forty species - several of which are significant forest, timber producing species (*P. abies*, *P. glauca*, *P. sitchensis* and *P. pungens*) with substantial value. In forest conditions the lower branches absciss but when grown as well spaced specimens they will remain clothed to the ground until of considerable age. They are natives of the Northern Hemisphere with a circumpolar distribution and southwards into warm temperate climates. Several of the Chinese species are native in continental climate locations and so tend to flush early and in the UK are susceptible to spring frost damage and therefore need a favoured location to grow normally.

Once they reach maturity, trees produce cones annually although they tend to produce heavy crops only in every third year or so. In the intervening years seed production is light and often tends to be infested with Seed Flies (*Megastigmus spp.*) The trees produce both male and female flowers during the spring, on different branches of the

same tree, the female cones tending to be around the crown of the tree. Pollination occurs in the spring and the cones develop during the summer - maturing in the autumn when they become pendulous. The cones are leathery to woody and tend to be sausage shaped. The seeds are liberated during the early winter as the scales dry and open, this occurs over a fairly long season as the seeds are shaken free and the cones remain on the tree until well after the seeds have dispersed.

The cones should therefore be collected without delay at maturity. The cones can be induced to open by gentle drying and shaking out the seeds.

The seeds are small, thin coated and 'oily' to the touch - but are not fleshy as in *Abies* or *Cedrus*. They have a relatively large wing but de-winging is not advised as the small seeds are easily damaged. In common with other genera in this group, storage is best achieved in moisture conserving conditions at c3°C.

Most of the species of the Spruces exhibit an endogenous dormancy condition mitigated by a period of chilling. This feature however is not constant throughout a sample or from year to year. A seed lot will, in all probability, germinate without chilling but the germination will be slow and erratic with some of the sample failing to respond. A short period of chilling will unify and synchronise germination; stratification for 35 days at 3°C will usually be sufficient. Those species which have a definite chilling requirement include *P. rubens*, *P. glehnii*, *P. jezoensis*, *P. omorika* and *P. orientalis*.

Observation has shown that *P. omorika* will germinate more successfully in the dark - therefore the seeds should be covered at sowing. The critical feature in the germination of seeds of this genus is the temperature at which the process will initiate. Many species will not respond below 15°C and optimally at 20°C. This relatively high range of temperature required for successful germination is part of the strategy for avoiding a winter or early spring germination (in the absence of a strong chilling factor - thus delaying germination until late spring or early summer when the soil temperature has risen. Despite this the following species will germinate at low temperature - *P. engelmannii*, *P. pungens*, *P. koyamai* and *P. polita*. The seedlings of Spruce species are particularly susceptible to

frost damage and thus the level of temperature at which many species will germinate can also be protectively critical in this respect. A high threshold temperature for germination is thus not unusual - ensuring that germination (despite a satisfactory chilling) does not occur until well into the spring when the danger of frost has passed. It would therefore be prudent to germinate all the species at 20°C.

Abietoideae

This sub-family includes six genera the Hemlocks (***Tsuga***), the Silver Firs (***Abies***) the Cedars (***Cedrus***), the Golden Larch (***Pseudolarix***) and ***Keteleeria*** as well as the little known ***Nothotsuga***. The relevant five closely related genera of conifers are characterised by the production of relatively thin coated seeds which contain an oily (sometimes virtually liquid) food reserve. This implies that successful storage may be a challenge and that mechanical seed treatment (ie de-winging) can cause considerable damage.

The common characteristics of the seeds of these five genera are that they store their food reserves principally as oils and have a thin seed coat. This indicates that there are potentially some issues for the plant propagator to address:-

- a) The thin seed coat potentially allows the food reserve to dry relatively quickly unless moisture is conserved in storage and that, when drying does occur, the subsequent reconstitution of the food reserves with a water component for mobilisation at germination is severely constrained. This causes a consequent depression of vigour at germination - the level depending on the degree of drying which has occurred.
- b) The storage of the seeds at other than cool temperatures (c3°C) can cause the oils eventually to become rancid with the consequent deprivation to the embryo.
- c) Any mechanical treatment to extract or dewing the seed is likely to produce an unacceptable level of damage both in terms of enhanced drying and the physical loss of the food reserves and perhaps more importantly the development of fungal infection.

In effect the most satisfactory outcome for the production of a high quality sample of seed is to collect, extract and clean the seed by hand, leaving the wings intact. If

storage is necessary the seed should not be allowed to dry in storage (the water content at dispersal being maintained) and that a relatively low temperature should be provided. It would be prudent to move as quickly as is feasible into the treatment and germination phase. As most of these species of conifer are only likely to be grown in relatively small quantities and will be treated and germinated under controlled and protected conditions - this option will generally be economic. The major implication is that it will be necessary to collect seed annually.

If the seeds are stored for extended periods at other than low temperatures under moisture conserving conditions the seeds are prone to fungal rot and especially so if there has been physical damage to the seeds during extraction.

A common physiological feature of the seeds of the majority of the species in these five genera is that they exhibit (albeit at a low level) a form of endogenous dormancy which requires the seed to be imbibed and chilled (even if for only a short period) if a uniform and synchronous germination is to be achieved. Some germination will usually be achieved without chilling but it will often be slow, erratic and incomplete.

All of these genera only grow effectively with the conventional mycorrhizal association and it would be prudent to consider the addition of a suitable inoculant to the germination substrate.

The Silver Firs (***Abies***) are an important genus, of some 40 to 50 species, of tall, upright, shapely, cylindrical to conical trees. Most of the species are significant either as ornamental subjects or as timber producers.

The trees have a strong central axis and tend to remain clothed to the ground until well into maturity. The foliage is usually dense and in bright shades of green - or occasionally 'blue'. Some species are currently fashionable as Christmas trees. They are chiefly natives of the temperate regions of the Northern Hemisphere and occupy in the northern ranges low elevations but the more southerly species tend to occur at higher elevations - in northern Africa and Central America. The species from continental climate provenances usually do less well in the UK as they tend to be early flushing and the young growth is often damaged by spring frosts.

At maturity the cones of both sexes are produced on the same tree on the previous season's shoots - to the outside of the tree. The cones are held erect. The female flowers of *Abies spp* are produced in the early spring and these develop along the top side of the branches. Pollination will occur in the late spring and the cones mature in the autumn of the same year. The mature cones are upright and disintegrate on the tree over the winter as the seeds and the scales are dispersed - leaving the central axis of the cone still attached to the tree. The greater proportion of viable seed appears to develop on the basal scales of the cone. The cones themselves can be ornamental and are often brightly coloured - green, blue and purple.

The cones should, therefore, be collected just prior to this disintegration phase and then gently dried so that the seeds can be separated when the cones break up. If the seeds are much lighter than the scales this can be achieved by winnowing - otherwise it may be necessary to sieve the material with a relevant gauge sieve. The seeds are angular and three dimensional, oblong to triangular in shape thin coated, soft and with an oily, virtually liquid, food reserve; such a condition means that they are easily damaged by physical activity during extraction. If they are not properly stored (in the short term) they can desiccate quite easily and lose viability, or the food reserve deteriorates and becomes rancid or the seed becomes subject to fungal infection. There is often much unsound seed (ie with an aborted embryo) although the seed appears normal with a normal oily food reserve. This characteristic is often more prevalent on isolated specimens - suggesting that there could be a degree of self-incompatibility.

The seeds of Silver Firs are more consistently dormant than seeds of Spruces or Douglas Firs and several species with an extensive range exhibit a variation in the depth of the dormancy condition and this can be attributed to the provenance. As is typical for this group of genera the seeds of most species will germinate without any period of chilling but under these circumstances is then erratic, incomplete and attenuated. A period of chilling synchronises emergence, maximises production and decreases the time taken to emergence. A chilling treatment of 35 days at below 3°C will usually be more than sufficient to ensure that the encumbrance is mitigated. Germination rates for Silver Firs are almost invariably poorer than expected

as many seeds which appear to be sound are not and so fail to develop. Best results are achieved when germination is at its speediest and this occurs at a temperature of around 18 - 20°C.

This genus ***Keteleeria*** is only satisfactorily grown in mild niches in the British Isles as the young growth is particularly susceptible to frost and the relatively early flushing habit makes it significantly prone to damage. It is unusual to find cone bearing trees in the UK (if at all) and production is usually achieved by using commercial seed imported from Mediterranean countries. The seeds are very similar to those of *Abies* and should be dealt with in the same way.

The Cedars (***Cedrus***) are all, potentially, large trees of substantial stature and require considerable space. They are therefore principally used in public parks, cemeteries, parklands and those properties with extensive garden areas. There are nominally four species in the genus but these are difficult to delineate clearly and are, by some authorities, treated as extreme geographical variants of one species. It is therefore important that the provenance of any seed lot is determined and recorded in order to provide a valid expectation. All four species grow quite satisfactorily in all but the northern parts of the UK. They will also set viable seeds once the individual tree has matured and the vegetative growth phase is no longer the plant's priority. The presence of cones is not an indication of seed production and the production of sterile cones is more often than not a symptom of this emphasis on vegetative growth.

Male and female flowers are usually produced on the same tree although not always so. The flower cones are erect and produced on the short spur shoots in July/August and are fully developed by September/October. Pollination occurs in October and the cones begin to grow the following spring - by the following autumn they are about two thirds developed and complete development to full maturity does not occur until the following autumn (ie about two years after pollination). The cones are substantial and barrel-shaped - up to 75mm tall and 40mm broad: when mature the cones break up on the tree during the winter - dispersing the seeds and scales and leaving the central axis on the tree in the same fashion as the Silver Firs. The cones are erect, relatively large and woody and initially tightly closed.

The cones should be collected in late November/December as they ripen and change colour from green to purple-brown and before they begin to disintegrate. Extraction is easier the closer the maturity of the cone is to disintegration. The cones seem to break up more readily under damp conditions - so that the most useful method for extraction of the seeds from a closed cone is to immerse the cones in warm/hot water until there is an indication that the scales are opening.

The seeds are relatively large, angular, thin skinned, soft and oily - containing a clear oil - with a large membranous wing; it is unwise to attempt to de-wing them as this is likely to cause damage. Because of the thin seed coat the seeds are prone to dry quickly so they should be kept cool under moisture conserving conditions until they are ready to be processed.

Much of the commercial seed offered (which is generally of high quality) is collected in Southern Europe; however there appear to be considerable variations in the hardness of individuals and it would be prudent to collect seed from a local specimen in order to provide an indication of hardness - as well as the ability to define the name and provenance.

The dormancy control, in this genus, requires a period of chilling to eliminate the effects. It is however very marginal and normally a seed lot can be germinated quite effectively without treatment but with an attenuated and erratic emergence; however experience will show that a short period of chilling will enhance germination by speeding and synchronising emergence. A stratification period of 28 days at 3°C will achieve this. Optimal germination is achieved by providing a temperature of 18-20°C when emergence will occur in 5-7 days.

The seeds of all the 'species' are remarkably similar - only varying in their 100 grain weight:- *C. atlantica* - 7.5gm; *C. brevifolia* - 8.5gm; *C. deodara*, c12.5gm and *C. libani* - 8.0gm.

The genus ***Pseudolarix*** is monotypic and thus has only the one species - the Golden Larch (*P. amabilis*) from Eastern China. It is a tall, erect, more or less conical, deciduous tree prized for its autumn colour. It has not been widely

planted in the UK because of a perception that it is of doubtful hardiness. There are however a number of fine specimens in the South West of the UK. This reputation is more associated with its slow growth rate which is probably a reflection of the greater light levels and higher temperatures that it experiences during the summer in its native continental climate - its winter hardiness is not suspect but it will be susceptible to late spring frosts.

Male and female flowers are produced in the spring and pollination and fertilisation occurs in April. The erect cones - which are described as 'being like small globe artichokes' are characterised by the open, loose and pointed appearance of the scales, these develop and mature in the one season. The cones gather a purple flush as they ripen and finish a reddish brown; each scale carries two seeds. The cones are 15-18mm long and 10mm broad at their widest. The seeds are dispersed in November-December as the cone completely disintegrates and falls from the tree.

The seeds are white to pale beige, egg shaped and 6-8mm long with a long wing which is shiny and yellow brown in colour and is somewhat oily to the touch. The cones break up fairly quickly so collection should not be delayed. Extraction is achieved by gentle drying until the cones can be broken up to allow the seeds to be separated.

The production of seed in the UK is not common - if at all - but how much this has been a function of the maturity of the available specimens is not clear and indeed whether the summer climate is light and warm enough to achieve seed production. It is likely however that the trees are self sterile and hence isolated specimens are unlikely to produce viable seeds - even though they cone regularly. Crops of good quality seeds are however available, annually, from northern Italy. The longevity of the seed is short but satisfactory storage for a few months can be achieved under water conserving conditions at a low temperature (c3°C).

As with all of this group of conifers, the germination of the seed will be unified and synchronised by a short period of chilling. A period of chilling for 35 days at 3°C will achieve this treatment satisfactorily. Germination at 18-20°C provides the optimal range of temperature for germination.

The Hemlocks (*Tsuga*) are a small genus of ten to fourteen species (depending on the current view of the taxonomists) of straight stemmed, upright, elegant, stately and graceful evergreen trees of North America and Eastern Asia in the Northern Hemisphere. The Asiatic species are only successful in the UK in areas where late spring frosts are not common as they tend to flush early in the season. The crowns are generally tall and conical and the mature branches are horizontal to drooping with very thin, lightweight twigs.

The flowers are produced in the early spring - just before vegetative growth begins; male and female flowers are produced on separate branches of the same tree. The female flowers are produced terminally on the lateral shoots of the previous year and the male flowers in the axils of these shoots.

The cones mature in the same year that they are pollinated and are small, brown in colour and consist of leathery overlapping scales. They are pendulous and remain attached to the tree for most of the winter. The cones open in the autumn to early winter and the seeds are liberated slowly throughout the winter and into the early summer of the next year - when the cones are empty they eventually detach themselves. In general the Hemlocks fruit consistently each year and are not periodic in their response. The cones should not be collected until they are fully mature in the autumn just before they are ready to open - as cones in the green condition do not open readily and many of the seeds are immature (the seeds do not mature until just before they are shed). Gentle drying will cause the cones to open readily and the seeds can be shaken free. The seeds are very small and are produced in abundance but viability is generally low.

The seeds are small and thin coated and are very susceptible to bruising so should be treated gently. The seeds can be stored 'dry' (ie at their dispersed moisture content) at 3°C in the medium term.

The species and their geographic variants vary greatly in their germination requirements however in order to provide a generalised formula for a protocol - the seeds should be stratified at 3°C for 42 days and then germinated at 20°C, this regime requires that the seed should be covered to exclude light. In common with Birch species, from the same

ecological niches, unchilled seed will achieve reasonable levels of germination if exposed to light.

Laricoideae

This sub-family contains the three genera ***Larix*** and ***Pseudotsuga*** plus the 'non-cultivated' genus ***Cathaya***.

The Larches (***Larix***) are a genus of deciduous conifers consists of about sixteen species which is native to the Northern Hemisphere where it has a circumpolar distribution - it is essentially an alpine or polar forest genus but there are outlying species further south - as far as the Himalayas - but always at medium to high altitude depending on latitude. Many of the species have an extensive geographical distribution and have developed races in particular provenances. Several species are important forest timber trees in the colder northern climates. They are usually tall trees with a single tapering trunk which retains the branches if grown as individual specimens at reasonable separation. They are sufficiently decorative to be used in an ornamental context - especially for their autumn colour in difficult or cold situations.

The male and female flowers are produced on the same tree in advance of leaf bud break. Pollination and fertilisation occur at this time and the cones develop and mature in the same year. The cones are erect, woody, relatively small, ovoid in shape - about 20-30mm long and 20-35 mm wide. The scales, in most species gradually open and shed the seeds over a long period from the autumn to spring - the spent cones are retained on the tree for several years. The cones should be collected in the late autumn before the scales begin to open (as some species liberate their seeds quickly eg *L. occidentalis*). The cones should be gently dried until the scales open and the seeds can be shaken free. Storage without further drying at 3°C is effective over the medium term. The cones generally develop good quantities of seed. However seed production can be periodic and in years of poor seed production most are infested by weevils.

The seeds are small and red brown in colour and have a relatively large wing which allows a good dissemination by the wind. De-winging although feasible is not easy without damage to the seeds. The seeds are somewhat slippery to the touch. However even in good years the quality of the seed is poor and there is a high proportion of non-viable seed.

Viable seeds can be readily recognised by the well developed red brown embryo set in a light coloured endosperm.

The germination characteristics of this genus are variable - the seeds will germinate if spring sown (when soil temperatures are high) but germination is likely to be erratic, slow and incomplete. The most reliable practice to achieve a reasonably complete response of all the viable seeds is to stratify the seed for 42 days at 3°C - and then sow and germinate the seeds at 20°C. This should take care of any extended variation in chilling requirement which relates to a particular provenance. It would appear that a longer chilling period (up to 63 days) *marginally* speeds, unifies and synchronises germination - although *L. leptolepis* often exhibits a deeper dormancy than the other species and would normally be stratified for 56 days.

The Douglas-Firs (***Pseudotsuga***) are a small genus, of about six species, of very tall, upright evergreen coniferous trees producing their branches in whorls. In the past they have been included in many of the above genera as they have apparent individual affinities with them all. They are easily recognised by their cones in which the bracts have a three pointed external extension - this distinguishes them from all the other genera in this group.

The most widely known and recognised species is the Douglas-Fir (*P. menziesii*) which has, in its widest interpretation as a species, a distribution which covers large tracts of the western side of North America. It is a significant forest timber tree and can grow to immense height (90+m) and size. In its early life it can exhibit considerable growth rates. Because of this wide geographical distribution there are many variants and it is relevant to know the source of the parent tree.

All the species can be ornamental as individually sited specimens - however the species from warm temperate or continental climates (of which there are three) do not generally succeed or thrive in the UK as they are susceptible to late spring frosts and are therefore only found in locations with a mild spring climate.

The male and female flowers are produced in the spring with pollination and fertilisation occurring then. The female flowers are produced in the upper crown of the tree and

soon become pendant. The cones and seeds mature during the one season as early as August - September and they begin to release their seeds in September-October, the seeds are dispersed fairly quickly. The cones are medium sized (8-10cm x 4-5cm in *P. menziesii*), blocky, light brown, pendulous and leathery. The cones should be kept under observation and collected as soon as the first cone scales begin to separate. The cones are gently dried until the seeds can be extracted by shaking them out. Storage under moisture conserving conditions at c3°C maintains quality in the medium term.

The seeds look very similar to those of Larch are dark brown and shiny and have a large rounded wing. As the seeds develop, the side of the seed which lies on the scale is flat and the upper side is rounded - it has been shown that the seeds germinate faster when sown with the flat side of the seed is oriented upwards - ie away from the medium. The food reserves are high in fats and oils and thus require storage at cool temperatures under water conserving conditions under such a regime they will retain viability for several years.

Seeds which are sown without any pre-treatment germinate poorly - slowly and erratically. If there is no dormancy control the seeds will germinate in 12-15 days if a temperature of between 20 and 30°C is provided although in this genus there is no light sensitivity. The response of the seeds of *P. menziesii* depends on their particular provenance - as does their size.

In general the best germination results are achieved by a stratification treatment of 35 days at 3°C followed by germination at 20°C.

Aceraceae

The taxonomic position of this monogeneric Family, based on DNA analysis and assessment, is still actively discussed. The debate centres on whether it should be included in the **Sapindaceae** or whether it merits a separate status. Currently it is separated - containing only the genus **Acer** and with the often associated genus **Dipteronia**, still, being included with the *Sapindaceae*.

Acer

The Maples (**Acer**) are a numerous and diverse genus of woody plants - currently about 150 species are recognised but some of these demonstrate wide variability. For taxonomic purposes the genus is divided into about sixteen Sections - which has the advantage of grouping similar species - and hence their possible seed dormancy breaking treatments - together.

The genus occurs throughout the Northern Hemisphere from sub-arctic conditions to sub-tropical conditions, occurring south of the equator only in South Asia. The genus contains species which have evolved to occupy specialist environmental niches to species with conventional distributions and to a few species (eg *A. saccharum*) which have an extensive geographic range and which vary clinally, quite dramatically, throughout the range.

They are all deciduous but a few species (all from warm temperate climates) do not abscise their leaves until the new crop is formed and these are described as semi-evergreen.

The species, covered within these notes, are chiefly limited to those which occur in conventional temperate climates.

The fruit of this genus consists of a one seeded, winged samara (often in conjoined pairs and occasionally in threes); flowering is normally in the spring with the fruits maturing in the autumn and generally dispersing quickly. The seed is usually short lived which is a typical characteristic of seeds which store their food reserves predominantly as non-carbohydrates. Long term storage is therefore problematical - it is suggested that a relatively slow drying procedure is the best option - as this, in

effect, probably causes less damage to the microscopic structures of the seed, nevertheless rehydration is, even then, usually less than satisfactory at best. Short to medium term storage is achieved by sealing fresh, ripened fruits (at the dispersal stage) in a polythene bag, to conserve moisture, and then maintaining the sample at a low temperature (3°C). The food reserve is stored in the cotyledons and there is no endosperm.

The production of viable seed crops in many species, when grown in cultivation in the UK, in relation to individual plants, is a matter of conjecture as many of the species are functionally dioecious and therefore need more than one plant, of a distinct genetic constitution, for cross pollination to occur. Other species are monoecious with the sexes being located in different parts of the tree and then sometimes with the different sex flowers maturing at different times. It is for these reasons that it is often prudent and necessary to obtain seeds from native stands or single species groups of seedlings in cultivation.

There are a number of groups of species, within the genus *Acer*, which are closely related and if the fruits are collected from specimens, within collections, where related species are growing within close proximity, the genetic status of the seeds should be treated with suspicion - as there is a high risk of hybridity occurring in the offspring.

The majority of species do not present any difficulties in the production of seedlings although virtually all of those species which disperse their seeds in the autumn exhibit an endogenous embryo dormancy which requires a period of chilling for its elimination.

As would be expected for such a numerous genus, there has been little critical observation conducted on the chilling requirement of most of the species. The results from those which have been assessed (and these are chiefly species from temperate to cold temperate distributions) seem to suggest that a period of 84 days at 3°C provides the optimal treatment for a rapid and synchronised emergence when an acceptable temperature for germination is reached - although shorter periods may achieve the effect, the emergence at germination is often erratic and certainly slower.

The embryo, of many of these cold temperate species (eg *A. saccharum*), will develop to the stage of radicle emergence at the same low temperatures once the cold stratification treatment has been completed ie after the dormancy control has been eliminated. It is therefore important to monitor the progress of any sample which is being stratified so that the sample can be transferred, if the radicle does emerge, to suitable temperatures for efficient germination, this is especially relevant if no previous experience is available as to time scales. It is probable that the radicle will only develop very slowly if maintained at low temperature but it would not be prudent to leave seeds in such a condition as they will inevitably deteriorate in some degree. In general Maples germinate most effectively and quickly when provided with an environment of 20°C.

The threshold temperature for chilling has not been critically assessed for most species and it is quite possible that species from warmer environments (eg *A. paxii*, *A. pectinatum* and *A. sikkimense*) will respond at higher temperatures - the threshold for these species could be as high as 7°C or possibly even 10°C.

The germination of those maples (eg *A. campestre*, *A. griseum*, *A. pennsylvanicum* and *A. circinatum*) which develop a significantly impermeable seed coat to water uptake, as part of their reproductive strategy, is normally delayed until the second, or later, spring after an autumn dispersal. It requires the warmth of at least one summer, in the soil, to enhance the degradation of the seed coat to a level at which the seed is capable of imbibing and when it will then respond to the chilling period provided by the following winter - which, in turn, will then eliminate the endogenous embryo dormancy.

Experience, however, has suggested that this attenuated time scale could be mitigated, by the propagator, by collecting the fruits (samaras) at an immature stage ie before the case has hardened to a stage at which imbibition is prevented. The seed will have developed to a complete, quiescent and mature condition relatively early in the season and it is when this stage has been reached that the hard seed coat begins to develop - if the fruits are collected at this crucial, early stage the hard seed coat can be avoided. This is usually when the samaras are just changing from green to yellowish green. It would appear that the samaras are still transferring photosynthate to

the seed while they remain green. At this stage, when collected, the seeds should be stored under water conserving conditions (so that any further drying is prevented) - subsequently the seeds can be successfully imbibed. They can then be subjected to a chilling treatment with the expectation that germination will occur in the following spring.

Section *Rubra*

Those species in the Section *Rubra* (*A. rubrum*, *A. saccharinum* and *A. pycnanthum*) which flower very early in the year and set their fruit in the summer (under normal conditions) exhibit a transient viability which is an indication that once the fruits are shed, and find suitable conditions, germination is almost immediate. Thus there are no dormancy controls. Under normal nursery conditions the seeds are sown fresh and without any drying and will germinate rapidly and uniformly. The storage of these seeds is therefore not worthwhile and fresh seed needs to be sourced each year - however *A. rubrum* has been successfully stored when fresh seed is sealed in a polythene bag (in order to maintain the water status) and stored at low temperature (c2°C), under this regime satisfactory viability has been retained for as much as twelve months. *Acer rubrum* has a considerable geographic range and the dormancy controls from north to south of the distribution varies dramatically - the northern distributions requiring a chilling period before germination will occur.

Section *Macrantha*

The Snake Bark Maples Section consists of up to 18 species. It occurs across Eastern Asia from the Eastern Himalayas, through China and Taiwan, to Japan, with one, eccentrically situated, species in Eastern North America (*A. pensylvanicum*). This grouping contains some highly ornamental small trees and large shrubs - all of which, in some degree, exhibit the characteristic striated bark patterns and many also develop a red colouration to the shoots and foliage during the spring. The greatest concentration of species is in Japan - *A. capillipes*, *A. caudatifolium*, *A. crataegifolium*, *A. micranthum*, *A. morifolium*, *A. rufinerve*, *A. tegmentosum*, and *A. tschonoskii*. They are of varying hardiness - depending on their provenance - *A. morifolium* (which is rare in cultivation) and the very ornamental *A. tegmentosum* are from southerly latitudes and require a mild niche to succeed in the UK. *Acer laxiflorum* occurs in Western China,

A. davidii (which now includes *A. grosseri* and *A. hersii* - although these latter two variants 'come true' if collected from single 'species' stands) and *A. maximowiczii* are both found in Central China and *A. forrestii* in Southern China. *Acer pectinatum* and *A. sikkimense* (*syn A. hookeri*) are both from the Eastern Himalayas and are usually found in warm temperate situations and would be regarded as verging on the half hardy - although there has been an introduction in recent years (from a high elevation) of an apparently more cold hardy provenance of *A. pectinatum*. This group of Maples shed their fruits during the autumn and do not develop a hard seed coat as a normal process - however if, when, the seeds are collected and allowed even to marginally dry then a hard seed coat develops which, although not intractable, is sufficient to delay imbibition; if the seeds are not dispersed quickly they tend to dry on the tree and develop similarly. Thus the usual advice to achieve their successful propagation is relevant - ie collect the fruits well before they mature, while the samaras are still yellow-brown and process them without drying. If a dry seed coat has developed it can usually be mitigated by a warm water soak. *A. pensylvanicum* is exceptional in that, in its natural environment, it develops a hard seed coat, which will delay germination for at least a year, as a matter of course. The solution is necessarily to collect and process the seeds as the samaras reach the stage at which they begin to turn yellow. All the species from cold temperate provenance will respond to a chilling procedure of 84 days at 3°C. The species from warmer provenances will respond to 56 days at below 7°C.

Section ***Trifoliata***

The trifoliate maples which occur in two series (*Acer griseum*, *A. maximowiczianum* (*A. nikoense*) and *A. triflorum* and secondly *A. mandschuricum* (with *A. sutchuenense*) present a particular issue insofar as the extremely hard, woody seedcases of the samaras are often void and the number of viable seeds produced is often extremely low (less than 10%). This may be a natural quirk or may be due to the self incompatibility of single specimens and even where seed is collected from a group of trees, in cultivation, they may be grafted and therefore likely to be clonal - so the same result applies. Even if samples with acceptable levels of viability (< 30%) are found the seed case is very hard and intractable and will require substantial warm stratification to overcome the problem. The embryo when exposed to water and imbibed still exhibits

an endogenous dormancy needing at least 84 days (at below 3°C) of chilling to overcome. This group represents another classic instance of the need to attempt to avoid seed coat dormancy by collecting the samaras at a very early stage; maintaining in a moist condition and warm stratifying immediately if the case is already beginning to harden.

Section **Platanoidea**

This Section occurs through Europe and Asia in cold temperate climates and is recognised a) by the production of a milky sap and b) the seedcases which are round and flat - *A. ambiguum* (often given as part of *A. pictum*), *A. amplum* (Central China), *A. campestre* (Western Europe), *A. cappadocicum* (Caucasus to the Himalayas), *A. lobelii*, *A. miyabei* (Japan), *A. pictum* (syn *A. mono*) (widespread in China, Manchuria, Japan and Korea), *A. platanoides* (widespread through Europe and the Caucasus) and *Acer truncatum* (Northern China), *inter alia*, all belong in this grouping.

Acer campestre and *A. truncatum* both exhibit a hard seed coat condition as a normal course of maturation and although warm stratification will overcome the problem it is easier to harvest the seeds as the samara colour turns from green to yellow and avoid the issue. All the species have a chilling requirement and this is provided by 84 days at 3°C. The remaining species should not develop any impermeability of the seed coat if they are harvested as soon as they are mature and either stored or sown without further drying. If the seed coat has dried it can usually be made permeable by soaking in warm water.

Section **Acer**

This Section is the second largest and is divided into three series. The first series contains the various Sycamore look-alikes - *Acer caesium*, *A. giraldii*, *A. heldreichii*, *A. pseudoplatanus*, *A. trautvetteri* and *A. velutinum* (inc *A. vanvolxemii*). The second grouping consists of a series of species occurring around the Mediterranean basin - *Acer granatense*, *A. hyrcanum*, *A. monspessulanum* (inc *A. trilobatum*), *A. obtusifolium* (inc *A. syriacum*), *A. opalus* and *A. sempervirens* - and all are adapted to that particular climatic biome.

The species from these two groups do not develop any significant hard seed coat problem even with drying but it would nevertheless be prudent to soak the seeds in warm

water to ensure imbibition. They will all need some degree of chilling (at 3°C) but for the warmer climate species this will be shorter (c56 days) than the cold temperate species (84 days).

The third series is limited to the various Sugar Maples. The Sugar Maple, *Acer saccharum*, exhibits a wide clinal morphological and physiological variation across a substantial geographical and climatic spread in North America. It is regarded as 'typical' in the North East where it is a major contributor to the 'fall colour' in that region - it becomes (either as a separate species or as a sub-species) *A. leucoderme* in Georgia and the Piedmont region across into Eastern Texas and *A. floridanum* (= *A. barbatum*) in the far South East; a variant *A. nigrum* occurs in the Mid-West and a disjunct population of a drought tolerant variant (an ecotype), the 'Caddo Maple', occurs in Oklahoma; *A. skutchii* is found in southern Texas and adjacent Mexico and despite its provenance appears to be reasonably hardy. In the Rockies and South to Texas from the Big Bend to the Edwards Plateau this population is, nowadays, designated as a distinct species - *A. grandidentatum*.

These 'species' do not in general develop a hard seed coat which prevents imbibition but if the seed has been dried it would be prudent to give the seed a warm water soak to ensure imbibition - especially *A. grandidentatum* which might just develop the condition to a significant level if the seeds are dried too extensively. The chilling requirement will vary according to provenance. At the most northerly *A. saccharum* requires 84 days at 3°C and will germinate to radicle extension at that temperature as well - so that chilling samples should be regularly monitored. For the most southerly species (*A. floridanum* and *A. skutchii*) chilling for 30 days at 7°C will suffice.

Section ***Ginnala***

This small section comprises - *A. aidzuense* (part of *A. tataricum*?), *A. ginnala* (China and Japan), *A. tataricum* (South Eastern Europe and Asia Minor) and *A. semenovii* (part of *A. ginnala*?).

These shrubby species develop a hard seed coat and so should be harvested as the samaras turn colour from green. They are then processed without further drying and chilled

at 3°C for 84 days. Germination will be most effective at 20°C.

Section ***Pentaphylla***

This section consists of one series containing, *inter alia*, *A. buergerianum*, *A. coriaciefolium*, *A. oblongum*, and *A. paxii* (of which the latter three are semi-evergreen) and a series containing only *A. pentaphylla*. Only *A. buergerianum* would be described as reasonably hardy (although it does have a distribution which covers milder areas and where it will become semi-evergreen) - the remainder require a mild niche for successful cultivation in the UK.

The Himalayan and Southern Chinese, semi-evergreen species, all tend to be frost susceptible in some degree and therefore need a favoured site to succeed and fruit. Their warmer provenance dictates that the chilling requirement is less severe (56 days at 7°C), germination will require at least 20°C for a rapid emergence.

Section ***Palmata***

This Section constitutes the largest segment of the genus and contains about fifty species which are divided into three Series.

The first series contains, *inter alia*, the well known Vine Maple, *A. circinatum* from Western North America and the Japanese *A. japonicum*, *A. palmatum* and *A. sieboldianum* - these species are generally cold hardy and are characterised by developing a hard seed coat condition.

These species benefit from collection at an early stage (*ie* before the seed coat hardens) and treating them, without delay, to a chilling regime of 84 days at below 3°C. A temperature then of 20°C for germination will see emergence in 7 to 10 days.

The second series contains several less well known species which, in general, are not fully hardy - but the semi-evergreen, simple leaved *A. fabri* and *A. laevigatum* are seen in cultivation. If the seeds are maintained without drying and are then imbibed, they will respond to chilling for 56 days at below 7°C and a germination temperature of 20°C.

The third series is the most numerous and the species are found throughout Eastern Asia, they are also generally less

hardy but *A. campbellii*, *A. erianthum*, *A. flabellatum*, *A. oliverianum*, *A. sinense* and *A. wilsonii* are seen regularly in cultivation in mild situations. The same remarks, relating to germination, as for the previous series apply.

Section **Glabra**

This section includes *A. acuminatum*, *A. argutum*, *A. barbinerve*, *A. stachyophyllum* and *A. glabrum*.

The available evidence suggests that these species are functionally dioecious and therefore more than one tree is required to ensure good seed crops.

These species will, in general, develop a sufficiently hard seed coat to delay germination for one year and it would therefore be prudent to collect the samaras at the immature stage - before imbibing and providing a chill for 84 days at 3°C.

Section **Indivisa**

The Japanese *A. carpinifolium*, with its Hornbeam-like leaves, hardly looks like a Maple and is the only species in this Section. It has the potential to develop a hard seed coat and should be collected at an early stage before the pericarp hardens, it will then require chilling for 84 days at 3°C.

Section **Negundo**

This section comprises three similar species which are however separated into two series - the first contains only *A. negundo* which is widespread in North America and the second which includes *A. henryi* from China and *A. cissifolium* from Japan. They are all large shrubs to small trees and all are dioecious. They flower and fruit profusely when both sexes of parent are present for suitable pollination.

The samaras are relatively small, narrow and linear. The samaras will dry sufficiently while on the tree, before dispersal, to develop a hard seed coat condition and this will be enhanced by dry storage. Practically this can be avoided by collection of 'green' seed however if only dispersed or stored seed is available, it would be prudent to scarify and then warm water soak. In many samples the proportion of filled seeds is often low.

The imbibed seed will require a period of chilling (84 days at 3°C) to permit germination.

Section **Lithocarpa**

This section includes *A. diabolicum* (Japan), *A. franchetti* (Central China) and *A. sterculiaceum* (syn *A. villosum*) (the Himalayas) in one series and *A. macrophyllum* (Pacific coast of North America) in a second. These species do not usually develop a hard seed coat and only require chilling for 84 days at 3°C after a warm water soak.

Section **Parviflora**

This Section contains *A. caudatum*, *A. spicatum*, *A. ukurudense*, *A. distylum* and *A. nipponicum*. All the species have the potential to develop a hard seed coat condition and hence should be collected when the samaras are turning colour to yellow and then processed and chilled (84 days at 3°C) without delay.

Summary

In summary the Maples show three possible dormancy scenarios:-

- a) no constraints to germination when conditions are suitable;
- b) the presence of a hard seed coat condition which can be intractable or as a result of marginally excessive drying. This condition is best avoided by the collection of the samaras as the colour changes from green to yellow during the late summer to early autumn - this is the most suitable policy to adopt if the condition for a particular species is not known;
- c) the existence of an endogenous embryo dormancy requiring a period of chilling to mitigate. All the species, despite their varying threshold temperatures and periods of exposure can be universally treated by chilling at 3°C for 84 days and then monitoring the sample for radicle emergence.

The temperatures required for optimum germination will, in general, be in the range 16 to 22°C with an economic, standard protocol being fixed at 20°C.

Adoxaceae

This small Family of four genera (two of them being woody and with temperate distributions) has been separated from the **Caprifoliaceae**. The two woody genera, **Sambucus** and **Viburnum**, both have species which exhibit unusual and somewhat eccentric dormancy controls which involve, *inter alia*, the maturation of an immature embryo.

Sambucus

This genus, particularly, has developed some unusual dormancy patterns - which because they have not been fully understood (and for several species are still not fully elucidated) - have often created uncertainty in achieving reliable germination protocols.

The genus **Sambucus** is a relatively small genus. It is, however, widely distributed in the Northern Hemisphere - in the Southern Hemisphere it is limited to Australasia and eastern South America. It is subtropical and temperate in its distribution. The genus is predominantly woody but there are a couple of herbaceous species.

The number of woody species in the genus appears to be a matter of taxonomic debate - some taxonomists taking the view that there are only three species - with two of these having very extensive, geographical distributions. These are then divided, in particular geographical areas, into subspecies or major variants; while others give specific rank to these more local entities.

These two portmanteau species contain the following entities which are relevant to temperate climates:-

a) the several variants with black berries (sometimes with a bloom which makes them appear blue or blue-black): if these are determined, *in toto*, as the species **S. nigra** - then the entities included are *S. australis* (eastern South America) *S. canadensis* (eastern North America) *S. caerulea* (western North America) and *S. nigra* (Europe and adjacent Asia) and

b) a complex of red-berried variants which if similarly determined as **S. racemosa** will include the entities *S. callicarpa* (western North America), *S. chinensis* (montane, eastern Asia), *S. latipinna* (Korea and adjacent Siberia), *S. microbotrys* (montane, south west North America), *S. pubens* (north of North America), *S. racemosa* (northern

Europe and adjacent Asia), *S. sieboldiana* (Japan and Korea), *S. tigrani* (Caucasus) and *S. williamsii* (north eastern Asia).

All of these entities are sufficiently distinct to come 'true from seed': thus for the purpose of these notes they are regarded, for all intents and purposes, as distinct species.

The Elder, Elderberry or Elderflower (the genus *Sambucus*) is readily recognised by the distinctive smell of the vegetative parts, its rapid and succulent annual growth with a virtually hollow pith and its prolific and dense flowering habit with its particular aroma. There are many selected variants (chiefly of the foliage) which are grown as ornamental plants.

The plants vary from small shrubs up to trees which may reach eight metres in height. They are deciduous and produce fairly large, pinnate leaves with the leaflets having serrated margins.

The flowers are produced prolifically in early summer and these are often harvested and used as a flavouring. Each individual flower is small, having five petals and is white or cream (occasionally pink) in colour: the individual flowers are carried in dense clusters of variously structured corymbs. They are capable of self pollination.

The fruits, which are fleshy, berry-like drupes, are also produced prolifically in dense clusters. The fruits, of suitable species, can be used for cordial, wine making and flavourings. Each berry contains three to five seeds referred to as 'stones'.

The fruits - which mature in the early autumn - should be collected as soon as they are ripe (or just before); they are quickly taken by birds once they reach a palatable stage. As the fruits are produced in dense clusters, and the shrubs are, usually, easily accessed, they are readily gathered by hand.

Extraction of the fruit can be achieved in two ways either:-

a) by macerating and fermenting the fruit clusters in warm water, when the seeds will eventually fall to the bottom of the container and the dross and liquid can be decanted off;

or

b) by drying - by separating the berries from the woody parts of the cluster and placing them on a sheet of paper in a dry sunny place - when completely dry the whole can then be lightly crushed when this dry flesh will turn to dust and can be blown off.

The seed coat (endocarp) is reasonably hard but is not impermeable (this provides protection while in passage through the bird's gut). Normally the seed coat does not develop a 'hard' (ie impermeable) condition (however see below) but the latter treatment may however, marginally, induce such a condition if drying is excessive.

At seed maturity (ie when it is dispersed) the embryo is only partially developed along the length of the seed and before it can germinate it must develop to complete the entire length of the seed.

Despite the received wisdom that the coats of *Sambucus* seeds are not permeable to water, recent evidence suggests that this is not so. Like many *Viburnums* this scenario was perceived as the cause of delayed germination when the immature embryo condition was not recognised. Nevertheless the seed coat does not allow rapid water uptake and full imbibition requires the availability of water for seven days at above 20°C before full water status of the seed is achieved.

All the relevant species exhibit an immature embryo and have a chilling requirement. The pattern of dormancy characteristics however do not appear to be relative to the particular taxonomic group but are a reflection of the environment in which the particular entity has evolved - regardless of the taxonomic position - with particular species from both groups showing the same responses in particular geographic areas.

This particular phenomenon is exemplified, firstly, by *S. caerulea* (from the *S. nigra* group) and *S. callicarpa* (from the *S. racemosa* complex), which are both native to western North America. Both species have immature embryos @ +/- 75% of the seed length and therefore need to mature the embryo, subsequently they require chilling to overcome physiological dormancy and will then be able to germinate. Unusually all three parts of this sequence is optimal at a single temperature regime at 5°C. A second scenario is

provided by *S. canadensis* (from the *S. nigra* group) and *S. pubens* (from the *S. racemosa* complex) which are both native to eastern North America. These two species have an immature embryo @ +/- 60% of the seed length and maturity of the embryo is achieved, optimally, by exposing them to an environment of 25°C - *S. canadensis* for 84 days and *S. pubens* for 42 days - this is followed by chilling for 84 days (for both species) to eliminate physiological dormancy and then (at 20°C) achieve germination.

Of the Eurasian species only *S. racemosa* (*sensu stricto*) from Sweden has been assessed and this showed more or less the same pattern as the western North American species (see above).

It would appear from reliable evidence that most (if not all) of the species not only require light for germination but that light might also be beneficial during the stratification period.

Viburnum

The genus ***Viburnum*** is relatively large (about 135 species) and widely distributed group of ornamental plants - both evergreen and deciduous. They are mostly shrubs but some grow into small trees. The Wayfaring Tree (*V. lantana*) and the Guelder Rose (*V. opulus*) have a European distribution and both are native to the British Isles. The genus has a distribution throughout the Northern Hemisphere and also below the equator in South East Asia and South America - in the tropics but at higher elevations.

The species are diverse in their characteristics - varying from deciduous in cold temperate climates to evergreen in warmer areas, from winter to spring to summer flowering and from smooth leaved to hairy leaved.

Flowers are produced in corymbs; the individual flowers having five petals, are white or pink and are often very fragrant; in some species the outer flowers of the corymb are modified as large sterile pollen guides.

Individuals of many species are more or less self sterile - or are functionally dioecious (eg *V. davidii*) and require a pollinator, of a distinct genotype, to produce a reasonable crop of fruits. In general it would seem prudent to grow

groups of seedling plants together, in order to develop a significant level of viable crop.

The fruit is a single seeded drupe with an external, brightly coloured skin, a soft flesh and an internal, thin stony shell. The seeds are dispersed by a wide range of mammals and birds and the stony seed coat acts as a protection for the seed as it passes through the gut - as the flesh is digested off. This 'hard' seed coat is not, generally, impermeable to water.

The degree of ripeness and hence the palatability of the fruit is advertised to the predator/vector by colour - the skin of the drupe is initially green and then turns orange and progresses through red to blue, purple or black - the fruits of several species (eg the European *V. opulus* and the Asiatic *V. betulifolium*) however remain red. As many species in this genus have an unusual dormancy mechanism, it is prudent to determine the sequential development of the colour of the fruit so that, if necessary, harvesting can be geared to a particular stage.

In most species the first sign of fruit maturation - indicating that the embryo has developed as far as it is going to and the seed has isolated from the parent - is when the fruit begins to turn orange. It is this stage which provides the first opportunity for the fruit to be harvested without detriment and so provide the earliest opportunity for extraction of the seed and its transfer into the necessary treatments to overcome the dormancy mechanisms.

The fruits should be hand picked - at the required stage - or before they are taken by birds. The berries are macerated, fermented in warm water for a few days, after which the water and dross is decanted off. The seeds can then be rinsed and cleaned and should not be allowed to dry further.

The mechanism of germination in *Viburnum* seeds is a more complex process than is found in most plants. In practice the seedlings of the cold temperate species do not usually germinate (emerge) until the second spring after an autumn dispersal. A characteristic usually associated with the need to degrade a hard seed coat before imbibition will occur and for germination to proceed. However in *Viburnum* the delay is usually caused by the time required (at a

suitable temperature) for the maturation of an underdeveloped embryo which then proceeds, without further check, into the germination phase to the stage of radicle emergence.

Subsequently the embryo exhibits an epicotyl dormancy which requires a period of chilling before germination can continue when temperatures are again suitable for growth. Thus the natural sequence of temperature regimes (seasons) and the time scales involved dictate the time of emergence. Depending on their local environment, the great majority of species from warm temperate climates do not require chilling.

When the seed has completed its development (to the dispersal stage) it has an 'underdeveloped linear embryo' which initially has to grow (mature both physiologically and morphologically) to the stage at which radicle development and emergence can occur. This phase is reached after a period of exposure to warmth (warm stratification) and takes place in two stages - a period to complete a physiological conditioning and then a period during which the embryo will develop morphologically to a level of maturity at which the radicle will develop. The radicle will then develop, provided that the temperature regime remains suitable and will normally emerge from the seed and potentially develop a root system.

The epicotyl/plumule, at the stage of radicle emergence, will also begin to develop but is arrested until the embryo has experienced a specific period of cold temperature and will then develop further only when temperatures rise and reach a particular threshold.

Under natural conditions this strategy means, in practice, that the seed does not germinate to complete emergence until the second spring after dispersal. This time scale can be foreshortened sufficiently for germination to be achieved in the first spring after dispersal if the fruits are collected well before they ripen.

The period necessary for the maturation of the underdeveloped embryo is not particularly extensive. Thus if the fruits are collected and the seeds are extracted at an early stage of fruit development (ie after the seed has reached the stage in its normal pattern of development and has become isolated from the parent) the seeds can be warm

stratified to mature the embryo. This maturation period will normally be between 56 and 84 days at 20°C - according to the particular species - and this will be sufficient to achieve the maturation of the embryo to the stage of radicle emergence. Because not many of the species have been assessed it will be prudent, in this range of time scale, to monitor the sample regularly so that when radicle emergence does occur the sample can then be transferred to the chilling regime.

The period required to mitigate the chilling requirement is also variable - according to the provenance of the species - in northern species it will be about 84 days at 3°C.

Subsequently germination will not occur until temperatures rise to a threshold temperature. Most species will respond most satisfactorily at c20°C. This implies that the chilling can overrun - as further development will not occur at low temperatures.

However those *Viburnum* species with a warm temperate or warmer distribution do not appear to exhibit an epicotyl dormancy condition - which requires a period of chilling (even at warmer temperatures) - as they will proceed to seedling emergence without chilling as long as temperatures remain above the threshold for normal growth patterns to proceed. There is however still a delay between radicle emergence and the emergence of the plumule - again this is species specific and can be as much as 42 days (*viz V. treleasii* - an endemic to the Azores). It would appear that there are no species (of these provenances) in which a chilling period is necessary before the warm period.

Some species have an extensive north-south distribution and the responses depend on the particular provenance of the sample. *V. dentatum*, for example, has a distribution from Massachusetts to Florida and east into Texas - in the north the requirements are conventional and the partially developed embryo requires chilling to achieve emergence - whereas the populations in Florida and Eastern Texas do not require a chill.

During the process of seed coat maturation, while the fruit is ripening, some species (eg *V. lantana*) will develop a hard seed coat, which although marginal and limited in degree, will need to be addressed. If, however the seed is collected at an early stage of fruit maturity (and then

warm stratified), this condition will be avoided and hence does not become an issue. The evolution of this condition presumably reflects the greater corrosive effect of the digestive processes experienced in the gut of the particular vector of the seed.

The seeds, when ready to sow (after chilling), already have an emerged radicle but are big enough to sow individually and this should be done with due care.

Aquifoliaceae

Ilex

The Hollies (***Ilex***) are a large genus of between 400 and 600 species. They have a world wide distribution but are found chiefly in the sub-tropics (where 300 or so of the species occur) and the tropics. This single genus is the only remaining representative of the Family ***Aquifoliaceae*** in the present day. The Family is very old and appears early on in the evolutionary Angiosperm tree. This fact is given credence by the structure of the seeds which, at dispersal, have only a rudimentary embryo of a primitive amorphous constitution.

The Family contains trees, shrubs and climbers and can be either evergreen or deciduous. The evergreen leaves are invariably glossy, long-lived and 'tough', the margins often serrated or with spines. The plants are dioecious. The flowers have four petals, are usually white and are small and inconspicuous, they are generally insect pollinated. The prominent fruits are drupes (usually described as berries) which have a highly coloured skin - red, yellow, brown, blue, purple or black and these contain usually four seeds, each with a very hard seed coat. The fruits of the temperate climate species usually mature during the winter.

Dispersal of the seeds is achieved by various animals who take the berries as a food resource. The chief vectors are birds (in the UK - Mistle Thrush, Fieldfare and Redwing - although not exclusively) they take them from the tree or bush but also rodents who pick up off the ground. This accounts for the hard seed coat condition which protects the seed in the passage through the gut; presumably in pre-history the vector had a strong digestive process which caused the development of the extreme nature of the condition of the seed coat. The berries are poisonous to humans but many animals are capable of dealing with or tolerating the toxins.

The Common Holly (*Ilex aquifolium*) has an extensive distribution in the Northern Hemisphere and is native from the western seaboard of Europe across Eurasia to China and also occurring in North Africa. It is the only species native to the British Isles.

There are some 30 or 40 species with a sufficiently hardy temperate climate provenance which are possibly suitable for cultivation in the UK. Some of the most commonly seen are:- the Chinese *I. cornuta*, the Japanese *I. crenata* and *I. latifolia*, the Inkberry - *I. glabra*, the American Holly - *I. opaca* and the deciduous *I. verticillata* all from East and Central North America.

Most of the literature, other posted comments and the perceived wisdom seem to give up on the controlled seed treatment and germination of holly seeds - indicating that there is little more to do other than sow the seed in an open ground seedbed, leave the elements and the seasons to do their stuff and wait for at least two or three years to get a partial germination at best!

However it would be possible to hasten the process and achieve a productive result if the nature of the problem is analysed and understood. Certainly the various contributory factors individually can require a lengthy resolution but the proposed treatments can each be reduced to the required minimum for the elimination of the particular constraint and then transferred to the next treatment in the correct succession without delay.

Holly species from temperate climates have three conditions which control the sequence of events to germination:-

- a) a very hard seed coat (which will have developed significantly when the fruit is mature),
- b) at the dispersal stage it still has an underdeveloped (immature) embryo which cannot be developed until the previous condition has been dealt with and imbibition is possible and
- c) when the embryo has been developed and matured it has an endogenous dormancy which will require a period of chilling to mitigate.

The following practical implications can be drawn from known experience and the available evidence:-

- a) collect the seeds as early as possible to reduce the level of hard seed coat development;
- b) extract the seeds from the unripe fruits;
- c) treat the sample with a 2% citric acid solution for 5 days;
- d) warm stratify (@20°C) for about 60 days - to continue to reduce this condition and reach water permeability and hence the pathway for imbibition.

e) continue the warm stratification of the now imbibed seed to mature the embryo (@ 20°C) to a level at which it is capable of germination - at dispersal the embryo consists of an amorphous aggregation of cells which have to develop to maturity both morphologically and physiologically - hence this period is relatively substantial - about 70 days.

(This warm stratification can effectively be merged into one treatment. This allows a routine to be established in order to monitor progress and ensure that moisture does not become limiting or that oxygen becomes deficient. Eventually when sufficient time has elapsed it will be necessary to make a regular assessment of the seeds by a cut test. This will provide an indication of the development of the embryo so that the end of the process can be recognised.)

f) once the stage of embryo maturity is reached it requires a chill to mitigate the endogenous embryo dormancy - a period of 90 days at 3°C is sufficient.

g) transfer to warm temperature (20°C) to achieve an enhancement of the rate of germination.

The Birch Family - *Betulaceae*

The Birch Family consists of six genera of deciduous trees and shrubs mainly occurring in the temperate climates of the Northern Hemisphere but with a couple of species (of Alders) being found down the Andes into the Southern Hemisphere. In general they are found as pioneer or early succession species in their various habitats and thus often depend for their success on developing symbiotic relationships. Some Birch species are adept at surviving in cold, hostile environments.

From the seed propagator's point of view many have evolved their reproductive strategies to be opportunistic and to take account of the various possibilities that the dispersed seed may encounter - so that more than one option may be available.

The Family is, currently, divided into two sub-families the ***Betuloideae*** (*Alnus* and *Betula*) and the ***Coryloideae*** (*Carpinus*, *Ostrya*, *Ostryopsis* and *Corylus*).

Betuloideae

This sub-family (*Alnus* and *Betula*) has developed similar seed germination strategies in both genera - this allows the seed to respond to the particular micro-environment into which it is dispersed at any particular time. Both genera also, being chiefly pioneer species, have developed symbiotic relationships to suit their particular environmental niches - many *Betula* species rely on mycorrhizal associations and *Alnus*, because of its adaptation to wet situations, has developed an association with the nitrogen fixing actinobacterium *Frankia* in root nodules.

Betula

The Birches (***Betula***) are an extensive genus of some fifty to one hundred species - depending on the taxonomic treatment of the genus. The genus has a circumpolar distribution in the Northern Hemisphere - ranging from the sub-arctic to virtually the subtropical (but there, at reasonably high elevations in more or less warm temperate situations). The species from temperate climates are mainly pioneer species and are relatively short lived.

Three species are native to the British Isles and the two tree types are commonly produced from seed - for specimen planting, as rootstocks for the ornamental variants and for silvicultural use. Many species with valuable ornamental characteristics, have been introduced to cultivation and are found extensively in Parks, Gardens and Arboreta in the UK. The ornamental value is in their usually medium size and lightweight structure of stems and leaves, the highly coloured bark and autumn foliage colours. There are specialist monographs on the genus which will validate the niceties of nomenclature.

Birch species tend to flower before foliage bud break and the flowers (the inflorescences are elongated, pendant and cone-like) are wind pollinated. The seeds of Birch are produced in cone-like structures described as strobiles. These mature in the late autumn when they dry out and break up while still on the tree. Thus the seeds are dispersed in the wind. Each tree flowers profusely at an early age and can produce very large quantities of seed. The seeds are small, lightweight and usually brown when mature and are winged. Seed collection is best achieved, therefore, just prior to the stage at which the strobiles begin to disintegrate. In practice it is possible to collect the cones when they are still greenish. These are spread out on a dry sheet in a shallow layer (to prevent overheating) and gently dried until they break up when rubbed. To some extent the seeds can be separated from much of the cone scale by fanning but the resultant sample will still contain a fair amount of debris; thus it is inevitable that making seed counts will be difficult and tedious.

The seeds do not retain good levels of viability for long and the seed is best processed and sown soon after collection. The seeds can be stored (in the short term) in an airtight container, at cool temperature, for several months without detriment.

The individual seeds are small and nut-like and the viability can be variable and difficult to assess. Hence in practice sowing the seed, plus the accompanying debris, is usually achieved by broadcasting it fairly thinly onto a seed tray so that the seedlings can be pricked off into plugs or suitable containers soon after germination. Thus growth is not constrained by a high seedling density - should it occur.

Although the seeds of Birch are normally dispersed in the autumn the seeds are often liberated sparingly over time during the early part of the winter and for various reasons may face a variety of environmental scenarios in terms of priming (the elimination of endogenous dormancy) to allow germination in the spring.

The successful germination of Birch seeds in nature is therefore governed by a number of alternative strategies - which the plant has derived to take account of the particular conditions which are experienced in the natural environment in which a particular individual seed is sited in that particular season. This reflects where the seed lands (*ie* the influence of shade), whether it imbibes relatively quickly and whether a sufficient chill occurs (the potential insulation effected by snow cover). Thus the imbibed seeds respond with the particular strategy which reflects the environmental conditions that the seed experiences - all, however, are organised to allow germination to occur in the Spring. The three factors which influence success therefore involve chilling, the presence/absence of an adequate light intensity and the provision of a high threshold germination temperature.

1. The autumn dispersal of seeds and the consequent exposure of the imbibed seed to chilling allows germination in the Spring without further intervention - hence if the imbibed seed is chilled artificially and then sown in controlled conditions and covered (*ie* with the exclusion of light) it is possible to achieve germination at conventional temperatures ($<15^{\circ}\text{C}$).

2. If the seeds are dispersed in the autumn, become covered and do not receive a sufficient chill then germination fails - however the seeds may well germinate when the soil temperature eventually exceeds 20°C .

3. If the seeds are dispersed to an area without shade and do not become covered then they will germinate at conventional temperatures without prior chilling (*ie* after an exposure to a sufficient period of an adequate light intensity).

It is probable that the temperature threshold for chilling will vary according to the parameters of the climate experienced by the species. Those species from northern provenances will require temperatures of around 3°C for a

period, this period is usually recommended as 84 days for the achievement of a satisfactory germination - although as little as 56 days has proved effective with some species. Those species from warm provenances appear to respond at temperatures as high as 7°C for as little as 28 days.

For a universal treatment it is probable that chilling the imbibed seeds for a period of 56 days at a temperature of 3°C, sowing the seeds onto damp compost in a seed tray, covering with grit and then providing a minimum temperature of 15°C will achieve germination in less than 30 days. As the viability is variable and the ability to make a reliable seed count is difficult, it is prudent to be prepared to prick off the seedlings very soon after germination especially if the density of seedlings is high. It is thus prudent to ensure that the germination medium is of a suitable consistency for the effective transfer without damage to the root system.

Birches are generally pioneer species and are often fairly heavily dependent on the development of mycorrhizal associations for successful growth rates. Thus it is sensible to inoculate the compost with suitable mycorrhizae or site the seedlings in a situation where spore rain could provide inoculation.

As befits pioneer species the rate of growth of seedlings in their first season of growth is relatively substantial - it is necessary to get some leaves into a good position for photosynthetic activity.

Ashburner, K and McAllister, H A (2013) **The Genus Betula**; Kew Publishing.

Alnus

The Alders (**Alnus**) are a, relatively, small genus of about thirty species of, chiefly deciduous, trees and shrubs which are distributed throughout the temperate climatic regions of the Northern Hemisphere but also occur down the Andes into Argentina. In general the species are adapted to growing in wet situations where they are often one of the pioneer woody plants. The Alders are not, in general, as decorative as the Birches but they produce good, strong green foliage which makes them eminently suitable for windbreaks and has the advantage that they are remarkably free of pests and diseases - especially those which affect

fruit trees - and hence they have value for protecting orchards.

The native Alder (*Alnus glutinosa*) is found prolifically along water courses and in wet places where it can develop into a substantially sized tree.

The male and female flowers are pendulous catkin-like structures which are produced separately on the same tree during the autumn but which do not open until just before, or at, bud break in the Spring and are then mainly pollinated by wind. The female flowers develop into the cone-like fruits known as strobiles which contain the seeds - unlike the strobiles of Birch, those of Alder are woody and the cones are retained on the tree where they open as they dry during the autumn. The seeds are shaken out by the wind and this can occur continuously throughout the winter. Alders tend to produce prolific seed crops from an early age. The strobiles remain on the tree for some time after seed dispersal.

The most effective way to collect the seed is to cut those branchlets carrying a heavy population of intact strobiles just before they open and then hang them up to dry - in a paper sack - in a warm, dry environment. With such treatment they will open readily and the seeds can then be shaken out into the bottom of the sack. As the cones do not break up the sample produced in this way is reasonably clean. Seed is produced prolifically and - as might be anticipated - usually has a fair amount of void seeds in the sample.

The seeds are small nut like structures with a small wing and when ready to be dispersed are red-brown in colour.

Alders have developed, effectively, the same strategies as the Birches for ensuring germination of at least some of the seeds in the Spring which, after dispersal, finds its way to the soil and becomes imbibed:-

1. Seeds, which have not been subject to exposure to cold but have been exposed to light, will germinate when temperatures reach 10°C however at this low level germination is slow, erratic and with only a small proportion of the sample responding; at higher temperatures the speed of germination increases, the emergence becomes more uniform and a greater proportion of the sample

responds. At temperatures above 20°C germination becomes commercially acceptable insofar as emergence is both rapid (c14 days) and reasonably synchronised, with a fair proportion of the seeds responding. Thus seed germination is delayed until the advent of suitable conditions for survival.

2. Seeds which have been covered or sufficiently shaded to prevent sufficient light accessing the seed will germinate when the soil temperature reaches 20°C or more.

3. If the seed is chilled by exposure to cold then subsequent germination at lower temperatures is improved - but most satisfactory results still come from temperatures at around 20°C when emergence levels show the best and most economic response. The period of chill and the threshold temperature are not fixed parameters as even relatively short periods of chill (eg 21 days at 5°C) will achieve some improvement in germination levels; however as the period of chill is increased and the threshold lowered to 2 to 3°C then responses improve dramatically - the most economically effective response appears to be 56 to 63 days at 3°C although longer periods will still exhibit some improvement. At this level of chill the subsequent temperature range at which improved emergence will occur becomes lower although the best results will still occur in the range 15 to 20°C.

Thus imbibition of the seed followed by 56 days stratification at 3°C and then germination at 18°C will usually cause emergence in 14+ days. This protocol seems to work well for the cold temperate species.

Those species which occur in warm temperate climate areas (eg *A. rhombifolia* and *A. rubra*) will respond to shorter periods of chill with higher threshold temperatures - however in the particular parts of their native habitats without cold winters, they are more likely to respond to the quick rise in soil temperatures in the spring - which can quickly reach 20°C in the early part of the year.

All *Alnus* species depend for their normal pattern of growth on developing a symbiotic relationship with the nitrogen fixing actinobacterium *Frankia*. This bacterium causes the development of large, easily visible, nodules on the roots of the tree. Care should be taken to ensure that the compost is suitably inoculated.

Seedling growth in the first season is usually substantial if space or nutrition is not limiting.

Coryloideae - the Hornbeams, Hop-Hornbeams and Hazel

The Hornbeams (***Carpinus***) and the Hop-Hornbeams (***Ostrya***) together with *Ostryopsis* and the Hazels (***Corylus***) make up the *Coryloideae* - one of the two sub-families of the family *Betulaceae*.

The first two genera are dealt with together here as the seed construction and treatment is similar in both genera. Both genera are deciduous and produce good autumn colour - usually in shades of yellow. The wood of both genera is heavy and hard and is sought after for a number of uses where durability and 'hardness' are needed.

Carpinus and Ostrya

The genus ***Carpinus*** contains some thirty species, of chiefly small deciduous trees, which occur across the Northern Hemisphere with the majority being native to China and Eastern Asia. *Carpinus betulus* (the European or Common Hornbeam) occurs widely in Europe including the British Isles; it is used as a hedging plant, for coppicing and for the production of rootstocks for grafting the many ornamental variants. Other species which are cultivated in the UK as ornamentals or as arboretum subjects include *C. caroliniana* from the Eastern United States, *C. japonica* from Japan and the very decorative *C. fangiana* from China which has only been introduced in the last twenty years or so.

The pendulous male and female catkins are produced separately on the tree during the early Spring and pollination is by wind. The more or less erect fruiting cluster is made up of several (10-30) nutlets each in a samara-like fruit with an asymmetrical wing. Each seed is 3 to 6mm long and has a hard seed coat when fully mature.

The genus ***Ostrya*** consists of eight or so species of small, deciduous trees which are native to Southern Europe, parts of Southern Asia and North America down into Central America. They generally produce a conical, sometimes spreading, crown and can become decorative trees for use in areas with limited space. The leaves are similar to Birch.

The male and female flowers are produced separately and are pendulous, catkin-like structures which are produced in the Spring and are wind pollinated. The fruits are usually towards the end of the branchlets and consist of an elongated, pendulous cluster of six to twenty seeds, each of which is a small nut (2 to 4mm long) enclosed in a samara type fruit - when green the whole cluster resembles the Hop fruit and thus gives it its common name. *Ostrya carpinifolia* from Southern Europe, the American *O. virginiana* and *O. japonica* from Japan will all succeed well in the UK. Other species may succeed in mild niches but generally are not successful otherwise.

Fruiting of all the species is generally prolific with each tree producing vast number of seeds every year - however as is common in such cases the number of void seeds is often considerable.

The fruiting clusters, of both of these genera, if collected whole when mature, will break up into individual seeds quite easily after marginal drying. The fruit is a nut encased in a samara - the wings of which are slightly twisted to increase the range of dispersal on the wind. The samaras are borne in clusters towards the tips of the branchlets, When they are ripe the clusters disintegrate and the individual fruits are dispersed in the late autumn (+/-November) by wind. The samaras are initially green then change to yellow and as they dry out become brown. At this stage the nut will have developed a hard case - which under natural conditions, in the soil, takes a summer season to degrade to a condition which will allow water to be imbibed. This strategy delays germination until the second spring after dispersal as the embryo also exhibits an endogenous dormancy condition which requires a period of chilling for mitigation.

Degrading the hard seed coat can be achieved by a warm stratification but the period required will depend on the degree to which the seed coat had dried. Separating the seeds from the fruits sufficiently to use a digestion process is too tedious. Thus the prudent option is to collect the seeds when they are still green to just changing to yellow and prevent any further drying - at this stage the seed coat will permit the passage of water and the seeds will imbibe and the chilling process can be undertaken straight away. If the seed has already advanced

into some degree of hardness then this can usually be dealt with by giving the seed a warm moist stratification (c20°C) for a month.

The chilling requirement, for those species which have a temperate distribution, is reasonably constant although, as might be anticipated for subjects which produce a hard seed coat the recommendations found in the literature vary considerably - largely, probably, because the seed coat has not been completely degraded at the beginning of the treatment. However experience and reliable sources would suggest that a period of 63 days at 3°C will usually be sufficient.

The seeds are big enough to handle and sow individually - however as the separation of viable seeds from the detritus and void seeds is not easy it is sensible to sow the seed broadcast onto a seed tray of suitable compost and cover with grit so that the seedlings can be lifted and potted on into a suitable container as soon after germination as is feasible.

Seeds of these species will germinate most satisfactorily at temperatures in the region of 20°C.

Corylus

This genus *Corylus* is a member of the Family *Betulaceae* and the sub-family *Coryloideae* and is thus closely allied to the hornbeams and hop-hornbeams but differs significantly in the size of the seed.

Corylus consists (depending on its taxonomic treatment) of about fifteen species of deciduous, small trees and shrubs. They occur in the temperate climates of the Northern Hemisphere through Europe, Asia and North America - some of the species are morphologically very similar and differ only in their distinct geographical distribution - thus they form discernible groups:-

- a) multi-stemmed shrubs with a leafy sheath to the nut - *C. avellana* (Southern Europe), *C. heterophylla* (Asia), *C. americana* (East and Central North America), *C. californica* (South West United States), *C. yunnanensis* (China);
- b) multi-stemmed shrubs with the leafy sheath much longer than the nut - the 'Beaked Hazels' - *C. cornuta* (North America), *C. sieboldiana* (Eastern Asia), *C. maxima* (Southeastern Europe), *C. colchica* (Caucasus);

c) single stemmed, small trees with a stiff and bristly sheath to the nut - *C. columna* (Western Asia), *C. jacquemontii* (The Himalayas), *C. chinensis* (Central Asia), *C. fargesii* (Western China), *C. wangii* (Southwestern China) and

d) multi-stemmed shrub with the nut enclosed in a fruit similar to a chestnut - *C. ferox* (syn *tibetica*) (Himalayas to Southwestern China).

The species are readily grown from seed. Seedlings of the relevant species may be required as rootstocks for grafting the decorative variants although these can be produced by layering which obviates any rootstock suckering problem. The Hazel Nuts, Cob Nuts and Filberts have a small but important niche in fruit production in the UK and for this purpose it is necessary to produce rootstocks for grafting the relevant varieties.

The Hazel Nut (*Corylus avellana*) is native to the UK and occurs widely in hedgerows and woodlands - it is often grown as a coppice to provide the flexible shoots which are used for basket making but also for use as pea sticks and stakes.

The various alien species can produce seed crops in the British Isles but the summer is often not warm enough to produce good enough crops every year to ensure the required supply. However supplies of reliably viable seed can be obtained from commercial sources although it will inevitably have been dried - which may have implications for the dormancy controls developed.

When suitable and adequate seed crops become available they can be collected in the autumn by picking up from the ground around the parents - however the critters also find them attractive and they generally disappear very quickly. Hence it is normal to pick the seeds before they become attractive to predators. Soundness of the seed is usually good although in some years weevil infestation can be significant - damaged seed can be separated by flotation. The seeds can usually be stored, after marginal drying, for two or three years at c3°C. However drying of the seed can cause the erratic development of dormancy conditions which will be reflected in the eventual germination success.

The fruits consist of a nut with a hard pericarp enclosed to some degree in an involucre which may be soft and leafy

or rigid and spiny. The removal of this involucre will be determined by the maturity of the seed at collection or dispersal - ie as it dries and separates from the nut.

To avoid difficult dormancy problems it is best to harvest the seeds in the 'half-brown' stage - which implies about August; at this time the embryo and food reserve has been completed and the pericarp is hardening and the involucre is just beginning to turn brown. At this stage neither the embryo nor the endosperm has developed any endogenous dormancy control. The seeds can thus be stored as collected without any further drying (ie under water conserving conditions) at 2-3°C for several weeks and then subjected to suitable temperatures for germination.

Seeds collected at maturity may have developed a sufficiently hard seed coat to prevent imbibition and will have begun to develop a chilling requirement - the degree of this can be variable and will probably need 84 days at 3°C before the condition is mitigated.

Germination of the seed is most prolific at around 20°C.

Cornaceae

Cornus

The Dogwoods (**Cornus**) are a relatively small genus of some thirty to sixty species. They are natives of the Northern Hemisphere chiefly in temperate climates - with a preponderance of species occurring in Eastern Asia. The divergence in the number of species cited indicates the uncertainties currently existing in the taxonomic opinions which determine the rank of many of the entities described. The number of species is broadly divided into four sub-genera (although this is also a matter of debate, as is the opinion that they constitute separate genera). All the species are more or less suitable for cultivation somewhere in the UK - although not necessarily producing fruit successfully or consistently - especially those from high light intensity, continental climate summers.

The four groupings (although there are some authorities which cite six) are:-

- a) **Benthamidia** is a small grouping which contains the species usually described as Flowering Dogwoods and includes *C. capitata*, *C. florida*, *C. kousa* and *C. nuttallii* - these are generally summer flowering, large shrubs to small trees, with conspicuous bracts subtending the flowers;
- b) **Chamaepericlymenum** consists of the two species of Dwarf cornels - *C. canadensis* and *C. suecica* - these are very similar to each other and are low growing, creeping, ground cover subshrubs;
- c) **Cornus** is a small group of species which are described as the Cornels - typified by the Cornelian Cherry (*C. mas*) and including *C. chinensis*, *C. officinalis* and *C. sessilis* - all with small yellow flowers produced in profusion during the late winter before the leaves and
- d) **Swida** contains the shrubby, sometimes creeping, dogwoods often with coloured bark, this is the largest grouping which includes *C. alba*, *C. sericea* (which includes *C. stolonifera*) and *C. sanguinea* as well as the alternate leaved, larger growing *C. alternifolia* and *C. controversa*.

The fruit, in this genus, is a one or two seeded fleshy drupe; the flesh of which contains an inhibitor to germination. In nature the pulp of this fruit is usually removed as the fruit is digested during passage through the gut of a bird. The seed is protected by a hard seed coat

which is sufficiently resistant to the digestive processes and so protects the seed tissues during this passage, but, as a result, the coat is sufficiently reduced to allow the pregermination processes to continue on expulsion - as water permeability is no longer impeded. When the seed is treated artificially to remove the pulp, the seed coat is not reduced by the digestive activity and in many species the seed coat remains impermeable to water. When dealing with mature fruits and seeds in which the seed coat is hardened, it will be necessary to degrade the condition for water permeability. This can be achieved by warm stratification, scarification or inorganic acid digestion.

Where it is feasible, it is therefore prudent to collect fruits well before the ripening process is complete - ie when they are just changing colour from green. The seeds can then be extracted and processed into the treatment protocol without allowing any drying to occur (which may induce development of a hard seed coat in some degree). It is unlikely that any significant seed coat impermeability will have developed by this stage.

Thus as a general rule of thumb - seeds, of any species in the genus *Cornus*,

- a) should be collected before the fruit is completely mature in order to avoid hard seed coat development;
- b) should be extracted from the fruits by maceration, fermentation, decanting the dross and washing the seeds thoroughly to remove all traces of the flesh;
- c) process into the chilling phase (84 days at 3°C) without delay and certainly avoid any drying as this may well cause hardening of the seed coat;
- d) germinate at reasonably warm temperature (c18°C)

Where only mature or stored seed is available, which has been extracted artificially, it is probable that some degree of warm stratification will be required to reduce the seed coat. This is especially true of the Cornels and Dwarf Cornels, which have a capacity to develop a hard seed coat of considerable effectiveness.

It would be prudent when dealing with the Cornels and Dwarf Cornels to i) harvest early and extract without allowing any further drying then ii) warm stratify the seeds for as much as 70 days before iii) transferring them to a chill of 3°C for 84 days; they can then be germinated with an acceptable level of productivity at 18 to 20°C.

C. capitata is from a warm temperate environment in the foothills of the Himalaya, it produces largish fleshy amorphous fruits - these are developed from the fusion of several drupes - so that they contain several seeds. The seeds are extracted by maceration of the fruits which are then allowed to ferment for a couple of days - after decanting the dross the seeds are washed to remove any traces of flesh. The seeds will then require a chill of 42 days at 3°C without delay - so that drying is avoided. The seeds will then germinate readily and prolifically at 20°C.

It would appear that all the species in the section *Swida* have the capacity to develop a hard seed coat in some degree - depending on the environment to which they are subjected and the generalised protocol suggested above should be used.

Alangium

This genus contains probably about twenty species of shrubs and small trees, which, principally, have a tropical and sub-tropical distribution. However several of the species have extremely extensive territories and, inevitably, are variable across this spectrum and there is, also, much debate about species determination. Two species have at least part of their provenance in temperate climates and are cultivated in the UK (albeit not commonly) - *Alangium chinense* which occurs from South East Asia to West Africa and *A. platanifolium* which is found from Eastern Asia to Russia and so both have an extensive geographical distribution as well. Neither is common in cultivation and it is difficult to identify each, with clarity, without experience and flowers and fruit. Although listed in nursery catalogues both of these species have probably been produced vegetatively (over generations) and it is doubtful if they produce seeds in cultivation in the UK.

The fruit is a drupe which contains a woody endocarp and this contains one seed. There is no evidence from the literature which suggests that there is any constraint to germination.

Davidiaceae

Taxonomically the genus *Davidia* has proved difficult to place satisfactorily - it has usually been assigned to the *Cornaceae*, sometimes to the *Nyssaceae* but often nowadays to its own Family (although not unanimously), the *Davidiaceae*.

Davidia

This (monotypic) genus of medium sized trees is prized for the prolific production of its spectacular flower bracts. It is a native of Yunnan in the South West of China and its introduction to cultivation is the stuff of horticultural legend. It has two variants which are sometimes regarded as separate species - on the basis that they have differing chromosome counts - however the only apparent significant difference morphologically is that one has pubescent leaves (*vilmoriniana*) and the other has leaves without hairs (*laeta*). The (variously called) **Dove Tree, Pocket Handkerchief Tree** or **Ghost Tree** (*Davidia involucrata*) is usually propagated from seed - despite its relatively complex dormancy control mechanisms.

The fruit of the *Davidia* is an oval to marginally pear shaped, drupaceous, fleshy structure usually about four centimetres long and three centimetres in diameter, with a longish slender stalk - about the size of a small walnut. It has a strong khaki coloured skin - covered in a pale purple bloom when fresh. It contains a multilocular (longitudinally radial), hard coated, ridged nut containing from two to five seeds.

The fruits should be collected when ripe (in the early autumn) although they will usually persist on the tree well after leaf fall into the winter. The nuts are extracted from the skin and fleshy part of the fruit by softening or macerating the pulp in a small amount of water and leaving it to ferment in a polythene bag for a couple of weeks in a warm place. The nuts can then be washed clean.

The nuts can be stored dry, in refrigerated conditions for several years and will retain high levels of viability.

Germination is initially inhibited by the presence of an extremely hard endocarp (the nut case). This must become sufficiently degraded to allow the seed to imbibe - for germination to proceed. The weak point in the structure of

the endocarp is at the suture causing the ridging on the nut, when this has been adequately reduced and the embryo has fully imbibed the power of the expanding radicle will force up the cap of the locule in a hinge like fashion. The only experience to date to achieve this action is to subject the nuts to a warm, moist stratification procedure. How long this will take is very variable but it will reasonably be assumed that the more effective the degrading process (endocarp decomposition) the quicker will imbibition occur. This process might well be accelerated by including a microbial compost activator in the stratification medium and the maintenance of a reasonably high temperature (20 to 25°C). It would therefore be prudent not to dry the nut after it has been extracted - avoiding any enhancement of its hardness - but to transfer it directly into the warm stratification treatment.

Radicle emergence will occur, without further treatment (so the stratification process should be monitored regularly to determine progress) once the embryo has imbibed; however the embryo is now constrained by an epicotyl dormancy condition which is mitigated by a period of chilling.

Before further treatment it would be prudent to separate the embryos with their emerged radicles from the fruit case - as the fruit contains from two to five seeds and all may well germinate at once.

The separated seedlings are now transferred to a cold temperature, to provide the necessary chill to allow the plumule to develop - when it is subsequently exposed to a warm temperature. The chilling process, when conducted under artificial conditions will require the seedlings to be extended in a suitable, moist medium.

There is little reliable evidence for the timing of the various periods of seed treatment. The warm stratification may well require 90 days to achieve imbibition and radicle emergence but this will depend on the degrading agencies provided and the temperature.

The chilling period has similarly not been critically determined but the local provenance of this species suggests that it would not exceed 63 days below 5°C.

Although the occurrence of several seeds in the one nut suggests that seedlings will emerge over several years,

under natural conditions - the object of the propagator will be to synchronise emergence as far as is possible and achieve maximum productivity.

The seedlings will develop when the fully chilled embryo is exposed to warm temperature (20°C) and, again, how long this process will take to emergence has not been the subject of critical observation.

Seedling growth in the maiden year (if germination is achieved in the Spring) is reasonable and seedlings of 50cm tall should be produced by leaf fall.

The required programme for achieving reproducible results will initially be developed by standardising a suitable recipe for the warm stratification medium and combining this with a standard temperature. Once this has been determined the length of the chilling period can then be assessed.

The blueprint for production will then be derived from the time required:-

- a) to harvest and clean the fruits,
- b) to warm stratify to radicle emergence,
- c) the chilling period and
- d) the period of warmth to plumule development.

The total period required, when progressing the process artificially, should permit emergence in the Spring following seed collection.

It may well be that an early collection of the fruits will arrest the development of the hard seed coat and immediate extraction and processing allow a much shorter time scale before radicle emergence.

Fagaceae

The Beech Family is a significant group (more than 900 species) of both evergreen and deciduous trees and shrubs. These are currently segregated into seven relevant genera - ***Castanea***, ***Castanopsis***, ***Chrysolepis***, ***Fagus***, ***Lithocarpus***, ***Quercus*** and the (relatively recently separated) monotypic genus ***Notholithocarpus*** (from *Lithocarpus*), there are three other monotypic genera - *Colombobalanus*, *Formanodendron* and *Trigonobalanus* (all three are, by some authorities, aggregated into the one genus *Trigonobalanus*) which are not dealt with here as they occur in the sub-tropics and tropics. The genus ***Nothofagus*** was included here but recent DNA assessment has shown it to be distinct and is now attributed to its own Family - the **Nothofagaceae**

The family has a wide distribution across the Northern Hemisphere but crosses the equator in South East Asia - where most of the species in this family are found. This tropical and subtropical area is the centre of distribution - so that relatively few species are found with a northerly occurrence in temperate climates. However, of those which have evolved and migrated to succeed in these climates, many are dominant in their respective habitats - eg *Fagus sylvatica*, *Castanea sativa* and many *Quercus* species.

Flower production is monoecious - the flowers are catkin-like and are produced in the spring. They are wind pollinated. Fruit production and dispersal usually takes one season but is sometimes eighteen months after pollination.

The nut-like seeds are carried in a fruit which is basically cup-shaped but which can be a spiny husk, which encloses the seeds completely - as in *Castanea* and *Chrysolepis* or which may be reduced to a scaly cup - as in *Lithocarpus* and *Quercus*. Each fruit contains from one seed, as is the norm in *Quercus*, to as many as seven.

The seeds usually have a rounded base which fits into the base of the cup of the fruit, they have a dry and protective skin when mature and are cylindrical to conical, sometimes laterally flattened (when there is more than one seed in a fruit) in shape and coming to a point at the apex. The linear embryo is situated at the apex with the radicle in the apex and the plumule below. There is no

endosperm and the food store of chiefly carbohydrates is in the cotyledons.

The chief problem with the collection and short term storage of the seeds is associated with water loss - viability declines rapidly with drying. The seeds should therefore be harvested as they are dispersed or picked just before dispersal and then cool stored under moisture conserving conditions. It is probably prudent to store the seeds in relatively small batches as large batches tend to heat up as a result of their ongoing metabolic activity.

The seeds generally are big enough to handle individually with some (especially the Chestnuts) being substantial in size. This facilitates sowing and allows them to be station sown. As has been indicated by the position of the embryo in the seed, the seeds can be readily sown with the correct polarity - so that seedling growth is not checked at emergence. Although it would seem logical to sow the seeds with the point underneath - so that the radicle emerges directly downwards this position seems to impair the quick emergence of the plumule and it is therefore best to sow the seeds on their sides sloping slightly downward towards the point so that both the radicle and the plumule emerge with equal success.

In general virtually the entire family requires mycorrhizal associations for an adequate and regular performance of the individual seedling.

The largest genus, with about six hundred of the species, is the Oaks (*Quercus*).

Quercus

The Oaks (***Quercus***) are a very large and diverse genus of, both deciduous and evergreen, trees and shrubs which encompass the size spectrum from small, low-growing plants at the tree-line (the evergreen *Quercus vacciniifolia* in the Sierra Nevada of California) to massive spreading subjects capable of living for several hundred years (the deciduous European *Q. petraea* and Californian *Q. lobata*). There are, currently, recognised about 600 species - which are distributed throughout virtually all climatic and geographic regions of the Northern Hemisphere (except the Arctic). Although probably more than half of the species are native to tropical and sub-tropical climates, there is

still a comprehensive range of species, with ornamental potential, which are found in temperate climates and many of these are suitable for growing in the British Isles.

As might be anticipated with a genus that contains so many species there is considerable diversity within the various characteristics, not least within the development, structure and production of the seeds and subsequently in the conditions necessary for seed germination.

Although the Oaks appear to be a relatively simple arrangement of species the picture just below the surface, at least for the taxonomists, is more complex. There are many groups of species which can develop considerable levels of genetic introgression but still represent, morphologically, a particular species. This is not an easily understood situation and for the propagator is only of concern for the specialist producer. Seeds should therefore be collected from single species stands as far from genetic pollution as possible.

The Oaks are part of the *Fagaceae* which also includes other genera with species occurring in temperate climates (*inter alia* - *Castanea*, *Chrysolepis*, *Fagus*, *Lithocarpus*) and which are of ornamental value in the various climates of the British Isles. In the case of Oaks the generic characteristic is to develop a single, nut-like, seed (acorn) which is carried in a cup (cupule), which may be stalked or sessile and, in general, is borne in an upright position on the terminal branchlets.

The genus ***Quercus*** is, initially, divided into two sub-genera:- a) *Quercus* - the larger proportion of species which would be recognised as Oaks in temperate climates and b) *Cyclobalanopsis* - the 'Ring-cupped' Oaks of Eastern and South-eastern Asia (c150 species) which occur chiefly in sub-tropical and tropical evergreen laurel forests. This latter group are characterised by a different cup structure which is made up of concrescent rings of scales and having the acorns produced in tightly packed clusters.

The sub-genus *Quercus* is sufficiently large to have sufficient distinctive characters to be divided into four or five sections:-

a) The White Oaks (section *Quercus*) range across the Northern Hemisphere through Europe, North Africa, Asia and North America. They have acorns which mature in six months

and taste sweet or slightly bitter; the acorn cup is smooth and hairless on the inside and the lobes of the leaves are more or less rounded and have no bristle points. The flowers have short styles. Virtually all the species here will hybridise with each other so that collecting seeds other than from dense single species stands will produce seedlings of doubtful authenticity. The two native Oak species in the British Isles will potentially hybridise with any of this group so that collection of alien White Oak species seed in the UK (or Northern Europe) is rendered unsuitable.

b) A further small group of White Oaks (section *Mesobalanus*) from Europe and Asia are typified by the Hungarian Oak (*Q. frainetto*) and the Canary Oak (*Q. canariensis*). They are distinguished by the flowers having long styles and the acorns having a bitter taste. Sometimes included in the previous section with which they will potentially hybridise successfully. This group will also hybridise with each other.

c) Another small group (section *Cerris*) from Europe and Asia is typified by the Turkey Oak (*Q. cerris*). In this group the acorns take 18 months to mature and have a very bitter taste. The inside of the cup is also without hairs. The leaves have acute lobe tips which have bristles at the tip.

d) A small and localised group of evergreen species from the South West of the USA and North Western Mexico (section *Protobalanus*) - is typified by the Canyon Live Oak (*Q. chrysolepis*). These species have short styles and the acorns mature in 18 months and taste very bitter. The inside of the acorn cup looks woolly. The leaves are, generally, evergreen and have acute lobe tips with bristles.

e) The Red Oaks (section *Lobatae*) are an American group of, both evergreen and deciduous, species occurring from Canada right down the Continent to the northern part of South America. The styles are long; the acorns take 18 months to mature and they taste very bitter; the whole nut is encased in a thin, papery skin. The inside of the cup looks woolly. The leaves have acute lobe tips with bristles. Although these may hybridise with one another they do not usually hybridise with White Oaks and so can usually be collected in the UK with more confidence.

The tropical and subtropical, sub-genus *Cyclobalanopsis* is entirely evergreen but does contain a few species hardy enough for cultivation in cold temperate climates -

occasionally good specimens of the Japanese *Q. acuta* and the Himalayan *Q. lamellosa* are found in favoured warmer situations in the UK - especially where late season frosts are infrequent. This group does not show any dormancy condition.

The acorn is normally dispersed in the autumn when the nut is separated from the cup either by the action of frost or strong winds. The nut is a well developed substantial structure which can, depending on the species, be as much as 30mm by 20mm and varies in shape from almost cylindrical through conical to nearly round - the base which sits in the cup is rounded and the apex more or less pointed. It consists of a hard pericarp enclosing the contents. The embryo sits at the pointed apical end with the radicle in the tip and the plumule vertically below it and the whole enclosed by two large fleshy cotyledons which contain the food reserve.

As the acorns mature the pericarp of the seed hardens and turns colour from green to brown. They can, however, be collected successfully from the tree when they are still just green when they can be chilled and/or germinated. The critical feature is to maintain the water status.

The food store consists chiefly of carbohydrates but also proteins and lipids and at dispersal the seed has a relatively high water content - up to 55 or 60% in White Oaks and usually about 15 to 20% in Red Oaks. Drying, as would be anticipated, leads to a deterioration in viability and consequently any storage should be conducted under water conserving conditions at low temperatures. Ideally White Oaks should be put into the germination process as soon as possible and only stored in the short term.

Acorns, being large seeds, are best not stored in bulk as they are likely to heat up as a result of normal metabolic activity and so should be kept in small units in all but the short term.

The White Oaks, in general, produce good crops of seed annually unless there are untoward weather conditions. They do not exhibit any dormancy controls and the germination process will normally commence straight away after the acorns are shed - if conditions are satisfactory. The radicle emerges fairly quickly but the plumule tends to delay until temperatures begin to rise in the spring.

The Red Oaks tend to produce good crops of seed intermittently and there can be several years between bumper crops. Crops in the intervening years are usually of poor quality and often have high levels of Weevil (*Curculio spp*) infestation. The acorns exhibit an endogenous embryo dormancy which requires a period of chilling for mitigation. The period of chilling varies from species to species depending on the climatic niche that they occupy. For species from the most northerly extremes the chilling period can be as much as 84 days to 56 days in the mid range and as little as 28 days for the more southerly; the threshold temperature for this activity appears to occur at around 5°C.

Acorns are relatively large seeds and they can very easily be station sown by hand. As would be expected, the quality of the seedlings will reflect the polarity of the seed as it is sown - ie it needs to be sown the 'right way up' so that the embryo is correctly oriented for maximum growth at emergence. This implies that the seeds are sown with the point down and the hilum scar upwards however as indicated above sowing on the side provides the best outcome. Ideally the seeds should be sown about an inch deep so that any drying of the seed is minimised and when the plumule emerges its base is immersed and provides some stability.

Oak seedlings generally produce, initially at least, a taproot system and it would be prudent to maintain this in the early stages of growth to achieve maximum development during the first season. Hence to avoid circling in the bottom of the pot or container it would be sensible to use a narrow, deep container which might also allow for air pruning at the base. At some subsequent stage it will probably be necessary to prune the tap root in order to encourage the development of a fibrous root system.

Acorns vary in size annually as a result of the climatic conditions during the preceding summer - particularly the level of light and temperature and this is reflected in the amount of food reserves made available to the seeds. The acorns from any one tree will also vary in size about a mean in any year. The following examples give an idea of the range of average seed counts per kilogram (taken at the season of seed dispersal):- *Q. cerris* - 320-350 (in 1975 which was a good summer - the seed size increased to 220), *Q. ilex* - 440-500, *Q. palustris* - c1,0000, *Q. petraea* -

280-300, *Q. robur* - 240-260, *Q. rubra* - 300-320 and *Q. suber* - 320-360.

Seedling growth in the first season is often limited - evergreen types often only making 15cm of stem height but some Red Oaks are more vigorous and will achieve 40 to 50cm.

Oaks will also need to make mycorrhizal associations - so this condition should be catered for at germination.

The chief setback to seedling growth, in temperate climates, can be the development of an infection by Oak Powdery Mildew (*Microsphaera quercina*) - which will effectively cause the cessation of growth for the season.

Lithocarpus

Lithocarpus is an extensive genus of evergreen 'Oaks' which are chiefly native to the tropical and subtropical laurel forests of South East Asia. However a few species occur in more northerly locations and these provide species which will grow in warm temperate climates. Many of the species are very decorative. Of the warm temperate species, several can be found growing reasonably well in collections in the warmer niches of the British Isles - particularly the Japanese *Lithocarpus edulis*, *L. henryi* from Central and South-western China and *L. pacyphyllus* from the Eastern Himalayas.

They produce seeds which are similar to an Oak acorn but which develop a woody shell. However seed production in the UK is often limited in quality and quantity by poor summer light and cool temperatures; it thus requires a 'good' summer for virtually any crop to be produced - despite adequate pollination. It should also be born in mind that the parent tree will need to be sufficiently well established and have reached a mature condition.

In common with all subjects in this family the seeds should not be allowed to dry out and must be kept under moisture conserving conditions to maintain best germinability. The seeds do not exhibit any dormancy controls and will germinate reasonably quickly when sown if the temperature is high enough (18+°C). The seeds can be sown individually in suitable containers - and with the correct polarity will

produce good quality seedlings. These will not be frost hardy when young.

Notholithocarpus

The monotypic genus (***Notholithocarpus densiflorus***) has been created to accommodate the Tan Oak from the West Coast of the United States - it was conventionally included in *Lithocarpus* although it was the only representative of this genus from outside Eastern Asia. Recent genetic and DNA investigation has indicated that it is not closely related to *Lithocarpus* or any other genus of the Family - it is probably closest to *Quercus* - and has therefore been given its own genus. It is a common and sometimes dominant tree in the forests of the Coastal Ranges across to the Sierra Nevada chiefly in California and Southern Oregon. It is capable of growing to more than thirty metres tall. Currently the populations are being decimated by the spread of the fungus disease 'Sudden Oak Death' (*Phytophthora ramorum*). It is an evergreen tree and the leaves are hard, tough and persistent with a covering, when young, of brown scurfy hairs.

It is a species which will succeed in the South of the UK and will fruit successfully. The fruits are very similar to the Oaks insofar as a single acorn type seed is produced in a cup - which is distinctly 'spiny'. The seed takes eighteen months to mature to dispersal. The acorn has a very hard woody shell.

If the seed does not dry significantly germination of fresh seed is relatively easy. The seeds are collected from the ground and are graded to take out the smallest and the empty or infested seed is removed by flotation. The seeds can be stored in the short term under water conserving conditions at low temperature.

For germination the seeds are fully imbibed and then sown when about half the seeds may emerge erratically and over a long period. A synchronised and rapid emergence will occur at high levels of productivity if the imbibed seeds are chilled for 56 days at 3°C and then germinated at 18 to 20°C when emergence will occur in about 21 days.

Castanea

The genus **Castanea** (the Sweet Chestnuts) contains eight or nine species of often substantially sized, deciduous trees and shrubs. They are native to the Northern Hemisphere with species of local importance in Europe, Asia and North America where they can be the climax vegetation in temperate deciduous woodland. Virtually all have significance as timber trees and the European *Castanea sativa* has been selected and cropped for its edible seeds.

The fruit has a spiny case (a 'burr') which encloses the seeds, this case splits at maturity to release the seeds - these can be picked up from the ground. Each fruit (in most species) may contain up to three seeds.

The seeds are relatively large and, generally, are variable in size - depending on the suitability of the season for food storage, the number of seeds which develop in the case, any inherent periodicity and other inherent genetic characteristics of the tree.

Depending on requirements, it would be prudent to grade the seeds as there is much evidence to show that bigger seeds produce bigger seedlings. As the seeds are large it would be useful to place the seeds in water so that 'floaters' can be eliminated - as these are likely to be non-viable.

The chief cause of subsequent poor performance will be the loss of water from the seed and this can have a detrimental effect as the food reserves are principally lipids and proteins. It is therefore necessary to store the seed under water conserving conditions or to process the sample into the chilling procedure as soon as is feasible after collection. The seeds are prone to surface infection by ascomycetic fungi and should therefore be surface sterilised (dilute hypochlorite) before storage - even at low temperatures.

The seed can be cold stored, under water conserving conditions, for several months - taking care to store in such a way that 'heating up' is avoided.

The imbibed viable seed has a variable chilling requirement (depending on the provenance of the sample) but is usually about 63 days at 3°C. Germination is most productive at 15-18°C. The main issue with successful treatment is to ensure

that these relatively large seeds do not come under any water stress as they tend to 'use' quite a bit of water. Thus the samples should be monitored regularly and the medium remoistened as necessary. The seeds can also chit a low temperatures so this regular monitoring should include assessing this feature and sowing as soon as this happens. (Do not mix seeds from different sources as they may have different chilling requirements).

Castanopsis

Castanopsis is a genus of evergreen trees and shrubs which is limited to Eastern Asia and is chiefly tropical and subtropical in its distribution. There are however a few species with a temperate provenance of which *C. cuspidata* from South Korea and southern Japan is most commonly seen in the UK.

The fruits are like a hard beechnut which contains one seed - which resembles an acorn but with three longitudinal ridges. These are shed from the split fruit case in the autumn. The seeds do not show any dormancy controls.

Fresh seed should be stored at cool temperatures under water conserving conditions in the short term and the imbibed seed germinated at 18-20°C when emergence should be synchronised and take in the order of 21 days.

Chrysolepis

This genus **Chrysolepis** (the Chinquapins) consists of only two species, both are evergreen - one growing to tree stature (c30m) and the other a small shrub. They are native to the West Coast of North America and were once included in the genus *Castanopsis*. They are distinguished by their simple, entire, linear leaves which have a dense layer of golden scales on the lower surface and which persist for three or four years.

The fruits are produced in dense, green, prickly cluster which mature to a light brown. The fruits consist of a cup like structure densely covered with spines which more or less encloses the seeds - like a chestnut, this contains three seeds.

Seeds take two seasons to mature before dispersal in the second autumn after a spring/summer pollination

Natural regeneration of both of these species from seed, throughout the natural range, is extremely sparse or even non-existent although there is prolific and often extensive regeneration over a large area from root sprouts. Success under artificial conditions is also very variable. The number of viable seeds in a sample rarely exceeds 50% and although these can be germinated quite easily - the survival rate subsequently is very low and it is possible that the seedlings may require to engage in a mycorrhizal association at an early stage. It also appears that pruning of the tap root is counterproductive.

The seeds do not exhibit any particular dormancy conditions and germinate when temperatures exceed c15°C.

Fagus

The Beeches consist of a genus (***Fagus***) of eight to ten species with a circumpolar distribution in the Northern Hemisphere and occur in temperate climatic areas. They are often dominant forest trees in their particular climatic and geographical areas viz - *F. sylvatica*, *F. orientalis* and *F. grandifolia* and are important timber trees. The following species are also seen in cultivation in the UK:- *F. crenata*, *F. engleriana*, *F. japonica* and *F. lucida*.

The beeches are the classically quoted example of periodic seed production, as they generally only produce substantial seed crops intermittently - usually between four and seven years. This production will depend on the quality of the summers and hence the quantity of stored food which is achieved.

Common Beech (*F. sylvatica*) will produce populations of seedlings with a relatively high proportion of coloured leaf seedlings if selected from parents with coloured leaves (ie shades of red and 'purple'). *F. sylvatica* is also grown in the UK for hedging and as rootstocks for grafting the wide spectrum of clonally reproduced variants.

The relatively inconspicuous flowers are produced at leaf bud break, are wind pollinated and the fruits mature by the same autumn. The fruit is a cupule and this encloses one to three (generally two) seeds. The seed is dispersed when this nut splits to liberate the seed. If the fruits are readily accessible, it is simplest to pick the nuts just

before they are ready to split and gently dry them to liberate the seeds - otherwise they can be picked from the ground before the critters get them. It is only worth collecting the seeds in good 'mast' years as the seeds in the 'off' years will be mostly empty and of low quality.

The seeds are pyramidal in shape about 10mm by 6mm at the base. Although beech seeds will withstand drying more than most of this Family, it will be prudent to maintain the water status and cool store them until required as there is inevitably loss of viability with drying.

The seeds have a dormancy which is mitigated by chilling - however there is no consistency to the duration of the period required. It is said that the variation between years and between samples can be as little as four weeks to a maximum of twenty weeks. As the chilling requirement appears to vary so significantly about the norm (which is postulated at nine weeks) the usual practice is to chill the seeds at 3°C until 10% of the radicles emerge and then transfer to conditions for germination.

The temperature for successful (ie synchronised and speedy) germination is relatively low (+/-15°C) - high temperature appears to hamper productivity significantly.

The seeds are big enough to handle individually and so can be station sown. Polarity does have an impact and the seeds should be sown on their side as the radicle is at the tip.

Hippocastanaceae

This small Family is another which is nowadays often included in the **Sapindaceae**, on the basis of DNA analysis and assessment, but debate, among taxonomists, continues as to whether it should remain as a separate entity. It contains three genera, **Aesculus** with a circumpolar distribution in the temperate climates of the Northern Hemisphere, **Billia** - from sub-tropical and tropical America and the Chinese, monotypic **Handeliodendron**; of these only **Aesculus** has a temperate distribution.

Aesculus

The most satisfactory practical and economic method of producing the species of the horse chestnuts and buckeyes (**Aesculus**), and their naturally occurring variants, is undoubtedly from seed. This production process should ensure normal and realistic growth patterns and the production of typically developing specimens - without any of the rootstock influences which can be encountered if grafting is employed.

Grafting should only be employed where the production of particular clonally propagated individuals is required. Reasonable experience has shown that the most satisfactory grafted plants will be produced by using a rootstock of a closely related species with similar growth patterns and rate of growth. Fortunately the wood in the hypocotyl/stem region of an **Aesculus** seedling is soft and even, cuts readily and makes an efficient union if the carpentry and environmental aspects are dealt with effectively.

The trees are characterised by their substantial compound palmate leaves. Mature trees produce an inflorescence which is an erect panicle described as a 'candle' - during late spring or early summer. The fruit is a largish capsule, which can be spiny, warty or smooth surfaced; it may contain up to three seeds which, if there is more than one in a capsule will have flattened sides. The capsules split into three, during the autumn, to release the seeds which fall to the ground. The seed coat is brown (different shades according to species) with the characteristic roundish pale scar like hilum.

The production of seedlings is a relatively uncomplicated procedure as none of the species develop any difficult or complex dormancy problems and the seeds are big enough to handle individually. The only technical issues involved are associated with maintaining the viability of the seed until it is sown and in the sowing process itself - to ensure the development of an acceptable proportion of vigorous, straight, upright seedlings.

Seeds of all the species mature in the late summer to autumn and are shed when the fruit capsule splits open and liberates the seed. The seeds can then be readily picked up from the ground.

Not all of the species experience sufficiently warm and bright enough summers in the UK to produce seeds with a fully developed food reserve. This condition, however, is often associated with young trees which are still growing vigorously and producing extensive vegetative growth - as the tree matures and annual growth rates decline more food can consequently be diverted into seed production.

The viability of all species is limited to a short term and under natural conditions rarely exceeds six to eight months.

At dispersal the seeds have a relatively high water content (about 50% on a fresh weight basis) and this internal moisture is conserved by the shiny, waxy surface coating present on the seed. However once this deteriorates the seed coat is not efficient at preventing water loss.

Food reserves in the seed are mainly of non-carbohydrate materials. These are chiefly fats, waxes and protein and when these lose water, by the drying out of the seed, they will not rehydrate successfully (because these substances are naturally water repellent). Thus the seeds cannot be reconstituted by re-wetting and this therefore makes these food materials unavailable to the embryo and dramatically influences the potential germination of the seed.

The first essential therefore in the successful production of a crop of seedlings is to collect the seed as soon as it is shed and maintain it under conditions which will reduce water loss to a minimum - ie maintain the water status as

at dispersal. In the short term this can be achieved by placing the seeds in a sealed polythene bag. However seeds of this size when kept in bulk will soon heat up and degenerate rapidly unless kept cool - hence the sample should be transferred to cold storage (3°C) as soon as possible. To prevent the potential for heat build up as a result of metabolic activity the seed would be best stored in small units.

Successful storage therefore is dependent on the collection of the seeds immediately they are shed, conserving their moisture content and transferring them quickly to cold temperature storage. Under these conditions useful viability will be maintained for six to nine months and usually for as much as a year. This scenario is dependent on understanding that these optimal storage conditions will only be effective in reducing the rate of degeneration on the initial viability of the sample when it enters the storage regime.

Before storing the seed it would be prudent to surface sterilise the seed with a mild antiseptic (such as hypochlorite) in order to prevent the development of fungi (especially Powdery Mildew) externally on the seed coat.

The most reliable guide to the internal viability of a sample of seed is shown by the condition of the external surface of the seed coat - while it still has a shiny and polished appearance viability is normally high - thus the internal reduction of viability is progressively associated with a loss of shine to a dull but still, taut appearance and then the development of a wrinkled seed coat. Internally the deterioration can be seen by cutting the seed in half and observing the level of the development of brown necrotic spots which become progressively more invasive until they can be seen within the embryo tissues.

Although many species require a short chill to break embryo dormancy this is normally provided by the above storage regime and seeds can be satisfactorily sown in the early Spring - if so required.

The seeds are normally sown in open ground seedbeds in the autumn. However the seeds of those species which germinate almost immediately - such as *A. californica*, which germinates normally and *A. parviflora*, which produces a radicle but has a marginal epicotyl dormancy - will need to

be provided with protection over the winter as the young shoots are not hardy.

If the seeds are variable in size (they usually are) it is as well to grade them so that the small sizes can be discarded or sown separately - as the size of the seed will govern the size (grade) of the ultimate seedling. If plenty of seed is available it would be as well to grade the seed before storage.

As the seeds are relatively large they can be individually station sown at a predetermined density with an expectation of maximum productivity. They can, of course, be sown individually in suitable sized containers.

The seeds will be sown at a density compatible with the expected size of the seedling and the productive use of the seedbed - large seeds (eg *A. californica*) at 15cm x 15cm (40/m²) and down to 7cm x 7cm (200/m²) for the small seeded types (eg *A. sylvatica*).

The depth of sowing should be sufficient to prevent the seed drying - even if the surface layer of soil dries out. Thus the seeds should be sown with at least their own depth of soil covering them.

Topping off the seedbed with a thin layer of grit helps to prevent drying of the sowing medium and mitigates any surface panning - as well as easing the removal of weeds.

Many species of trees which produce large nut-like seeds develop unsatisfactory seedlings if they are not sown with their correct polarity - ie 'the right way up'.

In those species of *Aesculus* which have been assessed the position in which the seed is sown can have a significant effect on the eventual size of the maiden seedling. Seeds sown with the hilum scar underneath produce seedlings with the earliest emergence and the straightest upright axis through the shoot, hypocotyl and initial tap root - by the end of the season these have developed into the tallest, most substantial, grade of seedlings.

Table 1

A trial to determine if the polarity/orientation of seeds of *A.x carnea* at sowing subsequently influenced the size and quality of the seedling.

Autumn sown 1976 - assessed at leaf fall 1977

Position of the hilum scar when sown	Total sown	Development of Straight	stem/hypocotyl Angled/bent
Scar on top	84	65 (76%)	20 (24%)
Scar underneath	112	110 (99%)*	2 (1%)
Scar to the side	134	124 (93%)	10 (7%)

* This group not only produced the 'straightest' seedlings on the root/hypocotyl/shoot axis but also developed a significantly greater stem and root length.

Horse Chestnuts and Buckeyes
- occurrence and potential for seed production in the UK

The genus consists of twelve to twenty species (depending on the taxonomic distinctions attributed to particular variations). It has a circumpolar distribution throughout the Northern Hemisphere in temperate climate regions.

The eastern American *A. glabra*, *A. octandra*, *A. pavia* and *A. sylvatica*, if collected from pure stands, develop true to type. They are best obtained from relevant sources in native stands and dispatched, by air, immediately. None of these set reliable seed crops in the UK largely because the summers are rarely hot and bright enough. However as more trees mature in British collections and summers 'improve' it is possible that local supplies may become more satisfactory. *A. glabra* has an extensive clinal distribution westward and at the farthest extreme is known as *A. arguta*.

Aesculus californica is a native of California in areas with hot, bright, dry summers but normally by water courses; it produces huge seeds and really does not consistently set satisfactory crops in the UK.

Similarly *A. parviflora*, which is from the mid western United States, experiences a continental type of climate and crucially flowers in late summer (August). It has only set satisfactory seeds in the UK in hot, late summers such as 1959 and 1975.

Aesculus indica, which has been in cultivation since 1851, is a not uncommon tree in Parks and the larger Gardens and generally sets seed regularly - although in dull summers the crops tend to be of poor size and quality. Its local relative - the Himalayan *A. assamica* was rarely encountered in cultivation but seed collections within the last forty years have been planted and although most are still 'young' (having been derived from these relatively recent introductions from the Himalayas) they are beginning to produce good crops of seed. Very similar to *A. assamica* (and taxonomically often lumped with it) is *A. wangii* from the other side of the Himalayas in southern China and Vietnam. This plant has only been introduced in very recent times and as yet has not reached a seed bearing maturity.

Of the Chinese species *A. chinensis* has been in cultivation for a long time but has rarely flourished - seed has sometimes been produced (at Kew) but this is not usual. However *A. wilsonii*, which has also been around for a hundred years, does produce good seed in quantity - at least in Cornwall. Both of these species are nowadays subsumed into a portmanteau *A. chinensis* by Chinese botanists who attribute a broad clinal variation in the wide geographic spectrum of distribution. Other Chinese species are little known and any trees in cultivation are very new.

The ubiquitous Horse Chestnut (*A. hippocastanum*) was introduced to the UK in the seventeenth century and is readily recognised, however its use as a rootstock for virtually all other grafted *Aesculus* has not proved the best option for successful mature tree development. Although satisfactory for its own variants, other hybrids and variants should be grafted onto much more closely related species which have similar and relevant growth patterns.

The Japanese *A. turbinata* is very similar in appearance to the European Horse Chestnut and is occasionally seen in cultivation. It has the largest leaves found in the genus. Some majestic trees can be found in cultivation - which produce seed freely.

The hybrid *A. x carnea* (*A. hippocastanum* x *A. pavia*) is (unusually) tetraploid, it develops viable seed and

produces offspring which are effectively identical to the parent. It sets seed, often prolifically, in the UK.

Aesculus parryi (from northern Mexico) is probably not in cultivation in the UK and in any case would be unlikely to set good seed even in a hot summer.

Nothofagaceae

This Family was created, as a result of modern DNA assessments, to house the genus *Nothofagus* when it was deemed not to fit in the *Fagaceae*.

Nothofagus

This genus of the 'Southern Beeches' is limited to the Southern Hemisphere in South America and Australasia. It contains about 38 species of trees and shrubs - many of which are subtropical or tropical. Species suitable for cultivation in temperate climates are more or less limited to those which are native to Chile and Argentina and New Zealand. Some of the species from the furthest south of South America are extremely hardy and have been successful as far north as the Faroe Islands. W Arnold Foster (1950) in his 'Trees and shrubs for the milder Counties', which was compiled on experiences of the twenties and thirties, eulogised this genus - but they did not really 'catch on'; However there was resurgence of interest in the seventies when the Forestry Commission started to promote certain South American species for quick growing timber production.

They are, in general, tall, forest trees with single stems and an upright habit. They are chiefly evergreen but some are deciduous; they have a light, airy, ornamental and elegant structure and the deciduous species have good autumn colour.

The following species have a temperate distribution and can be grown in the UK, albeit the species from New Zealand are not as hardy as those from South America:- from South America - chiefly the temperate rainforests of Southern Argentina and Chile - *N. antarctica*, *N. betuloides*, *N. dombeyi*, *N. nitida*, *N. obliqua*, *N. procera* (*N. alpina*) and *N. pumilio*; from the temperate rainforests of New Zealand - *N. fusca*, *N. menziesii*, *N. solandri solandri*, *N. solandri cliffortoides* and *N. truncata*; from Tasmania - *N. cunninghamii*.

The fruit is a nut (cupule) which is not dissimilar to beech, which when mature - in the autumn - splits, while still on the tree, to release the seeds; there are between 2 and 7 seeds in a cupule - the end two are three angled and the middle nuts are 'flat'.

The seeds are just big enough to handle and can be picked up from the ground but are more conveniently picked just before the release stage and then gently dried - when the nuts will open readily and the seeds separate. In common with many of such seeds the food storage material will deteriorate if they are dried - hence the seeds should be collected as soon as is feasible and then cold stored at low temperature under water conserving conditions. Viability, in the short term, is usually good and normally exceeds 90%.

The seeds of the great majority of temperate species exhibit a simple cold temperature dormancy control. The period of chilling for each species can be quite different and the threshold temperature will depend on the provenance of the sample, as many - especially the South American species - have an extensive north-south distribution.

As a general rule all the temperate species can be chilled at 3°C for 70 days - this will cover all and those species with a lesser requirement are not harmed by an attenuated treatment.

Germination is prolific at 20°C and will often occur in as little as 14 days. Seedlings will usually develop quickly and make 50 to 60cm in height in the first season.

Nyssaceae

This small Family has been constituted, as a result of modern DNA determinations, to contain, *inter alia*, the two genera - **Nyssa** and **Camptotheca** - these genera had been previously included in the **Cornaceae**; the Family **Davidaceae** was also created, and separated from the **Cornaceae**, to house **Davidia** - which however is sometimes attributed here.

Nyssa

This small genus contains about three species of deciduous trees and large shrubs, which have potential ornamental value for use in temperate climate areas and are reasonably commonly seen in cultivation. Five species - **N. aquatica**, **N. biflora**, **N. ogeche**, **N. sylvatica** and **N. ursina** are native within Eastern North America and four species - **N. leptophylla**, **N. sessiliflora**, **N. sinensis** and **N. yunnanensis** are all native to milder parts of China. Virtually all the species are found in damp or aquatic habitats.

Their ornamental value lies in the 'guaranteed' autumnal hues which usually finally (after passing through other colours) become a brilliant scarlet. In general all the species produce a tap root and are difficult to transplant and establish - as a result of disturbing this feature - hence they should be planted at a small size and initially grown in suitably configured containers.

The flowers are small, inconspicuous and greenish white - in clusters on a long stalk in late spring (usually about bud break) - they provide excellent honey forage. The flowers are unisexual and generally the plants are monoecious but are usually functionally dioecious, same sex flowers making up the cluster - usually the female flowers are individually larger.

The fruit is a smallish one-seeded drupe with an astringent flesh. It is nominally oblong in shape and thin fleshed. It contains a linear, ridged 'stone' or 'pit'. The skin is, typically, basically black but in the case of **N. ogeche** is red. The fruits are taken by birds.

The seed ('stone' or 'pit') is long and narrowish with a reasonably substantial, brown, ridged (in some degree) surface. The embryo is large and linear and sits in an oily

endosperm. Hence storage is only suitable in the short term - under water conserving conditions.

The seeds are separated, fairly readily, from the fruit by maceration and floating the skin and flesh away in running water.

N. sylvatica (the Black Tupelo) - can develop into a tree to 30m - with a single dominant upright trunk with the branches produced stiffly at right angles to the trunk. The leaves are generally oval - but can be variable about this shape. The species has an extensive geographic distribution, in Eastern North America, from New England south to Florida and from the eastern seaboard across to southern Ontario and Eastern Texas.

The fruits develop on the end of the long stalk - up to three but more commonly one from each flower cluster. They are about 15mm long and round to oval in shape; the skin is blue-black when ripe with an astringent flesh. The seed is a ridged stone about 10-12 mm long, brown in colour.

The Swamp Tupelo (*N. biflora*) grows in swamps and flood plains and is often under water at times of inundation - it is sometimes regarded as a sub-species of *N. sylvatica*. It has a trunk which is swollen at the base and which tapers ultimately to 20m+. The fruits have a purplish-blue coloured skin and the seeds are slightly larger than those of *N. sylvatica* and have more prominent longitudinal ridges.

The seeds of both these entities will germinate without treatment but *N. sylvatica*, with its extensive north-south distribution, will germinate with better synchronisation and greater numbers at emergence if seeds from northern populations are chilled for 60 days at 3°C; seeds collected from the mid-range populations will benefit from a 30 day chill.

Nyssa aquatica, the Water Tupelo, occurs in wetland areas in the Southeastern United States. The trees are tall and single trunked - they develop a swollen bole. It flowers (the trees are functionally dioecious) at bud-break and the fruit, which is produced in early autumn, is tear drop shaped about 25mm long, initially purple but ripening off to blue-black. The stone is deeply grooved. The seeds will

germinate without pre-treatment but emergence is enhanced if they are chilled for 30 days at 5°C.

Nyssa sinensis, the Chinese Tupelo, also occurs in damp conditions and is native to Southern China and Vietnam. It is a small, single boled tree to 10m or so. The young leaves are red throughout the growing season. Autumnal colours are brilliant. There are no constraints to germination - which will be rapid at 20°C+.

Camptotheca

This small genus of only two species - of which only one (*C. acuminata*) appears to be in cultivation - is a native of Southern China through to Tibet. It thus has an extensive geographical and hence climatic range. In cultivation in the UK it is only suitable for planting in the mildest niches but this is probably associated with the provenance of the original seedlings and thus selections from cooler provenances may prove hardier.

It is a deciduous tree to 20m tall with the young leaves appearing red - which continues while new material is produced. Interest, currently, in this species is high because it produces a phytochemical - camptothecin - which appears to have useful properties in the treatment of some cancers.

The globular aggregations of insignificant white flowers are produced in early summer and give way to eye-catching globular clusters of elongated pale skinned, one seeded drupes.

Extraction is the same as for *Nyssa* and although the seeds will germinate without pre-treatment they appear to benefit from a short (30 day) chill at 5°C; before germination at 20°C+.

Rosaceae (1)
Malineae
(Genera of the Rosaceae with Pome Fruits)

This group of genera from the **Rosaceae** all produce pome fruits ie fleshy (in some degree) fruits with a 'core' (ie like an apple) which contains 2 to 5 carpels - these contain the seeds.

The section *Malineae* occurs principally through the cold temperate regions of the Northern Hemisphere (but with a few southern outliers) and includes the following genera which could be found in cultivation in the UK:- **Amelanchier** - Snowy Mespilus, **Aria** - Whitebeams, **Aronia** - Chokeberries, **Chamaemespilus**, **Chaenomeles** - Japonicas, **Cormus** - Service Tree, **Cotoneaster**, **Crataegus** - Thorns, **Cydonia** - Quinces, **Docynia**, **Eriobotrya** - Loquat, **Heteromeles** - Toyon, **Malus** - Apples, **Mespilus** - Medlar, **Osteomeles**, **Photinia**, **Pyracantha** - Firethorns, **Pyrus** - Pears, **Raphiolepis**, **Sorbus** - Rowans, **Stransvaesia**, and **Torminaria** - Wild Service Tree

This particular group of the *Rosaceae* is characterised by a base chromosome number of 17 (as opposed to the more normal 7, 8 or 9) and represent a particular evolutionary group which expresses many features in common. In several genera the 'vegetative' production of seeds (a process described as apomixis or agamospermy) is not an uncommon occurrence - especially in *Amelanchier*, *Aria*, *Cotoneaster*, *Crataegus*, *Malus* and *Sorbus*.

The individuals of many of the diploid species exhibit self incompatibility in the pollination/fertilisation process and therefore need another individual of distinct genetic complement from the same species (ie not the same clone) to achieve seed production. Apomictic development of seed also often requires the presence of distinct pollen on the stigma to initiate and stimulate the development of the seed.

The main logistical issue, when dealing with this group of plants, is extracting the seeds from the sometimes not inconsiderable amount of the fleshy fruit which surrounds them. This development of a fleshy fruit is part of the strategy associated with seed dispersal. The fruits are attractive to various animals and birds and indeed there is evidence that the passage of the seed through the digestive tract reduces the seed coat and so makes it more readily

permeable to water, the thick seed coat having evolved to be coarser initially to protect it through the digestive tract ie it is not part of a strategy to spread germination through time.

In those species which have fruits with large quantities of flesh, it is sensible to reduce the fruit down to the core by paring away the flesh before attempting to extract the seeds.

It would also be prudent to collect the fruits before they become overly ripe to avoid them being taken by the predators (vectors). However it is also evident that, in some species, the flesh develops significant quantities of chemical germination inhibitors as it ripens and that these chemicals will contaminate the seeds. If they are not removed they will cause the chilling period to be attenuated and so confuse any established time scale within a protocol.

The pared down fruits or the complete fruits of the smaller fruited species are macerated to break up the flesh and tissue but not sufficiently to damage the individual seeds. This pulp is then mixed with a relevant volume of warm water and left to ferment in a warm environment. This will cause the flesh to break down and the seeds will fall to the bottom of the container - a period that will take several days. The scum and detritus can be decanted off and the seeds collected and rinsed until they are clean - if there is still some pieces of flesh, skin etc mixed with the seeds this can be separated by swirling them in clean water and separating the seeds from the fruit remains.

It is prudent, at this stage - if there is no hindrance from the seed coat and the embryo is imbibed, to proceed directly into the cold stratification treatment - as drying the seeds, more often than not, induces the development of a degree of hard-seededness. A short period of warm moist storage however is not detrimental.

However there are a considerable number of species in which there is a sufficiently developed 'hard' seed coat to prevent an immediate imbibition. For these species it would be sensible to collect the fruits and extract the seeds at an early stage - preferably at, or just before, the time that the fruits are beginning to change colour from green. Most of the relevant genera belong to the *Crataegeae* as

opposed to the *Maleae* (in which the seeds are 'pips') with a relatively soft seed coat but which nevertheless can harden if dried.

If the seed has been dried (or has been harvested after the development of the hard seed coat condition) it is quite possible that it will have developed a sufficiently hard seed coat that it will prevent imbibition. Subjecting the seed to a mild scarification regime will usually overcome the problem. The seeds can then be imbibed.

The chilling requirement within this group can be very variable not just between the genera but also between species - according to their evolutionary position. In many 'primitive' species the presence of inhibitor is only in the endosperm - demonstrable by the fact that excised embryos will germinate without chilling - more evolutionarily advanced species have developed endogenous embryo dormancy.

The great majority of the species, which have an endogenous dormancy, require a significant period of chilling - in the order of 60 to 84 days below 3°C - this is especially true of those species from northerly (colder) latitudes; areas with continental winter climates and higher elevations in warmer areas. Any period of chilling which requires significantly more than 84 days suggests that there is some other factor complicating the process - possibly a hard seed coat which delays imbibition and hence the beginning of chilling or the presence of inhibitors derived from the fruit which have not been fully eliminated prior to chilling.

Particular and relevant characteristics of individual genera and species relating to their propagation by seed.

The various Quinces and Medlars (*Chaenomeles*, *Cydonia*, *Mespilus*) have a hard flesh until well on into the ripening season. This requires considerable effort to pare away and it will be practical to leave the fruits to ripen until the flesh softens. By this stage there may well be a build up of inhibitor and so care should be taken to clean and rinse the seeds to remove this factor. The amount of chilling required is, in most species, in the order of 84 days below 3°C.

Seeds of plants in the *Crataegeae* have a seed coat with a nut-like, somewhat woody structure - eg ***Crataegus***, and ***Cotoneaster*** and will probably best be dealt with by collecting the seed when the fruit is immature (ie the fruit is still green and has not developed any colour) at this stage the seed coat has not fully developed the 'woody' or 'tough' consistency. Then extract the seeds from the fruit but do not allow them to dry out.

Crataegus and *Cotoneaster* are stratified for 84 days at 3°C.

Heteromeles arbutifolia (which occupies a warm temperate niche) seeds are virtually non-dormant but germination may be delayed by a marginally tough seed coat (which is a protective device against digestion when the fruits are taken by birds) but a short warm water soak is usually enough to cause permeability. As the plant does not flower until after mid-summer it is important not to harvest the berries until they are fully ripe as the embryo and food reserve are not fully developed and matured until well into the late autumn. A short stratification of 21 days at less than 7°C will speed and synchronise germination. ***Osteomeles*** (also from warmer provenances) has a hard seed coat but this is readily overcome by a reasonably prolonged warm water soak.

Pyrus is an example of a genus exhibiting an endogenous dormancy condition in which there is a wide spectrum of chilling requirement. The genus (which contains deciduous and semi-evergreen species) occurs from the sub-arctic to the sub-tropical. The chilling requirement thus is directly related to the severity of the temperature of the winter climate experienced by a particular species. Species from northerly latitudes (eg *P. betulifolius* and *P. ussuriensis*) tend to experience severe winter conditions and exhibit conventional chilling requirement of 84 days at 3°C. Species from milder climates (eg *P. amygdaliformis*, *P. calleryana* and *P. koehnii*) respond below 7°C and will generally need 63 days of exposure. Species from warmer climates (*P. pashia*) need only a chill below 10°C for around 35 to 42 days. After stratification the seeds of all species should be transferred to at least 15°C to achieve a rapid and synchronised germination.

The genus ***Aria*** contains a relatively large number of apomictic, so-called, micro-species which often have a very

local geographic distribution eg *A. devoniensis* - French Hales - in West Devon and East Cornwall and *A. bristoliensis* in the Cheddar Gorge. Understanding the parameters of these microspecies is a difficult task and expert advice should be sought on the correct naming of each individual and its provenance.

There are also a significant number of apomictic microspecies among the Himalayan species of ***Sorbus*** - however these appear to be more clearly defined. The advantage with all of these species is that they do come true from seed - they are effectively clones.

The individuals of the diploid species of ***Sorbus*** are mostly self incompatible and have a high tendency to hybridise if the opportunity is provided. This is as much true of the native *S. aucuparia* as it is of the exotic species. The chilling requirement of the cold temperate species of *Sorbus* is fairly typical ie in the order of 84 days below 3°C but those from milder climates will probably respond at higher threshold temperatures and for shorter periods (eg *S. harroviana*).

Most ***Malus*** species are individually self incompatible and require a distinct (separate genotype) pollen source to induce fertilisation - hence there is a high possibility of hybridisation if the opportunity is provided. Care should therefore be exercised in selecting parents for seed propagation in order to ensure 'trueness-to-type' - unless hybrid offspring are sought.

The recommendations for stratification vary dramatically, from reference to reference, in terms of the length of the chilling period required to eliminate the dormancy condition for *Malus* species. Virtually all appear to respond most satisfactorily at or below 3°C and although periods of exposure for as much as 120 days (or even longer) are cited - satisfactory germination is usually achieved with an 84 day period - provided that the seed is not contaminated with inhibitor and that imbibition was effectively completed prior to the commencement of treatment. To avoid the impact of 'external' inhibitor, the fruits should be collected at an immature stage (before the development of the inhibitor) and the seed extracted just as it is complete and effectively isolated from the parent - or if the ripe fruit only is available then the extracted seeds should be thoroughly soaked, washed and rinsed to

remove any polluting inhibitor. If fresh seed is available then there should be little or no effect of the seed coat on imbibition, however sometimes when seed is dried there can be the development of a sufficiently hard seed coat to impair imbibition - this can be treated by a mild scarification.

The following two genera produce relatively small sized seeds which resemble the pips of *Sorbus*.

The genus ***Amelanchier*** (probably of about 20 species), described as the Snowy Mespilus in Europe, produces good fruit crops in the UK - and these contain acceptable quantities of seed. However in *Amelanchier* the species are very close to one another both physically and genetically which causes confusion with naming - taxonomists recognising as few as 6 or 8 species or as many as 33! If grown together the species hybridise readily. It is therefore important to collect fruits from isolated individuals or where groups of the same species are planted together. Some of the species and hybrids (*A. x lamarckii*) are apomictic and this, as in other related genera, tends to create confusion.

The genus is native to the Northern Hemisphere - typically in the United States and Canada, there are two Chinese species (*A. asiatica* and *A. sinica*) and one European (*A. ovalis*). The generalised name for the species in North America (where they occur in all the States except Hawaii) is Shadbush. They are ornamental shrubs or small trees with spectacular and prolific flowering in the spring and often exhibit brilliant autumnal hues - especially reds.

The fruits, which are small fleshy pomes, are edible and are harvested locally and used to make pies and jams - one species is used to flavour Pemmican.

Because some of the species develop hard seed coats it is prudent to collect the fruits at an immature stage before any such condition has become advanced. The fruits should be macerated and fermented to extract the seeds. As many of the species also produce their fruits early in the year (more than one species is sometimes referred to as Juneberry) it means that season of collection will be relatively early in the year.

Assuming that there is no problem created by a hard seed coat then the only germination pre-treatment required is chilling - for the northern species a period of 84 days at 3°C is adequate but for more southerly species it is not clear what the requirements are. Germination in some northern species will occur below 5°C ie beneath snow melt but in nursery practice the most uniform results are obtained by germinating at 20°C. Hard seed coat conditions do develop in a few species (*A. canadensis*) and can be satisfactorily treated by scarification.

Aronia is a small genus of three species (*A. arbutifolia*, *A. melanocarpa* & *A. prunifolia*) of low growing, suckering, shrubs of moist soil conditions from Eastern North America. They are extremely decorative in the autumn with their vivid fall colours (which are not dependent on an acid soil for their expression) and highly coloured fruits. Their common name - the chokeberries - refers to the edible fruits which are astringent to the taste in the raw state. The fruits are now recognised for their medicinal value insofar as they contain high levels of valuable antioxidants.

The fruits, which are generally produced prolifically in the UK, are small fleshy pomes which are produced in erect clusters during the late summer and autumn. The fruits of *A. arbutifolia* and *A. prunifolia* persist well into the winter and are eventually taken by birds while those of *A. melanocarpa* drop very soon after ripening. It is just as well to collect the fruits early in the autumn and extract the seeds before there is any possibility that inhibitors developed in the ripening flesh can become significant. The fruit contains five carpels but in practice only two or three develop into mature seeds - the remainder appear as aborted 'chat' seeds. The seeds are extracted by macerating the fruits and leaving them for about forty eight hours to ferment - further agitation will see the seeds drop to the bottom and the detritus and scum can be decanted off - the seeds can be cleaned of remaining skin and flesh by successively swirling the seeds in water and pouring off the detritus. The clean seed sample can then be air dried to dry the surface. The seeds can be stored in the short term by maintaining the water status and maintaining a warm temperature. Germination is delayed by an endogenous embryo dormancy. In the case of *A. arbutifolia* this control is the deepest and will require stratification for 84 days at

below 3°C. The other two species will require in the region of 56 days.

Rosaceae (2)
Amygdalae
(The Stone Fruits)

This large group of woody plants (currently designated at about 430 species) has proved difficult for the taxonomists to delineate with any certainty - even in this DNA age - and currently they are all attributed to the one genus ***Prunus***.

They are natives of the Northern Hemisphere with a distribution through the temperate zones but they also occur in the warmer climates of Central and South America and Africa. The Cherries predominate in the species distribution in Eastern Asia and North America while the Plums and Peaches are chiefly from Western Asia and Europe.

They vary from prostrate shrubs to medium sized trees; although mainly deciduous, there are several evergreen species. Most flower in the spring often before leaf bud break. The fruit is a fleshy (generally edible) drupe (a prune) which contains a single, hard coated seed which is described as a 'stone' or 'pit'. Many species have been developed and selected from ancient times as edible fruit crops - especially in Europe and Asia. Others have been used, selected and bred as ornamentals - eg the Sato Zakura Cherries of Japan.

The genus ***Prunus***, if determined to be one genus, contains in the region of 430 species and is generally divided into the following sub-genera:-

Amygdalus - the Almonds and Peaches;

deciduous;

single flowers;

fruit is grooved on one side;

stone is deeply grooved.

Prunus - the Plums and Apricots;

deciduous;

lack terminal bud,

many flowers per bud;

fruit is grooved on one side;

stone is rough.

Cerasus - all the Cherries;

deciduous;

inflorescence an umbel;

fruit is not grooved;

stone is smooth;

axillary buds are single.

Lithocerasus - the Sand Cherry (*P. pumila*)

as above but

axillary buds are in threes.

Padus - the Bird Cherries;

deciduous;

racemose inflorescence;

fruit is not grooved;

stone is smooth.

Laurocerasus - the Cherry Laurels;

evergreen;

racemose inflorescence;

fruit is not grooved;

stone is smooth.

The fruit should be collected when it is fully ripe - ie when the flesh is softening. The stones are extracted by hand or by maceration and fermentation - depending on individual size and quantity. Subsequently the 'stones' should be thoroughly cleaned to remove all flesh as there is the possibility that germination inhibitors may occur in the flesh. The seeds should not be allowed to dry (or surface dry only if to be stored). The seed coat (endocarp) is hard - this condition is to provide protection for the seed in the passage through the gut of frugivorous birds and mammals which eat the fruit and so disperse the seeds. However this hard seed coat is not normally impermeable to water - but it can become impermeable if dried and the condition can then be difficult to overcome.

Seed treatment will begin with a warm water soak for 48 hours and in most cases this will achieve imbibition. The seeds should then be warm stratified; this is a necessity and is beneficial insofar as it appears to cause the maturation of an otherwise imbibed, morphologically mature embryo - 28 days at 20°C would appear to exceed the requirements of those species which have been observed, thus this could be used as a standard treatment in a protocol.

Most of the temperate species then exhibit an endogenous physiological dormancy which is mitigated by chilling. However the constraint does not appear to be in the embryo insofar as excised embryos will germinate without treatment although the resulting seedlings usually produce dwarf plants. A chilling treatment of 63 days at below 3°C will usually overcome the constraint.

Germination at 20°C will be speedy and synchronised.

Miscellaneous **Sapindaceae**

The scope of the Family **Sapindaceae** does not yet appear to be fully settled and, despite the availability of DNA analysis etc, it is one in which the taxonomists still agree to differ. It occurs chiefly in the tropics and subtropics but a few genera extend into temperate climate provenances. It may or may not include *Acer* and *Aesculus* (depending on the opinions of the taxonomist and the genetic markers to which they attribute prominence) but it does appear to include the following genera, which contain species suitable for cultivation in temperate climates:- ***Alectryon*, *Dipteronia*, *Dodonea*, *Koelreuteria*, *Ungnadia* and *Xanthoceras*.**

The seeds of these genera are all of a sufficient size to be handled individually both at harvest and during the germination process. Generally the viability levels are high (<90%).

Alectryon

The genus ***Alectryon*** consists of about fifteen species of evergreen trees and shrubs which occur in the tropics and subtropics of South East Asia, the Philippines and Eastern Australasia. The Titoki (*Alectryon excelsus*) of New Zealand, however, is exceptional in that it occurs in temperate climatic areas. It develops into a spreading, evergreen tree - sometimes with a twisted trunk, and could reach nine or ten metres tall with tough, shiny green leaves.

The Titoki flowers in early summer with inconspicuous purplish flowers. The fruit is initially a green hairy capsule which takes a year to mature - when it becomes hard and woody; it then splits to allow a red, raspberry-like, fleshy aril type structure to emerge which contains the single black seed with a small pale coloured hilum scar.

The seeds remain on the tree for some time until they are taken by birds - so they can readily be picked by hand when convenient. The seeds are separated from the arils by fermentation. Fresh seed will then germinate without further treatment at 20°C. Stored seed may develop a hardish seed coat condition which can usually be overcome by an extended warm water soak.

Dipteronia

The genus **Dipteronia** contains two species - *D. sinensis* and *D. dyeriana* and, superficially, appears very close to *Acer*. Both species are native to Central and South West China. The latter is regarded as rare and endangered.

They are generally large multi-stemmed shrubs but sometimes single stemmed trees. They are deciduous and have pinnate leaves. The racemes of inconspicuous flowers are produced during the spring. The flowers are structurally bisexual but are functionally male or female. In the autumn however the shrubs can be covered with large clusters of fruits which are initially green and mature to a distinctive red.

The individual fruit is a samara which consists of two nutlets which are compressed and are surrounded by two semicircular wings.

The seeds, once mature (ie having dried to the dispersal stage), have a hard seed coat which can usually be mitigated by an extended warm water soak. Once the seed is imbibed it exhibits an endogenous embryo dormancy - which requires a chill of 84 days at 3°C to permit germination which then will occur in seven to ten days at 15°C.

If it is possible to collect seed locally, then it would be advantageous to collect the samaras as they turn colour - ie before the seed coat hardens.

Dodonea

The 'Hopbushes' (**Dodonea**) are a genus consisting of about seventy species which have an extraordinarily extensive geographic distribution through the tropics and subtropics of Africa, Southern Asia, Australasia and the Americas - chiefly in the Southern Hemisphere and with about sixty of these species endemic to Australia. Several occur in Tasmania and therefore have a temperate provenance and are suitable for cultivation in such climates.

The inconspicuous flowers are wind pollinated and the species are either monoecious or dioecious; the flowers are produced in short racemes. The fruit is a colourful capsule with two or three wings which at maturity dries, hardens and bursts to expel the seeds. The seeds are usually black and develop a hard seed coat by dispersal.

The commonest species in cultivation is *D. viscosa* - which has a huge range through the subtropical/warm temperate climates of the whole distribution of the genus - it therefore tends to be variable in habit - depending on its provenance. The three to four winged capsule turns purple red at maturity, becomes brittle and then breaks up liberating two to three black seeds which are 2-3mm in diameter. The seeds have a hard seed coat which, if treated when fresh can be mitigated by a warm water soak which starts with pouring boiling water over the sample (4 to 5 volumes). If the seed has been stored it may need scarification to degrade the seed coat and permit imbibition. Germination will be prolific at 20+°C.

Koelreuteria

The genus ***Koelreuteria*** consists of three species of medium sized, deciduous trees from South and East Asia. They are characterised by their pinnate leaves and large panicles of small, but showy, yellow flowers in late summer.

Koelreuteria paniculata - the so-called Golden Rain Tree of China is the hardiest - although in the south of the country *K. bipinnata* is sometimes seen.

Fruit is sometimes produced in the UK but it requires a warmer and brighter late summer than is the norm to achieve this and develop a viable crop of seeds. The fruit itself is a trilocular, bladder-like pod which turns from green to beige and then to red/pink. In a good year they are produced in profusion. The seed is easily extracted by collecting the pods just before they split open and then gently drying in a paper bag - The fruit splits down the median sutures to liberate the seeds - which are produced one per locule.

The seeds are brown at dispersal and mature to black (about 7.0K seeds per Kg). They have a pale hilum and are like small Aesculus seeds. When mature they can be successfully stored dry for a couple of years. Unless the seed is treated immediately it is shed it is likely to have developed a reasonably hard seed coat - in the early stages this can be overcome by a warm water soak but later will require a mild scarification to permit imbibition. The seeds also have an endogenous embryo dormancy which will require a 63 day chill at 3°C to mitigate.

Ungnadia

The Mexican Buckeye (***Ungnadia speciosa***) is a monotypic genus - this Buckeye is native to North East Mexico and adjacent Texas. It is a very decorative shrub or small tree and will tolerate arid summer conditions. It can be cultivated in the drier, milder niches of the UK.

It produces its attractive crowded clusters of purple-pink, 2-3cm diameter, five-petalled flowers just before bud break, on the otherwise bare branches.

The fruit is a trilocular capsule - which when mature is about 5cm across, smooth, light brown and splits on the median suture of each locule to liberate the seeds. Often the capsules will persist until spring. The seeds are like small *Aesculus* seeds, globular - 2cm in diameter (about 750 per Kg), dark brown-black and develop one per locule.

The fresh seeds will usually germinate without constraint - provided that the temperature is warm enough (20°C+). It would be prudent to give them a warm water soak before attempting germination. If the seeds have dried then scarification to abrade the seed coat slightly before the warm water soak is advisable.

Xanthoceras

The monotypic genus (***Xanthoceras sorbifolium***) is the only remaining survivor of the early stages of evolution in the *Sapindaceae*. It emanates from Northern China where it develops as a spectacular, deciduous, large shrub to small tree. It is hardy in all but the coldest areas although late spring frosts can be a problem for the emerging vegetative buds.

The plant produces light green, pinnate leaves and erect, tall (20 to 30 cm) panicles (like a Horse Chestnut candle) of five petalled white flowers, each 2 to 3cm in diameter, with a maroon centre - these are produced at or just before bud break.

The fruits are round, trilocular capsules, 5 to 6cm in diameter, leathery, green (quickly maturing to light brown) and smooth-skinned like a small *Aesculus x carnea* capsule. This will split, from the apex, into three sections along

the median sutures of each locule to liberate the seeds. Each capsule could potentially produce 16 to 18 seeds but 10 to 12 is the norm. The fruits can be collected quite successfully at this stage and allowed to open by gentle drying in a paper bag.

The round, *Aesculus*-like seeds are 1.5cm in diameter and are sometimes flattened on one side. They generally exhibit a very high level of viability (90 to 100%) when fresh. When fresh they are light brown in colour and as they age the colour deepens to dark tan. Stored seed often develops a hard seed coat which requires low level scarification to allow for water uptake and imbibition, although a prolonged warm water soak may achieve the same result. The imbibed seed will respond to a chill of 63 days at 3°C - this will certainly speed and synchronise germination at 18 to 20°C.

Altingiaceae

This very small Family has been, as a result of recent taxonomic treatments, hived off from the **Hamamelidaceae**. It contains only three very closely related genera - which may eventually, as a result of further study, be lumped into one single genus. Currently the genera included here are **Altingia**, **Liquidambar** and **Semiliquidambar** of which only *Liquidambar* has relevance as an ornamental for cultivation in cool temperate climates.

Liquidambar

This small genus of highly ornamental, deciduous, single trunked trees includes four species with temperate climate distributions - *L. acalycina* (China), *L. formosana* (South East Asia), *L. orientalis* (Asia Minor and the Eastern Mediterranean) and *L. styraciflua* (Eastern North America) - all worthy of cultivation in the UK.

All the species are noted for their autumn colour; they have palmate leaves with three to seven lobes which turn, eventually, to deep shades of red. The leaves are aromatic when crushed. There is, currently, an increasing tendency to selection with the regular appearance of new cultivars. These are normally propagated by budding or grafting and thus there is a requirement for the production of seedlings for use as rootstocks; although the market for seedlings as ornamental subjects will take time to decline markedly.

The flowers are numerous, yellow, individually small and are clustered together in a dense spherical structure. These give rise to the fruit which becomes a dense woody globular cluster of numerous seeds - about 4 to 5cm in diameter; the ends of the seeds have a pointed hook making the whole fruit prickly - to aid dissemination on animal coats.

The fruits are collected just before they mature on the tree - when they will break up naturally and disseminate the winged seeds. If dried gently, in a paper bag, the fruits will break up easily and the seeds can be separated from the detritus by tumbling and/or shaking - then they can be cleaned in an air flow.

The seeds have a shallow, physiological dormancy which becomes deeper the more northerly or higher the provenance.

Generally a chill, of the imbibed seeds, for 35 days at 3°C will be sufficient - even seeds from warm provenances perform better if chilled. The seeds will then germinate prolifically, in only a few days, at 20°C.

Atherospermataceae

This small Family is now separated from the *Monimiaceae* and contains fourteen species in seven genera. They are all natives of the Southern Hemisphere and occur in Chile (2 species) and Eastern Australasia (12 species). They are chiefly subtropical and tropical in distribution but the three genera - ***Atherosperma***, ***Laurelia*** and ***Laureliopsis*** - occur in adjacent temperate areas of the Southern Hemisphere - they are however only marginally hardy, as the young growth is susceptible to late sprig frosts which are not a normal occurrence in their native environments, and therefore will only develop satisfactorily in milder niches in the UK.

All the species are evergreen trees or shrubs and have aromatic wood, leaves and flowers. They all flower early in the year, are normally dioecious and produce their fruits after midsummer. The seeds are feathery achenes and they all have some degree of immaturity to the embryo at the dispersal stage.

Atherosperma

The monotypic genus - ***Atherosperma*** *moschatum* - is an evergreen tree or shrub - it occupies some of the hardiest provenances of the entire Family. It occurs commonly in coastal parts of South East Australia and in most of Tasmania. In this latter, southern extreme of its distribution it can reach a height of 40m. It therefore has the widest potential for cultivation in the British Isles.

The flowers are produced in clusters, in the axils of the leaves, during midwinter and have white petals with a yellow (sometimes maroon) centre. The fruits, which mature soon after midsummer, are roundish green capsules; these open at the top to release the numerous feathery achenes which are dispersed by wind. The viability level between samples of seeds can be notoriously variable but is however usually low. As the quality of a sample will deteriorate fairly quickly after dispersal it is advisable to process the fresh seed.

The seed does not exhibit any dormancy controls and germination will occur at reasonably high temperatures (18-20°C) but allow for the period of embryo maturation before emergence occurs.

Laurelia

The second genus consists of two species - **Laurelia sempervirens** (from Chile) and *L. novae-zelandii* (from New Zealand). Both of these very similar species are inhabitants of temperate rainforest or damp woodland at low elevations. Neither of the species is fully hardy - especially when young - although the presence of many mature trees in the South West of England and similar mild niches bears witness to the greater hardiness of the adult specimen which by implication has survived some extreme conditions during its existence.

The plants are dioecious - but hermaphrodite flowers do occasionally occur. The flowers are small, inconspicuous and yellow.

The fruits are pear shaped, green capsules, the seeds are liberated from the top of the capsule which opens to allow the numerous wind dispersed achenes, which have a feathery 'tail', to disperse. The small seeds show low viability and have an oily food reserve.

Preferably fresh seeds should be processed quickly in order to prevent losses in viability. The maturation of the imbibed embryo in the seed will occur naturally after a latish summer dispersal and this is then followed by a winter chill.

Thus imported seed will require a warm water soak to imbibe the seed and then warm stratification for 60 days followed by a chill for 42 days.

Laureliopsis

Laureliopsis is a monotypic genus (now separated from *Laurelia*) and contains only *L. philippiana* (*Laurelia serrata*) which is an evergreen tree native to the southern, temperate rainforests of Chile and Argentina. It resembles the previous genus morphologically and is similar in having aromatic wood and leaves. The plants are monoecious - the racemes overall appear to be made up of white flowers - these however have reddish centres with greenish white tips to the petals. This plant is from a southern provenance in Chile and Argentina and during the winter can be under a considerable blanket of snow - it should therefore prove

hardy (more than it is currently credited with) in southern parts of the UK.

The fruit is a greenish, fleshy urn shaped capsule which splits to liberate the wind dispersed achenes which are dark brown spindle shaped seeds, about 1cm long, subtended by coffee coloured hairs. These have low viability - rarely exceeding 30%. It is therefore prudent to process fresh seed quickly.

The dispersal of the seed takes place soon after midsummer which thus allows the imbibed embryo to mature during the late summer and autumn before it is subjected to a winter chill. Thus a suitable protocol for imported seeds would be a) imbibition by a warm water soak, b) warm stratification for 60 days and then c) 60 days of chill.

Bignoniaceae

This large Family of more than a hundred genera (and about 700 species) is chiefly found in tropical and sub-tropical regions around the world - the centre of diversity (with the highest density of species) is in South America.

The Family contains trees, shrubs and herbaceous plants but is predominantly (about half the species) made up of climbers (lianas, vines).

The flowers are generally large, showy and colourful and are hermaphrodite. The fruit is usually a capsule in the form of an elongated pod - which dehisces longitudinally to release the seeds. The pods contain numerous seeds and these are normally winged.

The seeds germinate without pretreatment - however, in those cases where the seeds appear to have a hardish seed coat, it would be prudent to give them a warm water soak before sowing to facilitate imbibition. Germination will then be most efficient and productive at relatively high temperatures (25°C).

The following genera of climbers are suitable for mild niches in the UK - ***Bignonia***, ***Campsis***, ***Doxantha***, ***Eccremocarpos***, ***Pandorea***; while ***Clytostoma***, ***Distictis***, ***Podranea***, ***Pyrostegia***, ***Tecoma*** and ***Tecomaria*** are more suited to Mediterranean climate areas or, in the UK, in very mild niches or in a frost free conservatory.

The 'Indian Bean Tree' (***Catalpa***) is certainly hardy in most of Southern Britain and is regularly encountered in supermarket car parks where it seems to flourish and fruit! In warm, arid areas the 'Desert Willow' (***Chilopsis linearis***) is a useful small tree and has a range of flower colours.

Celastraceae

This extensive Family of some ninety to one hundred genera and containing about thirteen hundred species of shrubs, trees and climbers chiefly occurs in the tropics and subtropics.

Only three genera contain species with a relevant temperate distribution - ***Celastrus***, ***Euonymus*** and ***Maytenus***.

All of these three genera have brightly coloured, valved, fruit capsules which, when ripe, split open to display the red aril type seeds which still adhere to the fruit case; these are normally taken by birds. Thus it is relatively easy to collect the fruits just as they are about to split (or have split) and then dry them sufficiently that the seeds can be separated from the capsules. It is not advisable to collect the fruits prior to this stage as artificial drying does not cause the capsules to dehisce and extraction is then manual and tedious.

Celastrus

The genus ***Celastrus*** contains thirty to forty species of shrubs and climbers which have mainly a tropical and subtropical distribution but with a few outliers in temperate climates. Only three or four species are suitable for cultivation in the UK. The plants are dioecious with greenish yellow inconspicuous flowers which are followed, in the autumn, by a two to four valved, dehiscent capsule which is normally orange to yellow.

Each fruit cell contains up to two seeds which are red fleshy arils. The seeds can be separated from the flesh (which may contain a germination inhibitor) by drying the seeds and agitating them roughly to separate the flesh or by maceration and fermentation. If fresh seed is used and separated by the wet method it is unlikely that the seed coat hardens sufficiently to prevent water uptake. If it is suspected that the seed coat has hardened then an organic acid treatment will reduce the seed coat.

These temperate provenance species exhibit an endogenous dormancy control which is mitigated by chilling the imbibed seed at 3°C for 63 days. Germination will then occur satisfactorily at 20+°C.

The following species from temperate provenances, which are all twining or scandent climbers, are found in cultivation in the UK - *C. hypoleucus*, *C. orbiculatus*, *C. paniculatus*, *C. rosthornianus*, *C. rugosus* and *C. scandens*.

Deciduous Euonymus

Euonymus is a large genus of some 160 to 170 species. The species are chiefly found in the Northern Hemisphere. There are both deciduous and evergreen species which barely look as though they are related - however the fruits and flowers easily distinguish their relationship. The deciduous *Euonymus europaeus* is native to the UK and adjacent Europe - its English name Spindle Bush (or Tree) indicates its traditional use as a preferred wood for making spindles for the textile industry.

The deciduous species of *Euonymus* are chiefly distributed in temperate climates and virtually all the cultivated species are grown for their decorative, colourful fruits and often brilliant and intense autumn foliage tints - as well as being tolerant of 'chalky' soils. The flowers, which are produced during the summer, are usually small, insignificant and dull. They are normally greenish yellow in colour.

These deciduous species are normally propagated from seed although the particular variants are usually propagated from cuttings. It is prudent to grow several stock plants (not of the same clone), so that cross pollination occurs - as sometimes isolated plants (which are necessarily self pollinating) leads to poor quality and low levels of seed production.

The fruits consist of a locular capsule which has four (or sometimes five) locules, each enclosing a single seed (if there has been a satisfactory pollination). The more or less globular seed usually has a distinct bright yellow or orange covering 'skin' and this is exposed *in situ* when the capsule opens. Each locule of the fruit has a median diagonal suture which, when ripe, splits and flattens backwards to expose the seeds. The capsule, when ripe, is usually brightly coloured - normally shades of pink or red. The seeds are taken and dispersed by birds but some species, in their natural domain, are eaten by deer, other ruminants and bears. Internally the seed has a hard

protective seed coat which is a protection against digestion in the gut. In the UK the majority of these species ripen the fruits from mid-October onwards and the seeds should be collected before the birds remove them. It is not suitable to collect the fruits, at an early stage, before the sutures open as the capsules are strong and are tedious to split open; however if the capsules are collected just as the very first suture on the plant is splitting then they can be harvested and gently dried for 24 hours - when they will split and open readily and after a further day of drying the seeds will separate easily.

Each seed consists of a conventional embryonic core which is protected by the hard seedcoat, outside this is a thin but nutritious, fatty (white) layer enclosed in the brightly coloured skin - which is the attractive advertisement agency for dispersal. The seeds remain stuck to the fruit, for some time, from where they are taken by the predator.

The seeds are prepared for propagation initially by separating them from the capsule and then removing the external skin and flesh - this is achieved by macerating and then fermenting in warm water for a few days - the seeds will sink to the bottom of the container and the dross can be decanted off. The seeds should then be rigorously washed using a small amount of detergent and then rinsed - this ensures that all the fatty flesh has been removed and is not a potential barrier to imbibition. The next stage is to reduce the 'hard' seed coat to a level at which it becomes water permeable. This can be achieved either by a few weeks of warm stratification with or without an accelerator. Alternatively it may be achieved by an organic acid digestion using a 1% (10,000ppm) solution of citric acid - the seeds are soaked in the acid for +/-96 hours in warm environmental conditions - which should be a sufficient period to degrade the seed coat.

Once the seeds have imbibed they require a period of chilling to mitigate an endogenous dormancy condition. It would appear that a period of 63 days at below 3°C will be sufficient. Germination can then be achieved with a speedy and synchronised emergence at temperatures in excess of 15°C.

It is possible that an early collection of the fruits before the seed coat hardens will avoid the problem and

allow for immediate imbibition but the extraction of the seed from the capsules is difficult and thus essentially impractical.

The following species will all respond to the treatment indicated above-

Euonymus alatus, *E. bungeanus*, *E. europaeus*,
E. grandiflorus, *E. latifolius*, *E. maackii*,
E. oxyphyllus, *E. phellomanus*, *E. planipes*,
E. sachelinensis, *E. sargentianus* and *E. yedoensis*.

Maytenus

This genus of evergreen and semi-evergreen trees and shrubs contains over 100 species which principally have a tropical and subtropical distribution throughout the world. There are two species, however from the southerly parts of Chile and Argentina which have a temperate provenance - *M. boaria* (which is marginally hardy) and *M. magellanica* (which is cold hardy).

The inconspicuous yellow flowers are produced in profusion in early summer and are hermaphrodite (or sometimes monoecious). On an established plant flower and fruit production is prolific.

The fruit is a two valved capsule which splits in the autumn to display the one or two seeds, these remain attached for some time and are taken by birds. The capsule is bright yellow in *M. magellanica* and dull green in *M. boaria*. The seed is enclosed by a red skin containing an oily/fatty material and inside this is the seed which usually has a rugose seed coat.

The detail for seed extraction is the same as for *Euonymus*.

Although the seeds are usually taken by birds the seed coat does not seem to harden sufficiently to prevent imbibition.

Germination at 20+°C is normally prolific.

Cercidiphyllaceae

This monogeneric Family survives from fairly early in the evolutionary tree of the Angiosperms and is named for the Cercis-shaped leaves.

Cercidiphyllum

The genus, of highly ornamental trees or shrubs, contains only two species - both of which have an oriental distribution in chiefly temperate areas. *C. japonicum* occurs in China and Japan and can grow into a substantially sized tree while *C. magnificum* is a narrow endemic in Japan - it is a much smaller tree but with larger leaves. Both are called the Katsura tree. They are elegant trees or large shrubs and are often multi-stemmed.

The plants are dioecious and the flowers are produced in the spring - the female flowers are red and the males are green - and are wind pollinated.

The fruits are not often (if ever) seen in the UK because of the need for both sexes to be present and adjacent. Thus imported seed is the norm.

The fruit is a follicle and is produced in a cluster of two to four small, dehiscent pods - each between one and two centimetres long. The pods are initially green but mature to a coppery colour. Each pod contains numerous, small, flat, compressed, oily, winged seeds which are released over the autumn and winter. Viability is often low (as little as 20%). The pods should be harvested before they split and then dried to release the seeds. The seeds have thin seed coats and are susceptible to water loss - which can cause a serious loss of viability - so that drying should be limited to causing the pods to open just so that the seeds can be shaken free.

The seeds are sown, in a tray, without delay and watered in so that they imbibe and so maintain viability. The whole can then be kept moist through processing and germination. Chilling is not essential for germination but a chill for 14 days at 3°C will unify and speed germination. Successful chilling can be achieved by enclosing the tray in a polythene bag and then refrigerating before transfer to the germination environment at 20°C - when emergence will occur in 14 days.

Lardizabalaceae

This is a small family of woody plants containing eight or nine genera of climbing plants and one monotypic, shrubby genus. They are characterised by their fruits which are usually colourful and in some degree fleshy and edible. They are, in part, native to warm temperate climatic areas but are also found in the sub-tropics. They are distributed in South East Asia and South America. The following genera all show some degree of hardiness:- **Akebia**, **Boquila**, **Descainea**, **Holboellia**, **Lardizabala**, **Sinofranchetia** and **Stauntonia**.

Generally the species are monoecious with both sex flowers in the same drooping raceme (usually the females are at the end and are subtended by the males). Some species are however dioecious.

The fruit is either a berry, or more commonly, a fleshy pod follicle which dehisces ventrally to expose the seeds. The flesh is below the rind with the seeds carried inside this. The ripe fruits can be collected at dehiscence and the mass of seeds and central material extracted manually - if simple washing does not clean the seed, this can then be macerated and fermented to separate and clean the seeds.

The seeds of species within this family can all be treated in much the same fashion - at the dispersal stage they have an immature (ie a small but differentiated) embryo which requires a period of warmth to bring to maturity - usually c28 days at 20+°C. Germination will then occur in a few days - unless a period of chilling is advantageous. The food store in the endosperm is oily which implies that the seeds should not be dried extensively and that storage should be at cool temperatures in order to avoid the development of rancidity. In general it would be prudent to deal with fresh seed.

Akebia

The genus **Akebia** contains five species of strong growing, twining, evergreen climbers - from China, Korea and Japan. It contains two fully hardy species (*A. quinata* and *A. trifoliata*) - which are often invasive in habit. The fruits are edible - if insipid - and are sometimes harvested and sold in the markets in northern Japan.

There are reports that these two hardy species respond to chilling (56 days at 3°C) after the period of embryo maturation although it does not appear to be essential.

Boquila

Boquila is a monotypic genus (*B. trifoliata*) from the temperate rain forests of Chile and Argentina. It is an evergreen climber which is native to marshy areas in deep shade. The fruits are white, fleshy, globose berries about 5mm in diameter which contain from two to five seeds. These fruits are edible.

Descainea

The genus **Descainea** is regarded as monotypic by the taxonomists but practically is separated into the Chinese *D. fargesii* (which has bright blue fruits) and the Nepalese *D. insignis* (which has yellowish green fruits) - this trait is the only relevant distinction. The pulp of the fruits is white and glutinous and contains the flattened circular black seeds about 1cm in diameter. It is a deciduous shrub to about 3m tall and spread with pinnate leaves and yellowish green flowers which are followed by the brightly coloured sausage shaped fruits.

Treat the seed when fresh as there is a tendency to develop a hard seed coat with drying - however this can be mitigated by a 24 hour warm water soak. Experience suggests that there is no chilling requirement and that germination will occur satisfactorily at 20°C.

Holboellia

The genus **Holboellia** consists of about twenty species of vigorous, evergreen climbers and is native to South East Asia - the Himalayas and China. The flowers are monoecious - the male flowers occur in terminal racemes and the female flowers are found in the leaf axils. The fruit is a purple, fleshy, sausage-shaped pod containing many seeds.

H. coriacea and *H. latifolia* are sufficiently hardy to be cultivated reasonably commonly in southern parts of the UK.

The seeds do not require chilling and will germinate prolifically at 20°C.

Lardizabala

Lardizabala is monotypic genus - the sole species *L. biternata* is an evergreen climber which occurs in the temperate rain forests of Central and Southern Chile. The plants are dioecious and the female flowers are solitary while the male flowers are produced in hanging racemes. The fruit is a fleshy, purple, sausage shaped pod which is edible. The extraction and germination processes show no divergences from the norm.

Sinofranchetia

Sinofranchetia is hardy monotypic genus (*S. chinensis*) which is a native to Central and Western China. It is a hardy, very vigorous (to 15m), deciduous climber - with distinctive white stems and three lobed leaves which are glaucous below. The plants are dioecious and the drooping racemes of inconspicuous white flowers are produced in early summer. The fruit is a rounded, fleshy, mauve berry and these are produced in long, substantial elongated bundles.

Although the seeds will germinate without pre-treatment at 20°C, the emergence will be speedier and better synchronised with a short period of chilling (35 days at 3°C) after the maturation phase.

Stauntonia

The monotypic genus **Stauntonia** contains the variable, evergreen, climbing species - *S. hexaphylla*. This ranges extensively through the more southerly, warm temperate, islands of Japan. The fleshy fruits may vary from plum-shaped to sausage-shaped depending on their particular island provenance and are usually yellow which may be extensively flushed with purple or pink.

Extraction and germination is as described above with no particular individual traits.

Legumes

The Plant Family name **Leguminosae** - which was once widely accepted - is now more often replaced, in modern systems of nomenclature by the name **Faboideae** or **Fabaceae**. This huge Family (700+ genera and 19000+ species) of plants consists of both woody and herbaceous subjects. The seeds - especially in the woody species from temperate climates - are characterised by being, in some degree, impermeable to water when they are dispersed. This situation becoming enhanced as further drying occurs. Most of the species develop the seeds in a longitudinal pod (the legume) - which dehisces and disperses the seeds by an often violent 'explosive' action. Relatively few of the woody genera are native to temperate climates although, of those that are, many are prominent in Mediterranean and similar climates and hence will succeed in milder areas of the British Isles. A few have a cold temperate distribution and are hardy (eg *Cytisus*, *Laburnum*, *Spartium*, *Ulex*).

The Family is divided into three sub-families:-

a) the **Caesalpinoideae** are chiefly trees which are found in the moist tropics; however a very few genera have a distribution in warm temperate climates and the relevant genera (ie which are potentially possible for cultivation in the UK in mild niches) include **Cassia**, **Ceratonia**, **Cercis**, **Gleditsia** and **Gymnocladus**. Root nodulation is rare in this group.

b) the **Mimosoideae** contains the smallest number of genera. These genera all occur in warm climatic areas - and of these only **Acacia**, **Albizzia**, **Calliandra** and **Mimosa** are relevant for milder niches in the UK climate. They are characterised by the flowers having small petals and large, usually brightly coloured, stamens - which produce the recognisable 'fluffy' flowers.

c) the **Papilionoideae** is the largest sub-family - including both woody and herbaceous species - with a distribution throughout the world - mostly in warm climates but with several genera which have adapted to temperate climates and are suitable for cultivation in relevant areas of the UK:-

Adenocarpus, **Amorpha**, **Anthyllis**, **Caragana**, **Carmichaelia**, **Castanospermum**, **Chorizema**, **Cladastris**, **Clianthus**, **Colutea**, **Coronilla**, **Cytisus**, **Desmodium**, **Erythrina**, **Genista**, **Hardenbergia**, **Hovea**, **Indigofera**, **Kennedya**, **Laburnum**, **Lespedeza**, **Maackia**, **Ononis**, **Petteria**, **Piptanthus**, **Podalyria**, **Pueraria**, **Pultenaea**, **Robinia**, **Sophora**, **Spartium**, **Ulex**, **Virgilia**, and **Wisteria**. The flowers are typically

pea-like (ie five-petalled flowers arranged as a standard, two wings and two constituting the keel). The symbiotic nitrogen fixing root nodules are well developed and common in this group.

Most of these genera are native to areas with warm temperate climates - these have high summer temperatures and often experience dry or arid conditions - hence the hard seed coat condition protects against excessive water loss and in nature its degradation is often also associated with high temperatures or even wild fire.

The pods can, in general, be collected just before they are ready to dehisce and disperse the seeds. At this stage further drying in paper bags allows them to open and at the same time entrap the seeds as they are dispersed - this is especially significant if dispersal is as a result of the explosive dehiscing effect. When the process is completed the remains of the pods can be separated by picking over or by sieving - with the result that a very clean sample can be achieved.

In the short and medium term, the seeds can be stored dry in an airtight jar.

The only condition which will prevent germination in the seeds of this Family is the presence of a water impermeable seed coat - there are no endogenous dormancy conditions.

Inevitably there is, in such a large Family, a tremendous range in the shape and size of the seeds. The size may vary from large seeds eg *Gymnocladus dioicus* (0.8-1.0K seeds per kg) through *Wisteria sinensis* (1.6K seeds per kg) and *Gleditsia triacanthos* (7K seeds per kg) to *Robinia pseudacacia* (60K seeds per kg). Usually the seeds are more or less spherical but can be flattened in a disc shape. The seed coat is generally hard, brittle and bony in some degree but occasionally it is more of a leathery texture.

It is not unusual for seeds, in this Family, with a hard seed coat for this feature to become enhanced if the seeds are not processed reasonably quickly and are allowed to dry even marginally. So that seed treatment, for a particular species, will often vary according to the age of the sample and the storage conditions provided - there will be no hard and fast rules. It may be possible to extract the seeds at

an earlier stage but this process will usually be tedious and unrewarding.

Seed treatments to create water permeability

If seeds are very dry the initial stage of imbibition can be very rapid and may cause injury to microscopic structures in the seed.

When the seed coat is made permeable, the seed will imbibe water quickly and swell, indicating that the particular treatment has been successful.

In order to achieve a sufficient seed coat degradation for imbibition to proceed, it may be necessary to process through a series of treatments - grading up the scale until success is achieved:-

a) soaking the seeds in warm water (20-30°C) for up to 48 hours, removing the seeds from the water once it is evident that the seeds are beginning to swell.

b) hot water treatment - pour five times the volume, of the seed sample, of boiling water over the seeds and leave to cool and soak as in a); repeat for a second time if there is no response.

c) percussion treatment (agitate the seeds in a metal drum or glass jar, so that they bounce vigorously, for several minutes), this activity should cause the dislodgement of a strophilar plug or alternatively may cause the brittle seed coat to crack, follow with a warm water treatment as in a).

d) subject the seeds to a dry heat treatment regime, by placing the seeds on a metal tray mixed with sand and place in an oven at 90-120°C for five to ten minutes, this will cause the seed coat to crack. Higher temperatures will cause damage to the embryo but it will be necessary to monitor the time scale to achieve the required result, follow with the warm water soak as in a).

or

e) scarification - agitate the seeds in a drum lined with sand or glass paper (or similar) or in a suitable container with an abrasive material (a very 'sharp' angular grit) until the thickness of the seed coat is abraded down to a level at which water can penetrate (only a very small area of the seed coat needs to reach this stage); follow with a warm water treatment as in a).

With seeds which are large enough to handle individually the seed coat can be chipped manually either by paring away

a piece of the seed coat with a knife or rubbing on a rasp. They can then be imbibed by warm water soaking.

The seeds of the majority of the species of temperate climate, leguminous woody plants are big enough to be sown individually. They can be sown in modular containers quite successfully - as viability is usually high and seeds which have not imbibed can be discarded.

Once the seeds have imbibed, germination is usually rapid at temperatures of 20°C+ - often in the order of only seven to ten days.

Seedlings of ***Wisteria*** are normally produced for use as one year old rootstocks for grafting during the following winter. They are most satisfactorily sown and grown in a conventional ameliorated soil seedbed in the spring. The seeds are sown individually at a density of 400 per square metre. As the viability and size of the seeds can be variable it is prudent to grade out the smallest seeds and to imbibe the remainder of the sample before sowing - so that seeds which do not swell can also be discarded. The top growth produced by a seedling *Wisteria* in its maiden year is sparse but the hypocotyl and tap root will have made sufficient size for use as a rootstock. *Wisteria* seeds, at dispersal, have a waxy impregnation in the outer part of the seed coat which protects both against water loss and imbibition in the short term and hence postpones germination until the following spring, this material however is readily removed with the warm water soak.

Philesiaceae

This small Family, of about five genera, is native to the temperate to sub tropical rainforest areas of Chile. They are a constituent part of the Liliales.

Two, very showy, monotypic genera (**Lapageria** and **Philesia**) are found in temperate areas and are suitable for cultivation in milder parts of the UK or as conservatory plants. They both have very striking, colourful, flaring, tubular flowers.

Lapageria

The Chilean Bell Flower, **Lapageria rosea**, is a climbing plant from the shaded understorey of the temperate rain forests of Southern Chile with sparsely foliaged, wiry, twining stems rising from a fleshy rootstock and impressive and substantial flared, tubular flowers. The flowers are pollinated by Humming Birds in nature - thus it is necessary to pollinate artificially if seeds are required in the UK. This process can be very successful in producing good crops of viable seeds. The colour of the flowers is normally pink or red but white and a range of colours have been selected and clonally propagated in cultivation.

The fruit is a substantial indehiscent, fleshy berry in which many seeds are embedded in the flesh. The seeds are oily and deteriorate readily so that fresh seed should be processed and used as quickly as possible. The seeds should be washed free of the flesh - as this appears to hamper germination. The conventional germination of dried and stored seed can be lengthy, only partially successful and erratic. Fresh seed responds very adequately.

The seeds respond, with the speediest and most synchronised emergence, if they are soaked in warm water for 48 hours, then chilled for 28 days at 3°C and then germinated at 20°C.

Philesia

Philesia magellanica is one of the jewels of the spectrum of shaded, understorey shrubs of the southern Chilean, temperate rain forest. This low, thicket forming evergreen shrub has wiry stems and stiff lanceolate leaves which are dark green above and glaucous beneath. The flowers are

about 5cm long and are very similar to those of *Lapageria* also in a variety of colours ranging from red through pink to apricot and white.

The germination pretreatments and environment are the same as for *Lapageria*.

Rhamnaceae

This large, extensive and diverse Family contains between fifty and sixty genera (with eight to nine hundred species). It has a cosmopolitan distribution but occurs chiefly in tropical and sub-tropical areas. A few genera have a distribution in temperate climates of which the great majority are in the warm temperate sector.

Ceanothus

This genus of principally evergreen shrubs and small trees, occurs chiefly in the Mediterranean climates of south western North America, mostly they occupy ecosystems that are fire dependent for their renewal and regeneration (eg chaparral and scrub). This situation is reflected in the seed regeneration strategies exhibited by many of the species.

Virtually all the species have hard seed coats and exhibit considerable longevity. The fruit is at first viscid and a fairly typical drupe however as it ripens it develops into a hard, tight, dry, three lobed capsule. This dehisces violently when mature ejecting the seeds for several yards. The final maturation phase, which involves the rupture of the case, occurs quite suddenly (a situation that would not be unexpected for plants growing in such hot dry conditions). Thus collection can be a problem - the simplest solution, where it is feasible, is to enclose the fruits in a paper bag so that they are trapped at dehiscence. Collecting the seeds just prior to dehiscence is feasible - if the stage can be recognised - ie when the first capsules dehisce collect the remainder of the fruits and place them in a warm environment in direct sun, in a paper or cotton bag, and they will rupture naturally and the seeds can be separated from the husks. If the fruits are collected even just prior to this stage and they do not split naturally, then the capsules can then be pressed and rubbed between two boards until they break up when the seeds can be separated from the husks. Collecting and drying the cases before this stage does not cause the explosive opening and the cases have to be crushed in order to get to the seeds which is difficult and causes damage.

Extracted, cleaned and dry seeds can be stored in an airtight container at low temperature for many years.

The great majority of ornamental species are native to fire ecology niches and germination is initiated after the passage of wild fire. This causes a sufficient degradation of the seed coat (the hilar fissure is irreversibly opened) which allows water penetration once it becomes available. Species from higher elevations or those native to a continental climate exhibit an endogenous embryo dormancy requiring a chill for its mitigation.

Heat, for this purpose, can be provided by using a conventional hot water treatment - ie by pouring about four volumes of more or less boiling water over one volume of seed and then leaving to cool for twenty four hours - if the treatment is effective the seeds will imbibe and swell. Often this technique does not work and although it can be repeated it usually fails again.

Heat treatment can also be achieved by a dry heat regime in a preheated oven. The seeds are extended in about four volumes of sand and placed in a suitable container and then placed in an oven at a reasonably constant temperature in the range between 90°C and 120°C. Temperatures in this range are usually equally effective and an exposure time of four to five minutes is usually sufficient, longer exposure is not usually detrimental so there is plenty of leeway. Temperatures below 90°C are not normally effective and at above 120°C the embryo will be irreversibly damaged. After treatment the seed should be soaked for 12 to 24 hours to achieve imbibition. The seeds (depending on the species) can then either be sown for germination or proceed into the chilling treatment.

The chilling requirement for *Ceanothus* species have not been examined critically but the consensus recommends a period of 84 days below 5°C; however there is reasonable evidence to demonstrate that a period of no more than 56 days should be adequate. Many of the species are native to coastal communities, from the coastal ranges, the lowland chaparral and scrub and semi-desert conditions. For these species it is difficult to envisage that the 84 day period of chilling (as recommended in the literature) would be experienced in their native habitats.

The following species will germinate satisfactorily, once they are imbibed, without a need for chilling:-

C. arboreus, *C. cuneatus*, *C. dentatus*, *C. fendleri*,
C. foliosus, *C. gloriosus*, *C. griseus*, *C. impressus*,

C. imcanus, *C. jepsonii*, *C. maritimus*, *C. megacarpus*,
C. oliganthus, *C. papillosus*, *C. rigidus*, *C. parryi*,
C. soledatus, *C. spinosus* and *C. thyrsiflorus*.

The following species all require a period of chilling in order to remove an endogenous embryo dormancy before submitting them to satisfactory conditions for germination. It is probable that 56 days at 5°C will be sufficient for most species - although the actual period may be much less. It would appear that seeds of the following species which are all native to montane areas and/or are native to colder winter environments will require some degree of chilling to achieve a synchronised and rapid germination:-

C. cordulatus, *C. crassifolius*, *C. cyaneus*,
C. diversifolius, *C. foliosus*, *C. intergerimus*,
C. parviflorus, *C. prostratus* and *C. velutinus*.

Ceanothus sanguineus is a deciduous species from the eastern USA - the seed coat of which is not an impediment to imbibition when fresh; however even marginal drying will cause a hardening which will need to be treated. It will also require chilling.

The seedlings of all *Ceanothus* species are very susceptible to root disturbance and it is therefore sensible to move the seedlings, immediately the radicle has extended, into a liner container. The genus also relies on its own nitrogen fixation (it has a symbiotic association with the Actinobacterium - *Frankia*) and therefore nitrogen fertilisation of the compost should be only minimal.

Rhamnus

All the following genera are basically natives of warm climates but there are species which have adapted to temperate climates and one or two species which can be cultivated in the UK and a few which have potential in the event of genuine climate warming.

Alphitonia

20 spp SE Asia, Oceania and Polynesia - in Australia fringes into the warm temperate - *A. excelsa* - at its most southerly found in med climatic areas
 semi deciduous
 dull black globular drupe 10mm diameter 2 locules a seed per locule - raised ring around the middle
 powdery red flesh dries
 2 hard cells
 scarify nick or abrade and/or HW soak (even boil for 5mins!) - imbibition
 @25 C 4 days to germination

Berchemia

Extensive genus of trees and shrubs and scandent climbers

Colletia

Hovenia

A genus of x spp of which only *hovenia dulcis* is cultivated in the UK Japanese Raisin Tree - native to

Pomaderris

70 spp in Australia (65, 10 in Tasmania) and NZ (5) shrubs and small trees
 fruit a dark brown hairless capsule
 n fix
 3 carpels one seed each
 a few in fire ecologies

thin leathery seed coat, impermeable - scarify

<i>P. apetala</i>	Tasmania	15 C
<i>P. aspera</i>	lowlands ESE Aust & Tasmania	15-20
<i>P. intermedia</i>		15-20
<i>P. paniculata</i>	SE Aus and Tasmania	15
<i>P. elliptica</i>	NSW, Vic and Tasmania	20
<i>P. phyllifolia</i>	upland Tasmania *wks at 5 C	20

P. racemosa

P. gilmourii var cana fire

P. hamiltonii NZ fire - smoke N fix

P. kurmerano NZ nil

Some Rutaceae

The Family Rutaceae is a large and diverse group of woody plants consisting of about 160 genera and in habit varying from sub-shrubs and prostrate shrubs up to medium sized trees. They are principally evergreen and usually produce sweetly scented flowers and have aromatic foliage - from both of which oils may be extracted (viz Bergamot and Neroli from Bitter Orange). Many are used in local medicines and there are several in which the leaves are chewed regularly to maintain 'well being' ('Buchu' in South Africa).

The Family is chiefly limited to warm temperate to tropical areas but a few genera have species which fringe into a temperate distribution.

Although the great majority of species do not present any particular problems for the seedling producer some of those from particular provenances in warm temperate areas do not respond conventionally - especially those from arid ecologies in Southern Africa and Australia. The perceived wisdom for most of these was that they exhibited a hard seed coat condition but recent critical assessments have accepted that in the greater proportion of examples this is not the case. What is clear is that, in general, the cues which promote germination are very imperfectly recognised and understood - hence germination protocols tend to provide erratic results at best.

There is some evidence to suggest that in many of the relevant species it is not prudent to collect the fruits and extract the seeds before the fruit is ripe as the embryo is relatively late to mature.

Citrus

Citrus is the archetypal genus of the Family. It is a large genus containing many species of economic importance - Kumquat to Bitter Orange through Grapefruit, Lemon and the Orange complex. All are evergreen and have sweetly scented, usually white, flowers. As a result of cultivation over a millennium or more there has been much selection and eventually hybridisation and species are often difficult to recognise. Most are only satisfactorily cultivated in warm temperate to sub-tropical climates. Some selections produce apomictic seed.

Seedling production is not usually constrained and provided that the seed is fresh and imbibes satisfactorily, germination is prolific, rapid and uniform at 22+°C.

There are a number of fruiting variants which produce particular varieties from apomictic seeds.

Tetradium

The genus ***Tetradium*** will probably be more familiar to most growers as *Euodia* (even *Evodia*!) but that genus is now limited to a substantial number of tropical species.

Tetradium is now defined as a genus consisting of (+/-) nine species of deciduous, pinnate, shiny leaved trees (to 20m or so) - which are native to the temperate and warm temperate climates of Eastern Asia. They produce a profusion of panicles of small, white to grey-white flowers which are a good bee forage.

The fruits are produced in the autumn and are bright purple-red capsules which dehisce to expose the two, shiny black seeds. These remain attached and adhering to the fruit case for some time if not taken by predators. The fruits and seeds can be rapidly taken by birds and so collection should take place before this occurs and then slowly dried to cause the seed cases to split.

A germination protocol will consist of a twelve hour warm water soak, followed by a 28 day chill to overcome a potential shallow dormancy and so synchronise emergence; germination is then speediest at 20°C.

Most species have a warm temperate distribution but the Korean *T. daniellii* (with black-red fruits) and the Chinese *T. hupehensis* (with red fruits) together with the Himalayan *T. fraxinifolium* fringe into colder conditions and can be cultivated in the UK.

Phellodendron

The Amur Cork Trees (***Phellodendron***) are a relatively small genus of deciduous trees which are found in Eastern and North Eastern Asia. The number of species varies (about ten) depending on whether specific or sub-specific rank is attributed. They are characterised by the corky bark and the aromatic, thick, leathery, pinnate leaves. The leaves

turn shades of attractive yellow in the autumn. All the species are dioecious.

The yellow flowers are produced in spring and these are followed, on the female trees, by the aromatic, fleshy fruit - which is a black-skinned drupe. The seeds are extracted by maceration, marginal fermentation and then separation after rubbing in running water. The seeds are black.

To achieve germination the seeds should be imbibed in warm water for 24 hours: they have only a shallow physiological dormancy which is mitigated by a chill of 35 days at 3°C. This treatment will synchronise and speed germination.

Germination should be prolific at 20°C.

The most widely distributed species is *P. amurense* (the Amur Cork Tree); however in most modern taxonomic treatments the species - *P. sacchalinense*, *P. japonicum*, *P. lavalleyi* and *P. wilsoni* - are all accepted as distinct geographical variants of this species. From a horticultural view it would be prudent to maintain these provenances and designate seed sources accordingly. *P. chinense* from China and *P. molle* from Korea are also found in cultivation.

Skimmia

This small genus of four species, of evergreen, ornamental shrubs, emanates from the warm temperate regions of Asia - from the Himalayas through China to Japan. *S. japonica* and *S. laureola* are dioecious while *S. reevesiana* is self fertile.

The evergreen leaves are entire and are distinctly aromatic when crushed. The dense upright panicles of individually small, white or pink flowers are produced in spring and are highly scented.

The brightly coloured fruits (red or black) develop in the autumn and are eventually taken by birds when ripe. The fruit is a fleshy drupe from 6 to 12mm in diameter and contains one seed.

The seeds are extracted by maceration and marginal fermentation and the dross is then separated off in running water. They are then washed and rinsed clean.

The species from colder provenances require a chill of up to 63 days - the length depending on the particular provenance - to ensure a synchronised and speedy germination. Germination at 20°C produces a satisfactory response.

Poncirus

The monotypic ***Poncirus trifoliata*** (sometimes now reabsorbed into *Citrus* by taxonomists) - from Northern China and Korea is a hardy citrus which is used as an ornamental in its own right. It is also often used as an understock for citrus in marginal climatic conditions and to provide various disease resistances. It develops into a largish, sprawling shrub. Various cultivars have been selected.

It is a semi-evergreen shrub which can defoliate completely in cold winter conditions - especially in the UK. The leaves are compound trifoliate. It is dramatically thorny - with thorns from three to five centimetres long.

The typically citrus type, scented, white flowers appear in the spring and are followed by the fruits in the autumn.

The fruits, which are produced, on mature well established plants in the South of England and in other favoured, South West niches, in 'good' summers. The fruits are like small oranges - about the size of a golf ball - and containing many seeds (c30 per fruit).

The seeds are extracted by cutting open the fruit, when it is ripe, and picking out the seeds. They should be washed clean and then sown. Germination at 20°C is prolific and emergence will be in 10 to 14 days depending on the exact temperature.

Choisya

This small genus of three or four evergreen shrubs is native to Central America. *C. ternata* is best known and *C. dumosa* is also grown. The aromatic, tough, leathery, dark green leaves are trifoliate to pinnate. The scented white flowers are produced in late spring.

The fruit - a leathery capsule, containing two to six segments, is produced in the autumn.

The black seeds will germinate readily after imbibition at temperatures of 20°C.

Warm Temperate Southern Hemisphere Genera

There are a number of genera in this Family which have species with distributions in warm temperate climates - especially in Southern Africa and Australia - some of which will succeed in mild niches in the South and South West of the British Isles. They include many ornamental, small trees, shrubs and sub-shrubs which will provide potential in the event of climate warming (as well as species with defined medicinal value):- **Acradenia**, **Agathosma** (the Buchu of Southern Africa), **Boronia**, **Coleonema** (inc. *Diosma*), **Correa**, **Crowea**, **Eriostemon**, **Geijera**, **Philotheca** and **Zanthoxylum**. Most of these genera are native to arid, scrub, heathland and fynbos communities and hence favour acid soils; they are virtually all evergreen.

Many of these species have fruits which dehisce explosively and thus collection of the fruits should occur as the very first begin to go 'ballistic'. Collect at this stage and then keep in a paper bag to dry and allow them to dehisce naturally in captivity.

It is in this group that is found the problem issues with successful germination under nursery conditions - usually germination is erratic and unreliable. In the past these taxa have been regarded as having hard seed coats but recent evidence indicates that they are permeable and, in the vast majority of cases, a warm water soak for 72 hours will achieve imbibition. However once imbibition is achieved most species still exhibit a physiological dormancy and it is the elucidation of this condition which has proved elusive. The environmental cues which promote the elimination of the factor have not proved to be easily ascertained.

It is important to process fresh seed as viability tends to decline rapidly. The embryo is morphologically mature at dispersal but sustains a physiological control to further development. Germination has been achieved in some species and quite arbitrarily after:-

a) an initial period (in excess of 30 days) of dry, warm (20 to 25°C) storage - an apparent 'ripening' (a

physiological embryo maturation?) period - before imbibition;

b) an extensive period (in excess of 42 days) of leaching - either in running water or as a warm water soak which is decanted and replaced on a daily basis;

c) a soak in commercial 'smoke water' - although a successful outcome is not necessarily restricted to species from fire ecology communities.

Zanthoxylum has proved to be particularly difficult to deal with as it does appear to have an impermeable seed coat initially.

Winteraceae

This small Family (of only nine genera) of ancient and fairly primitive woody plants has a circumpolar distribution in the Southern Hemisphere, from virtually the Antarctic Circle to the tropics, but with only a few species having a temperate climate distribution. The family is unusual in that the plants do not contain conventional xylem vessels for the conduction of water. The leaves, bark and fruits are generally aromatic and peppery and are often used as a condiment; edible oils are also extracted. The Family consists of evergreen trees and shrubs.

The fruit is a fleshy berry, with a coloured skin, which contains many seeds. These are extracted by maceration and fermentation in order to separate the seeds from the pulp. This is a significant task as the flesh appears to contain germination inhibitors and thus must be eliminated.

The seed contains a substantial endosperm and a developed embryo, which however is very small and requires a period of warmth to bring it to full maturity before germination proper can proceed - so consequently germination is often delayed.

Only three genera contain species with a temperate climate distribution - ***Drimys***, ***Pseudowintera*** and ***Tasmannia***.

Drimys

The genus ***Drimys*** occurs only in South America and contains eight species, it ranges from southern Mexico to Tierra del Fuego. Both *D. andina* and *D. winteri* have a southerly distribution in the temperate rain forest belts of Chile and Argentina and are suitable for cultivation in the UK. *D. winteri* has until recent years been represented in cultivation by a single (less than fully hardy) clone - probably since Victorian times - however there have been several collections made in the last twenty years or so and greater variation has been seen especially in relation to hardiness - the southern provenances being of much greater hardiness - but also in leaf shape and bark colour. The fruit is a bluish berry.

After embryo maturation which is usually achieved by the warm stratification of fresh, imbibed seed (42 days at

20°C) the seed requires a chilling treatment of 56 days at 3°C before germination at 18 to 20°C.

Pseudowintera

The genus ***Pseudowintera*** contains three species which occur principally in New Zealand and are found in temperate rainforest communities. The main species found in cultivation in the UK is *P. colorata* from the South Island. The fleshy fruit is a soft, red-black berry with orange flesh which contains up to eight seeds. The seeds are extracted by maceration and fermentation and then washing clean. As the embryo may need maturing, an initial period of warm stratification for 42 days would be prudent and germination is enhanced and synchronised by chilling for 28 days at 3°C; germinate at 18 to 20°C.

Tasmannia

As a result of the modern determinations made by taxonomists, the genus ***Tasmannia*** has been separated from *Drimys* and includes about forty species which are distributed from the Philippines - south through Australasia to Tasmania with several species occurring in South East Australia. Apart from its geographical integrity, the genus is characterised by the fruit which is a two-lobed berry. The best known species, which is cultivated in the UK, is *T. lanceolata* (probably more widely known as *Drimys lanceolata*). This has a temperate climate distribution in South East Australia and Tasmania. It is dioecious. The fruit is a pea-sized, shiny, fleshy, edible, red-black berry containing 10 to 18 seeds. Successful germination depends on removing the seeds from the flesh of the fruit and treating the fresh seeds to warm stratification for 28 days at 20°C, followed by 56 days of chill at 3°C and then germination at 18 to 20°C.

Berberidaceae

A Family with a global distribution - consisting of 500 to 600 species of trees, shrubs and herbaceous plants which are attributed to four genera (*Berberis*, *Epimedium*, *Mahonia* and *Vancouveria*) - of which ***Berberis*** is the largest and dominant component. *Nandina* has often been included here but currently, on the basis of DNA assessment, it is attributed to its own Family - **Nandinaceae**.

Berberis and Mahonia

Both of these, closely related woody plant genera have, regularly over the years, been 'lumped' (into the single genus ***Berberis***) or separated (into the two genera). They have a circum-polar distribution in the Northern Hemisphere chiefly in colder temperate climates but some species, on the southern fringes are also found in warm temperate situations - especially in arid conditions. They are also found in the Southern Hemisphere in South America.

Those species described as ***Berberis*** number about 450; while those described as ***Mahonia*** number about 100 species. The main distinction is that *Berberis* have simple leaves while *Mahonia* has pinnate leaves. Both groups contain evergreen and deciduous species. *Berberis* develops thorns from modified leaves on the stem while *Mahonia* produces well armed leaves.

The Barberries (*Berberis*) are found throughout most of the world except Australia but with most variety in South America, Africa and Eastern Asia. Mahonias are found in Europe, North Africa, Asia and North America.

The fragrant, hermaphrodite flowers in both groups are yellow but can sometimes be orange. Generally the plants are winter or spring flowering.

The fruit is a pulpy, colourful berry - in shades of pink, red and orange in *Berberis* - usually averaging about 1.5 seeds per berry and blue-black in *Mahonia*, often with a pruinose bloom and averaging 3 seeds per berry.

As a group these plants show a remarkable diversity of seed development - the Family contains seeds with linear and spatulate embryos and in many species the embryo is, at

seed maturity, immature. The embryo sits in an oily endosperm - which has implications for storage temperature.

The major issue for the seedling propagator when producing these two genera is the fact that the greater proportion of species will hybridise in some degree and the source of seed should be considered in terms of its genetic integrity. *B. darwinii* and *B. gagnepainii*, for example, are particularly promiscuous while *B. dictiophylla*, *B. julianae*, *B. thunbergii* and *B. vulgaris* are usually reliable - largely because there are usually no suitably related genera available for potential hybridisation.

The seeds can be readily extracted from the ripe berries by maceration and the removal of the detritus in running water. It is important to continue cleaning the sample until all the flesh is removed - as there is some evidence to suggest that germination inhibitors are present in the flesh - especially in species from arid provenances. It is probably this characteristic which gives rise to the recommendation that the seeds of some Mahonias will benefit from leaching in order to promote germination.

As a general protocol, for species with no reliably described pre-germination treatments the following sequence might well be adopted - these treatments would appear to cover most of the extremes and ensure germination, even if it is excessive for some.

- a) use freshly extracted seeds without drying;
- b) warm water soak for 24hrs (up to 72 hours for arid land species which often have a marginal 'hard' seed coat) in order to ensure a complete imbibition and any leaching residue requirement;
- c) warm stratification at 18°C for 30 days to mature the embryo;
- d) chill at 3°C for 84 days;
- e) germinate at 20°C.

Not all species appear to require a chill but those that will germinate without pre-treatment will emerge more quickly and uniformly if given a 28 day chill prior to germination.

Cannabaceae

(Nettle Trees and Hackberries)

This small group of three, quite similar looking, closely related genera are usually designated as part of the Family *Ulmaceae* but are now referred to the *Cannabaceae*. It contains ***Celtis***, ***Pteroceltis*** and ***Aphananthe***. They are deciduous and vary from shrubs to chiefly medium sized trees. None of the temperate climate species are particularly ornamental in the conventional sense but all are capable of maintaining full green foliage cover while withstanding reasonably hostile conditions without marginal leaf scorch, especially the arid summers which are experienced in the hotter areas of Mediterranean climates and many continental climate areas.

Celtis

The temperate species of the genus ***Celtis*** divide broadly into the Hackberries of North and Central America - these are not particularly decorative - and the Nettle trees of Eurasia - the oriental Asiatic species of which, especially, can develop as reasonably tall, deciduous, well shaped, upright trees with good foliage cover and they can make ornamental specimens in otherwise dry, hostile summers of Mediterranean climates - maintaining good green foliage.

The unisexual flowers are produced in the early summer in the leaf axils and are insignificant. The fruit, which is produced in late summer or autumn, is a one seeded drupe which has an edible flesh and a coloured skin - red, yellow, orange and black in various species.

The oriental Nettle Trees; which include *C. biondii*, *C. bungeana*, *C. cerasifera*, *C. jessoensis*, *C. julianae*, *C. koreana*, *C. labilis* and *C. sinensis*; are all hardy enough to survive suitable niches in the UK and most can develop as regularly shaped specimens suitable for street tree use in relevant climatic areas. The Eurasian species of Nettle Trees - of which *C. australis* is the best known and is used extensively as a street tree in many cities of Southern Europe - also include *C. caucasica*, *C. glabrata* and *C. tournefortii*.

The Hackberries from the New World include a number of hardy species - *C. laevigata*, *C. occidentalis* (inc *C. pumila*), *C. pallida*, *C. reticulata* (inc *C. douglasii*) and

C. tenuifolia but none of them exhibit significant ornamental characteristics.

The fruits should be collected as soon as they are ripe and the seeds extracted by gentle maceration (the case of the stone is brittle and will be damaged with vigorous action) and then fermentation for three days or so when the stones will readily rub free and sink to the bottom of the container, decant the dross and then wash the seeds - the stones are usually whitish with a rough patterned, rugose surface (the pattern of which is a species diagnostic).

Commercial seed is often available as dried berries but the fruits should be soaked and treated as above - as practical experience shows that sowing intact causes an erratic and attenuated germination - however there is no indication that the flesh contains a germination inhibitor. Stored seed also tends to perform poorly.

Thus the seed should be treated reasonably quickly without drying. Although the temperate species will eventually germinate, without chilling, after a considerable time and then erratically - the best results are achieved by a period of chilling (56 days wt 3°C) followed by germination at 18 to 20°C.

Pteroceltis

A monotypic genus of Nettle Tree, from Northern China and Mongolia is designated - ***Pteroceltis tataronowii***. It can grow into a deciduous tree to 20m tall.

The trees are monoecious and the tiny green insignificant flowers are produced in spring. The fruits mature in the autumn and consist of a single samara which develops in the axils of the leaves. The samaras are not dissimilar to those of elm - the central nut is globose, about 1cm in diameter and the two encompassing wings can spread to 2cm.

The seeds exhibit an endogenous dormancy which requires a chilling treatment of 63 days at 3°C. Germination will be most rapid and uniform at 20°C.

Aphananthe

The genus ***Aphananthe*** has a distribution from Madagascar through South East and East Asia to Australia and Mexico

and is mostly tropical in distribution and evergreen in habit. The only relevant species with a temperate provenance and significant hardiness is the deciduous, *A. aspera* from Eastern China, Japan and Korea. It is an upright, fast growing tree to 20m tall with good shape and foliage cover.

The species is monoecious and the insignificant flowers are produced in racemes at bud break. The fruit is a single-seeded drupe (about 6 to 8mm in diameter) produced in the autumn. It is blue-black skinned and although initially fleshy, it soon dries to a hardish condition.

The dry drupes should be soaked and macerated to extract the seeds and then chilled for 56 days at 3°C before germination at 20°C.

Daphniphyllaceae

The family *Daphniphyllaceae* appeared early in the evolutionary history of the Angiosperms and today contains only one genus ***Daphniphyllum***. This occurs in East and South East Asia, India, Sri Lanka and Australasia.

Daphniphyllum

Daphniphyllum contains 25 to 30 species of evergreen trees and shrubs of which 15 to 17 species are found in China, Korea, Taiwan and Japan - these include a few 'hardy' species of which *D. macropodum* is the best known. All the species are dioecious. The racemes of inconspicuous, generally purple, pungently scented flowers are produced in the early summer - hidden in the Rhododendron-like leaves. In order to obtain fruit production in the UK, it is necessary therefore to grow a group of plants which contains at least one male plant.

The fruit is a fleshy, indehiscent drupe which is black, blue-black or purple-black - depending on the species - and contains one stone. This stone has a hard, rugose-surfaced coat which protects the seed during the passage of the fruit through the gut of a bird.

The seeds in this genus are characterised by having a small (ie immature) embryo at dispersal. Thus the imbibed seed requires a period of warm stratification to mature the embryo before further activity towards germination can proceed.

There is some evidence to suggest that the flesh of the fruit contains substances which will delay germination if not removed. Thus the seed should be extracted by maceration and limited fermentation when the seeds can be rubbed free and then washed with a small amount of detergent. All the species will mature the embryo after the imbibed seed is warm stratified for 84 days at 25°C. Germination will subsequently be rapid.

The nomenclature of this genus is confusing insofar as there has been much debate about the parameters of species and subspecies determination. The following species all have potential for cultivation in the UK:- *D. angustifolium*, *D. calycinum*, *D. kengii*, *D. longeracemosum*, *D. macropodum* (inc *D. humile*), *D. majus*, *D. oldhamii*, *D.*

paxianum, *D. sentandrum* and *D. teymansii* - especially when collected from their hardier provenances.

Eleagnaceae

This small Family which contains only three genera of shrubs and small trees - ***Eleagnus***, ***Hippophae*** and ***Shepherdia*** - is native mainly to the Northern Hemisphere through temperate and sub-tropical climates but it also diverges through tropical southern Asia to North East Australia.

The great majority of the species are native to xerophytic conditions - sea shores, semi-deserts etc (and indeed some have adapted to halophytic conditions). They tend to be successful in competition, on such depauperate soils, because of their ability to engage in a symbiotic relationship with the actinorrhizal bacterium *Frankia*. Thus they are useful soil ameliorants or can become invasive weeds - depending on the scenario! This competitive ability is also enhanced by their habit of prolific seed production. In many cases they succeed perfectly well as ornamental plants in conventional soil types.

The majority of species are thorny and the leaves and shoots are often covered with scales or hairs - a condition often associated with the need for the plant to conserve water. The fruits are generally fleshy, colourful, edible and highly nutritious and are eaten by a range of animals and birds; hence, in general, the seeds have hard, resistant seed coats (usually the endocarp) to protect the seeds in their passage through the gut - although not always impermeable to water.

Eleagnus

This genus of 'the Oleaster and the Silverberries' contains between fifty and seventy species of deciduous or evergreen shrubs and small trees. It is distributed through temperate and sub-tropical Asia and then via the Philippines to North East Australia and with one species in North America. There are only a relatively few species (probably about ten) which are relevant for cultivation in temperate climates.

The stems and leaves are covered in scales and/or hairs which produce a silvery cast to the overall impression of the plant.

The fragrant flowers are generally insignificant and are produced in late spring. These give rise, in September - October, to a prolific crop of persistent, fleshy drupes,

with edible flesh, which contain one, dry, dehiscent achene.

The fruits are collected by hand - but with care as the fruiting branches can be thorny. The seeds are extracted by maceration of the fruits and then decanting off the pulp and dross. The seeds can then be washed and cleaned fully. Although hard seededness is not a particular problem it would be prudent to process the seeds into treatment without drying.

Generally the seed coat (endocarp) is not particularly hard and imbibition will occur, with fresh seed, as a result of a twenty four hour warm water soak. However if the seed has been dried and possibly stored it would be beneficial to mechanically scarify the sample prior to soaking.

The imbibed seeds are dormant and will respond to a period of chilling of 84 days at 3°C. This physiological control however is not present in the embryo - as excised embryos will germinate in ten days at 20°C - suggesting that the inhibiting agency was in the testa and/or the endocarp. Germination is most satisfactory at 20°C.

Hippophae

The sea buckthorns are a genus of seven species, principally, from warm temperate towards very warm dry climates. The only species which are relevant for cultivation in temperate climates are the native *H. rhamnoides* and the Himalayan, *H. salicifolia*.

H. rhamnoides has a distribution from the Atlantic coasts of Western Europe right across the Northern Hemisphere to North West China and, over this range, is divided into eight sub species. In Western Europe it is generally confined to coastal areas inland as far as the salt spray reaches, as it will tolerate salty conditions. In Central Asia it is a plant of semi-deserts. It is native to and widespread in the UK where it is found above the shore line, in the range of salt spray, in such situations its root suckering habit makes it very suitable for stabilising sandy and dune areas.

In habit it will grow to three or four metres with a dense, stiff structure of very thorny braches; with narrow, silvery green, lanceolate leaves up to 8cm long.

Once mature the plant flowers prolifically, annually. Each inflorescence consists of only one flower which has no petals and develops only one seed. The plants are dioecious.

The roundish, orange, fleshy berry-like fruits are 6-9mm in diameter - juicy, soft and nutritious; they are very high in vitamin C. The berries are prolifically developed in compact bunches along the stem. Nowadays they are grown extensively, throughout the range, as a plantation fruit crop - improved strains with larger fruits and a higher nutritional status have been developed.

The fruits are difficult to harvest as the fruit clusters are liberally interspersed with spines which makes picking intolerable. For seed collection for nursery purposes it is best to shake the braches, when the fruits are soft and ripe, to dislodge the fruit onto a sheet on the ground. Probably only about 25% of the available fruits will fall. The seeds should be harvested as soon they are ripe and processed without delay, as germinability appears to decline the longer the seed remains in the softening flesh. The seeds should be processed without further drying, in order to avoid the possibility of hard seededness developing.

The seeds are extracted by maceration in water so that the skin, pulp and detritus can be floated off.

Although the seed coat is not particularly impermeable to water it will take at least forty eight hours of warn water soak in order to fully imbibe the seed.

The seeds have an endogenous dormancy which requires a chill for 84 days at 3°C to overcome. Germination occurs, optimally, at between at 20 and 25°C and seedling emergence will take seven to ten days.

H. salicifolia is from high elevations in the Himalayas and the same comments apply as above. However the chilling period is for 35 days (although lower elevation provenances may well not require this). Germination occurs optimally at 25°C.

Both species appear to benefit from shallow sowing (ie just covered) and the seedlings flourish best in full sun. These are plants that grow in full sun and dislikes shade.

Shepherdia

The Buffaloberries (***Shepherdia***) of the west and north of North America are a small genus of three species. They are shrubs to small trees inhabiting, generally, areas of dry and poor terrain. The branches are thorny and the leaves and stems are covered in small star-shaped scales which give the plants an overall silver sheen.

The plants are dioecious and the flowers are carried singly or in clusters in the spring. They are without petals and are yellow to yellow-green in colour.

The fruits mature in the late summer and are drupe-like - about 3-8mm in diameter and each contains one achene. They are red skinned and fleshy - which is bitter to the taste. The smooth achenes or nutlets can have hard seed coats (significantly so in *S. canadensis*).

The fruits are collected by shaking from the branches when ripe - as the plants are thorny and hand picking is hazardous.

The seeds are extracted by maceration in water so that the skins, flesh and detritus can be floated off and the seeds washed clean. As the seed coat can harden when dried it is prudent to process the seeds into pregermination treatments straight away.

The seed coats of *S. argentea* and *S. rotundifolia* can be effectively penetrated by an extended warm water soak (ie several days). The seed coats of *S. canadensis*, however, are harder and although the recommendation is to scarify with a short sulphuric acid soak; an aggressive and abrasive scarification can achieve the same result but with safer process. This is followed also by the warm water soak.

All the species require a chill to overcome a physiological dormancy - *S. argentea* for 84 days, *S. canadensis* for 49 days and *S. rotundifolia* for 63 days at 3°C. *S. canadensis* especially will germinate (at least to radicle emergence) at this low temperature so it is wise to monitor the

stratifying seed and to sow the seed lot once this stage is reached. Germination at 20°C is optimal for the germination of all the species.

Moraceae

A large Family of some 1400 species attributed to forty genera. It is principally tropical and subtropical in distribution and contains entities from herbaceous plants (although somewhat woody) to trees. They are usually evergreen; however there are three woody genera with chiefly temperate climate distributions - which are deciduous.

The Family contains *Artocarpus* (Breadfruit and Jack Fruit) and the Figs (*Ficus*). The genera containing species with a temperate provenance, addressed here, are ***Broussonetia*** (Paper Mulberry), ***Maclura*** (Osage Orange) and ***Morus*** (the Mulberries).

These three relevant genera develop 'multiple' fruits which consist of an aggregate of one seeded, fleshy drupelets. In general they are fast growing - especially in the juvenile stages.

Morus

The taxonomy and nomenclature of *Morus* is confusing and unclear, it is usually determined as '10 to 16 species' but in practice there are a few easily defined species which include *M. alba*, *M. microphylla*, *M. nigra* and *M. rubra* and a whole series of indeterminate entities (designated as species) occurring in South East Asia including *M. bombycis* and *M. cathayensis*. In this latter group hybrids are common and they in turn are often fertile - so producing a nightmarish taxonomic scenario!

The genus is deciduous and has a temperate distribution which fringes into the sub-tropical in South East Asia. The species are usually dioecious (sometimes monoecious with flowers on different branches). The inflorescences consist of compound, inconspicuous, oblong catkin-like flowers that are produced in April-May; each fertilised ovule develops into a one-seeded, fleshy drupelet and these aggregate to form the familiar berry-type, multiple fruits.

As the fruits ripen they change colour from pink through red to dark purple - the fruit juice stains dramatically, so that siting trees should be determined to avoid situations where this could be a problem. The fruits ripen in July -August and are some 2cm across; they consist of 12

to 14 drupelets. Each has a very thin, membranous coat and the seed is protected by a bony endocarp which, however, is not generally impervious to water. Although the fruits may be formed properly the seed are often void if a pollinator is not present. The fruits are taken by birds.

The fruits can be easily picked (wear gloves!) from the tree or from the ground. The seed is readily extracted from the ripe fruits by maceration and the detritus, which floats, is separated in running water. There is some evidence to show that, if the fruit is fermented for a couple of days, any marginal 'hard seededness' which may have developed is eliminated. Normally it would be prudent to give all samples of seed a 48 hour warm water soak prior to treatment.

All of the temperate species benefit from at least a short chill - which synchronises and speeds germination. *Morus alba* and *M. rubra* should be chilled at below 5°C for 35 days while the colder provenance *M. nigra* needs up to 63 days at 3°C. As the seeds are capable of radical emergence at low temperature, the lots should be regularly monitored and if chitting does occur then they should be transferred to suitable temperatures (20°C) for speedy germination.

The seedlings are generally fast growing in their early years but quickly settle out to develop a slow growing habit with an often dense and gnarled appearance

The seedling roots are fleshy and brittle so care should be exercised in subsequent handling.

Broussonetia

This genus of deciduous trees and shrubs is closely related to *Morus*; it contains four species native to Eastern Asia - Japan, China and Korea through SE Asia to India. All the species have a pioneer habit and are capable of being invasive. The species most often encountered is *B. papyrifera* - the Paper Mulberry from China and Japan (in Japan the bark is used for making paper) - it is suitable for cultivation in the UK but in parts of the World (eg Pakistan and the Pampas of Argentina) this potential for invasiveness has made it a pestilential weed. *B. kazinoki* from Japan is also sometimes cultivated. Because these species are dioecious it is necessary to grow several plants if the fruits are required.

The plants flower in April-May - the male flowers are catkin like and on established specimens are prolific, the female flowers are globular about 2cm across with long, hanging styles. The fruits which are orange-red are produced from August onwards, they are spherical, multiple fruits made up of one-seeded, fleshy drupelets. The flesh is soft and the fruits are taken by fruit eating animals and birds.

The seeds are extracted by maceration and then the detritus can be floated off in running water.

The seeds germinate readily at temperatures above 20°C and there is some evidence that light is beneficial.

Maclura

Maclura is a monotypic genus (*M. pomifera*) - the Osage Orange - it is a native of the United States - originating in the Red River Valley but is now naturalised over much of the continent as a result of its use (on government recommendation) as an agricultural 'stockproof' hedge during the nineteenth century. It is a pioneer species and can grow into a tree to 15m tall. It is deciduous and the simple leaves each subtend a spine - 2 to 3cm long and which is quite formidable. It is hardy enough to succeed in cultivation in most of the UK but as the plant is dioecious; seed production depends on the presence of plants of both sexes.

The inconspicuous flowers are produced in early summer. The female trees may still produce normal looking fruits - even if not pollinated - but the drupes are seedless.

The fruit is a 'massive' globular unit - often up to 15cm in diameter. It consists of an aggregation of one-seeded drupelets which are coalesced on the surface (making it bumpy in appearance) and the centre of which is filled with a white latex type material. This fruit is initially green but becomes yellow at maturity.

The seeds are extracted by harvesting the ripe fruits - slightly macerating them and then leaving them to 'rot' and ferment slightly in a warm situation. The whole mass can then readily be squashed in water, gently macerated and the seeds separated and washed clean.

The seeds can then be surface dried when they can be stored in the short term at cool temperatures. Germination will occur without pre-treatment but the most satisfactory and productive germination will occur if the seeds are given a 24 hour warm water soak and then chilled for 35 days at 5°C and then germinating at 20°C.

Pittosporaceae

This relatively small Family, of nine or ten genera and somewhere over two hundred species of trees, shrubs and climbers, is found from Australasia, through Oceania to tropical Africa and India and into Eastern Asia. It is chiefly tropical and sub-tropical in its distribution but ranges into temperate climates at the margins.

The Family appears early in the evolutionary development of the Angiosperms and this situation is typified by the embryo of the seed being differentiated but small in size (immature) at dispersal. Thus the imbibed seed requires a period of exposure to warm temperature in order to achieve embryo maturity and hence an ability to proceed to germination.

Those species which fringe into temperate climates include members of the Australian genus **Billardiera** (which now includes **Sollya**) and members of the largest and most widespread genus, in the Family, **Pittosporum**. The monotypic genus **Hymenoporum** *flavum* is grown in warm temperate climates often as street tree.

Billardiera

The genus **Billardiera** consists of about twenty four species of woody climbing plants which are all native to Australia; most are not suitable for cultivation in the UK but the relatively hardy, sparse growing *B. longiflora* is often seen - it is grown for the coloured fruits which vary from white to pink to red to purple to blue (and these variants generally come true from seed). Also seen are the two species of **Sollya** (*B. heterophylla* and *B. fusiformis*) - the Australian Bluebell Creeper.

The fruits are sausage to block shaped, locular, fleshy capsules about 15 to 20mm long and 10 to 15mm broad; these have a brightly coloured skin. The seeds are readily extracted when the fruits are ripe. The many seeds are contained in a sticky mass and the fruits are simply split open by hand and the 'mess' separated - this is then washed to clean the seeds which are then surface dried.

To achieve germination the imbibed seeds are warm stratified at 25°C for twenty one days in order to mature the embryo. The treated seeds can then be sown and

maintained at 18 to 20°C, in the propagation environment, when emergence will occur in seven to ten days.

Pittosporum

The genus ***Pittosporum*** contains about two hundred species of trees and shrubs, which has an extensive distribution from Australasia through Oceania to Eastern Asia - with outliers in Africa. At the northern and southern geographic extremes they fringe into temperate areas. They are evergreen or deciduous.

The following species are all hardy to some degree in the UK, but most will require a mild niche in order to flourish - *P. bicolor* (South East Asia); *P. daphniphyllodes* (China and Taiwan); *P. tobira* (Japan); *P. crassifolium*, *P. dallii*, *P. eugenoides*, *P. obcordatum*, *P. patulum*, *P. tenuifolium* (inc *P. colensoi*), *P. ralphii* and *P. turneri* (all New Zealand) and *P. phillyraeoides* and *P. undulatum* (both from Eastern Australia).

The highly scented, often colourful flowers are produced during the summer. The fruit is a capsule, initially somewhat fleshy and often brightly coloured but which dries to a woody condition and then dehisces violently. The seeds are covered in a black sticky pulp which keeps the seeds adhering to the flat, opened capsule case for several days. The seeds can then be picked off and washed clean.

The imbibed seeds are then warm stratified for twenty one days at 25°C to complete the maturation of the embryo. Germination is then possible at 20°C but in virtually all of these 'temperate' species the process will be attenuated and erratic. Chilling the seed at 3°C for twenty eight days, after embryo maturation, will unify, synchronise and speed germination.

Hymenosporum

The 'Native Frangipani' (***Hymenosporum flavum***) of Queensland and New South Wales is a small evergreen tree with dark glossy green leaves. It is widely cultivated in Australia and California. It produces, in Spring, cream flowers which age to yellow and are 5cm across, they are highly scented - the scent is very similar to Frangipani.

The fruits, which ripen after midsummer, mature as long pear-shaped capsules which ripen to a purple-brown colour and are somewhat woody. At maturity the capsule splits into two and exposes the seeds, these are small, brown and have a membranous wing.

There are no constraints to germination except insofar as the embryo has to mature before the germination process will begin. If the imbibed seeds are sown at 25°C they will mature the embryo and germinate satisfactorily at that temperature and emergence will occur in thirty five to forty two days.

Theaceae

Those genera, in the Tea Family, which contain relevant species with a temperate climatic distribution include ***Camellia***, ***Franklinia***, ***Gordonia*** (excluding ***Polyspora***), and ***Stewartia***. However also included here, as a result of recent DNA assessments by taxonomists, are those genera which were previously designated as belonging to the **Ternstroemiaceae** and have now been subsumed into this Family. Thus ***Cleyera***, ***Eurya***, ***Schima*** and ***Ternstroemia*** which all have species with a warm temperate climate provenance are treated here.

Camellia

This large genus contains more than two hundred species of evergreen trees and shrubs. They are native to Central, Eastern and South East Asia - where they occur from temperate climates to the tropical.

The genus is notable for containing the Tea plant (*C. sinensis*) and several species (including *C. oleifera*, *C. japonica* and *C. reticulata*) which are grown as plantation crops and from which edible oil is extracted by pressing the seeds; this is widely used in China for cooking. *C. japonica*, *C. reticulata* and *C. sasanqua* are among several important 'horticultural' species which have given rise to the vast array of ornamental selections and hybrids - historically in the Orient but in the last two hundred years - around the world.

Virtually all of the species cited above can be propagated vegetatively by stem cuttings but seedling production is necessary for breeding programmes; for the production of the species and for rootstocks for grafting (esp *C. reticulata* cultivars) and for the production of plantation crops for oil production (although elite selections will be propagated from stem cuttings).

Seed production in most of the UK is dependent on high levels of light and temperature during the summer although in milder areas seed production, at least of the hardier species, occurs in most years although, usually, on a limited scale. Seed is not normally produced prolifically until a plant has reached a substantial size and age.

The fruit of *C. japonica* is a dry, woody, three lobed, locular capsule (c25mm across) which contains up to five compartments each with a potential for up to eight seeds. The individual seeds are dispersed when the dry capsule splits in October- November. The seeds are more or less roundish but uneven, about 5mm across and have a brittle skin which is purple brown in colour. The seeds contain high levels of oil and hence quality and viability can deteriorate rapidly without suitable storage conditions - ie water conserving conditions at cool temperature. The fruits of some species (eg *C. oleifera*) are large and can be up to the size of a tennis ball with proportionally large seeds.

When the seed is collected as the fruits split, behaviour in response to the provision of conditions for germination can be erratic. The most consistent results can be achieved by collecting the fruits when they are still soft and shiny and just becoming brown - usually August in the UK - at this stage the seeds are fully isolated and mature. This means that extraction, necessarily, has to be done by hand.

Propagation should then be carried out with this fresh seed. A twelve hour, warm water soak will ensure full imbibition and the seeds can be station sown and maintained at 20+°C for germination.

However those species with the more northerly distributions (this includes *C. oleifera*) will germinate with the above regime but emergence will be slow and erratic. A synchronised, uniform and speedy response can be achieved if the imbibed seed is previously chilled for 63 days at 3°C.

If the seedlings are ultimately to be container grown it is recommended that they are transplanted at germination and that, in the process, the radicle is tipped to encourage a fibrous, branching root system; however if the seedlings are intended for growing in the open ground then the radicle is allowed to develop naturally - as a deeper penetrating root system will be developed.

Franklinia

This narrowly endemic (to Georgia, USA), monotypic genus (*Franklinia alatamaha*) and its story are the stuff of legends - it has not been seen in the wild since the late

eighteenth century. Fortunately it was found and collected by Samuel Bartram and so has survived in cultivation. It is a small tree with thick, shiny, bright green leaves and spectacular white flowers - in the autumn - but, usually, only after a hot summer. These are five-petalled, 7 to 9cm in diameter and are produced solitarily in the leaf axils.

The fruit is a five-valved, globular, leathery, fleshy capsule maturing to a woody dehiscent condition. Each cell contains 6 to 8 wingless, angular seeds - 12 to 14mm long, which are dispersed in the following autumn.

The fruits should be collected just before they open and are then gently dried - when the seeds will shake out. Viability is generally low.

Germination of the imbibed seeds at 20°C will occur but a synchronised and speedier emergence will occur after a chill of 30 days at below 5°C.

Gordonia

This genus of evergreen trees and shrubs has, nowadays, been drastically reduced in size as the majority of species, which were included have been transferred to the genus *Polyspora* - and these have warmer provenances in South East Asia than the climates represented in these notes. *Gordonia lasianthus* - the Loblolly Bay occurs in various disjunct populations in the South East and South of the United States; it is an evergreen large shrub or small tree.

The white flowers are produced, singly in axillary clusters, at midsummer and are sweetly scented.

The fruit, which is produced in October, is a five-valved, dehiscent, locular, ovoid, woody capsule which sheds its seeds by December; about 12mm in diameter and 20mm long. To avoid losing the seeds to an early dehiscence the capsules can be collected when they are still 'leathery' and brown and then gently dried in a paper bag until they open and the seeds can be shaken out; do not overdo the drying as this could lead to a loss of viability. Each fruit produces between 10 and 40 smallish, winged seeds.

There are no constraints to germination and at 20°C the imbibed seeds will emerge in 7 to 10 days.

Stewartia

This small genus of decorative small trees and shrubs consists of between eight and twenty species native to South Eastern Asia, China, Japan and Korea with two species (*S. malacodendron* and *S. ovata*) found eccentrically in the South Eastern United States. They are deciduous (the evergreen species are assigned to *Hartia*). All the species are ornamental - for their autumn colour; their late flowering habit (July and August) with showy white flowers which are produced prolifically for several weeks and their brilliant 'orange' and flaking bark during the winter.

The relatively large fruits are five-valved capsules - more or less globular but with a 'beaked' shape at the top; they are initially leathery but mature to be woody; each locule contains, normally between two and four seeds. They dehisce and disperse the seeds quite quickly when ripe. Thus they should be collected, at the latest, as the first fruits dehisce and gently dried in a paper bag - the seeds separate readily from the capsules to produce a clean sample - however in *S. malacodendron* the seeds are tightly packed in the capsule and have to be persuaded manually to release! At maturity the seeds have a high water content (c80%) and viability, naturally, declines quickly - especially if dried - thus it is important not to dry any more than is required to extract the seeds and even in short term storage it is essential to maintain the water status - so store under water conserving conditions.

As the seeds require a long pre-treatment prior to germination (naturally the seeds do not germinate until the second spring following dispersal) it is the practice to collect the fruits at an immature stage - as the embryo matures early in the development of the fruit. Hence the fruits can be collected as they change colour from green to brown. This early collection will allow the treatments to be carried out in time for germination during the following spring.

Seeds of *Stewartia*, effectively, do not germinate after a simple exposure to warm temperature after imbibition. In order to germinate the seeds require a relatively long period (84 days) of warm stratification (but it is not clear what action is promoted within the seed) followed by a substantial chill to overcome an endogenous dormancy -

the recommendations of up to seven months of chill for maximum germination response, however, seem to be excessive as none of the species experience such exposure in their natural habitats. The sanest protocol offered is:-

- a) twenty four hour warm water soak to achieve imbibition;
- b) four months period of warm stratification;
- c) three months chill and
- d) germination at relatively cool temperature - c15°C.

There are four genera of the 'old' **Ternstroemiaceae** - with species which have a temperate provenance - **Cleyera**, **Eurya**, **Schima** and **Ternstroemia** which are included here. They are dealt with, collectively, in one package as they do not have any particular issues in relation to the germination of their seeds. All of these genera are principally tropical and sub-tropical in their distribution chiefly in Southern and South Eastern Asia; however a very few species have a warm temperate provenance - eg **Cleyera japonica**, **Eurya japonica**, **Schima argentea**, *S. khasiana* and **Ternstroemia gymnanthera** - and can be cultivated in milder niches in the British Isles.

They are all evergreen trees or shrubs and have scented white or yellow flowers - which mature to capsules (a berry in *Ternstroemia*) from which the seeds are readily extracted.

Germination of the imbibed, viable seed at 20°C is normally prolific.

Ericaceae

This very large Family, of four thousand or so species, is segregated into about 126 genera and these are then categorised in nine sub-families - with further subdivisions in the larger groupings.

In habit it is extremely diverse - from trees and shrubs to dwarf shrubs, prostrate creepers and herbaceous plants. The species tend to occupy and tolerate acidic, depauperate, infertile soils and/or hostile conditions - often in extremes of arid, cold or damp conditions. They make mycorrhizal associations to compensate for this - some having complex arrangements. In general the species are evergreen.

The Family is virtually world wide in distribution - from the tropics outwards in both Hemispheres. The genera which appear below - itemised in their sub-families - contain species which have a distribution in temperate, alpine and sub-arctic climates and are suitable for cultivation in the UK - although often only in particular niches.

The Family is characterised as producing 'dwarf' seeds - ie small seeds with an immature (undifferentiated) embryo. The dormancy characteristics are not entirely predictable - in general the seeds, although requiring light for germination (even at only a short (30 minutes) duration per diem) - germinate at relatively high temperatures (20-25°C) and do not exhibit any other constraints. However seeds of some species with cold temperate distributions - or other environments which experience cold winter temperatures (eg semi-desert in warm temperate areas) will respond to a period of chilling although it is not essential in order to achieve some germination.

A few genera have species which produce seeds with a protective hard seed coat or fruit covering (endocarp). This provides protection during passage through the gut after ingestion by a bird or animal and it also provides protection during wild fires - although it is not, always, necessarily a barrier to imbibition of the seed. Those species (from fire ecologies) are often triggered for germination not by the passage of heat but by the products of the fire ie smoke constituents and/or the leachate from burnt material (charate).

As with many subjects which produce small seeds, the seed samples often contain a fair proportion of non-viable seeds. These non-viable seeds tend to be small and light and can be distinguished from the plump viable seeds (although making this distinction may need the use of a lens).

Collection and Extraction

The fruiting bodies vary from dry locular capsules (eg *Erica*, *Kalmia* and *Rhododendron*) containing several to many seeds to fleshy, usually globular 'berries' which may contain one or more seeds (eg *Gaultheria*, *Vaccinium*, *Arbutus* and *Arctostaphylos*).

There is however still considerable diversity within these parameters in the characters of the fruit produced but effectively these can still be categorised into two broad groups.

a) sub-families with **fruits consisting of dry capsules** - these are usually made up of five locules which contain the seeds. These are produced in the late summer or autumn and gradually dry as the season progresses. When mature each capsule splits longitudinally liberating the seeds. The capsules are collected prior to this stage and then dried in a paper bag until they open - when the seeds can be shaken out; otherwise they can be broken up with gentle crushing. The seeds can be separated from the detritus by sorting the larger pieces and then the seeds can be separated from the dust and non-viable seeds by gently vibrating down an inclined sheet of rough surface paper (or cloth attached over a board) - so that the plump viable seeds travel all the way to the bottom leaving the lighter material snagged on the surface. This detail is relatively important if it is intended to sow known numbers of seeds in order to achieve a particular population of seedlings in a container.

b) sub-families **producing fleshy fruits** - generally described as berries - this fleshiness may be 'juicy' (eg *Vaccinium* and *Gaultheria*) in consistency or can be 'mealy' (eg *Arctostaphylos*). The seeds are extracted from juicy berries by the gentle maceration of the ripe fruits until the seeds disengage from the other constituents. The material is then swirled in water in a suitable bowl so that the viable seeds fall to the bottom and the dross can be decanted off - it will probably be necessary to repeat

the process in order to obtain a clean sample. The seeds can then be surface dried to allow the seeds to be sown evenly. Extraction from mealy berries can be achieved in the same way or the fruits can be dried and then crushed to separate the seeds from the capsules and then treated as for seeds originating from capsules.

Germination - generalities

In general there are some universal applications, throughout the Family, which can lead to more assured germination and establishment. The process for sowing and germination although basically simple can vary considerably in detail according to the subject, the operator and the sophistication of the conditions and materials available.

The process should be conducted with fresh seed (ie from the current season's crop) as storage (under practical conditions) does not usually extend economic life for twelve months.

Seed imbibition

The technique required for the imbibition of these dwarf seeds will depend on the actual seed size of the individual species. It is probably best achieved by ensuring that the sowing medium is sufficiently damp either before or immediately after sowing and thus allowing the seeds to imbibe *in situ*. 'Large' seeds can be mixed with damp sowing medium for a few days prior to sowing - and the whole sown evenly. It is relevant that during imbibition - however the process is implemented - the temperature is maintained at a reasonably warm level in order to ensure that the process is effective and optimal.

Sowing and the germinating medium

As the seedlings are, initially, usually small it is prudent to provide a fine, even and flat surface for sowing. The fresh, dry seeds are broadcast evenly onto the surface of the compost and left uncovered. The container is then placed under intermittent mist (or similar) until the medium is sufficiently moistened for the seeds to imbibe. It is then necessary to maintain a humid atmosphere in order to prevent any drying of the medium.

Containers

The seedlings tend to produce a shallow and delicate fibrous root system initially - thus the container which holds the germination medium can be quite shallow.

Mycorrhizal association and the production of the medium

It would appear that, in the majority of genera, the roots need to make a mycorrhizal association quite soon after germination in order to achieve successful establishment and growth. Thus it would be prudent to inoculate the medium to ensure that the action of the process is maximised. Most of the relevant fungi require an organic matter base - with an acidic reaction - in which to proliferate.

The sowing medium, which readily fulfils these parameters, is, conventionally, sifted peat moss - this should have a uniform structure throughout its profile - whether it is extended with an inorganic material (to improve the air filled porosity) is a matter of individual circumstances and management system. This sowing medium is most easily inoculated before sowing - this can be achieved if the coarse peat and the inoculum are thoroughly mixed prior to sifting so that the medium is inoculated uniformly. The most suitable inoculum is obtained by collecting the immediate surface soil scraping and the lower strata of decomposing leaf litter from a planted stand of an ericaceous species (as closely related as is feasible) - this material will usually contain the necessary 'ericoid' fungal associates.

Summary

The germination medium should therefore be:-

- a) acidic,
- b) uniform in particle size, compatible with seed size and the subsequent separation for moving the seedlings on,
- c) capable of water retention,
- d) capable of maintaining adequate aeration,
- e) of a suitable organic constitution to support fungal activity and
- f) contain sufficient and suitable fungal associates.

Light

The germinating seeds require light to trigger germination and are thus best sown on the surface of the medium and then maintained in an environment with natural light and daylength - although observation has found that very limited photoperiods of exposure (as little as half an hour per diem) may be sufficient to provide the required stimulus for many species. Germination should be programmed

to occur as daylength increases in order to provide as long a growing season as is feasible.

Temperature

Germination is temperature driven - with greater success as temperatures rise from low levels; generally the seeds of all species tend to emerge most successfully in the range of 20 to 25°C - with some evidence that temperatures above 25°C starts to see a decline in numbers emerging.

Seed Chilling

As has already been alluded to above, there are many species which are native to cold temperate environments, which will exhibit a vastly improved germination response, both in terms of the speed and the synchronisation of seedling emergence, following a period of chilling. However the issue with seeds which are so small - is how to achieve this effectively. It will prove tedious to try and treat the seeds in a conventional way - as mixing the seeds with a suitable extending medium (with an adequate aeration and water holding capacity) and then trying to sow this evenly after chilling becomes difficult. On a relatively small scale it is simplest to chill the seeds once they have been sown and the medium is moist - ie to place the container with the sown and imbibed seeds into refrigeration for the determined period. During this period it is important that the medium does not dry (as the seeds are surface sown). This can be achieved if the container is enclosed in a polythene bag (or other method which achieves the same end). As this system depends on a satisfactory imbibition of the seeds, for effective chilling, it would be prudent to leave the sown container in a warm environment for a few days prior to treatment, both to ensure imbibition and the commencement of embryo maturation should this be needed.

It is apparent that during the process of chilling that the presence of light is not required.

Moisture

After sowing it is of paramount importance that the medium is kept adequately moist by maintaining a humid atmosphere but still maintaining a high degree of air filled porosity in the medium.

The Effects of Fire

There are many species in this Family which are native of various fire ecologies (eg *Erica* species in the Fynbos of

South Africa and *Arctostaphylos* in the Chaparral and Scrub communities in California) in which germination is promoted by the passage of wild fire - rarely is the effect one of the effect of heat, almost invariably the effect in promoting germination is attributed to the penetration of smoke or the leachate from the charred remains of vegetation on the surface. For such species the use of commercially available 'liquid smoke', to treat the seeds initially, is the most practical option.

Nomenclature

Below are listed the genera which are potentially relevant to these notes. They are dealt with in relation to their current taxonomic positions in the sub-families and using what are currently designated as the recognised generic names (2012).

Hence the following do not appear - *Bruckenthalia* (*Erica*), *Ledum* (*Rhododendron*), *Leiophyllum*, *Loiseleuria* (*Kalmia*), *Menziesia* (*Rhododendron*) although *Pernettya* still appears until it is amalgamated officially into *Gaultheria*.

Enkianthoideae

Enkianthus

This genus consists of about seventeen species from Eastern Asia in temperate to sub-tropical niches. They are very ornamental, deciduous, small trees and shrubs which are noted for their prolific flowering and intense autumn colour. The veined flowers - white, yellow or pink, are produced in May and develop dry, beige to brown capsules in the autumn; each capsule containing three to five, very small, dust-like seeds. *E. campanulatus* is fairly widely grown but generally the genus is not fully exploited in the UK.

There are no dormancy constraints to germination which succeeds best at 20-25°C.

Arbutoideae

Arbutus*, *Arctostaphylos*, *Comarostaphylis*, *Ornithostaphylis* & *Xylococcus

This sub-family is characterised as having many species which are native in wild fire environments (which implies that germination may be enhanced as a result of the passage of fire).

All the species produce medium sized, fleshy, globular fruits and as described above the seeds can be extracted either by macerating the fresh fruits, swirling in water and decanting the fruit pieces to allow the seeds to separate and fall to the bottom or allowing the fruits to dry and crushing the fruits to a powder, when sound seeds can be separated by sieving.

Arbutus

This small genus has a limited distribution. It has an evolutionary history which has produced two disjunct populations. One in the Old World - the Mediterranean Basin, some Atlantic Islands and Western Europe (the Strawberry trees) - which includes *A. unedo* (also in SW Ireland where it is a remnant of the Lusitanian flora), *A. andrachne*, and *A. canariensis*; the other in the New World - Western North America - chiefly in warm temperate areas, the Madrones (Spanish for Strawberry tree) which includes *A. menziesii*, *A. arizonica* and *A. xalapensis*.

The genus consists of up to 14 species (depending on the taxonomic view) of trees or shrubs, which are evergreen, have exfoliating bark in summer which is orange to mahogany red in colour. The flowers are small, white - sometimes pinkish and bell shaped (similar to *Arctostaphylos*) in pendant clusters, the flowers are followed by the edible, fleshy, red fruits.

The fruits are collected in the late autumn when they are ripe and soft - prior to this if they are being predated by birds. The seed coat is brownish black to black. Best results are produced from the current season's crop of seeds - ie fresh, unstored seed.

Germination will usually occur at some level without pre-treatment at 20-25°C. However the seeds from more northerly provenances (eg *A. menziesii*) and temperate semi-desert conditions (eg *A. xalapensis*) respond to chilling at 3°C for 49-63 days while *A. unedo* responds to 63 days. With this pre-treatment germination will be more rapid, better synchronised and will occur at the low temperature range of 15-18°C.

Arctostaphylos

This genus of small trees and shrubs (the Manzanitas) is chiefly from the West and South West of North America (90% in the Californian floristic province). There are also

three species (the Bearberries or Kinnikinnick)) which are circumpolar in distribution and have a cold temperate (high montane) to sub arctic occurrence in the Northern Hemisphere. This evergreen genus contains about 55 to 60 species (depending on taxonomic niceties). Most of the more southerly species are natives of wild fire ecologies.

The drupe-like (usually globular) fruit contains a single nut-like structure with a hard bony endocarp which contains two to ten seeds which are individually nut-like and may be separate or sometimes fused together - they also have a hard coat.

The seeds are extracted, conventionally, by maceration etc of the fruit and liberating the seeds by twisting and breaking the endocarp.

Most species (the Manzanitas) are native to fire ecologies and there is virtually no natural regeneration until the passage of wild fire when subsequently germination is extraordinarily prolific. However seed germination is not triggered by heat - it would appear that the leachate of the charred remains of relevant woody vegetation (charate) is the trigger. In artificial conditions the use of commercial 'liquid smoke' is effective. Domestically the burning of suitable vegetation and leaching the charred remains onto the imbibed seeds is also possible. The hard seed coat itself is normally impermeable to water but the presence of a small 'hole' (periole) allows the uptake of water. References to the need for acid scarification is thus likely to do more harm than good. Germination is then normally prolific at 20°C or above.

The Bearberries (*A. uva-ursi* etc) do not respond to this treatment but do benefit by chilling the imbibed seeds at 3°C for 35 days.

Cassiopeoideae

Cassiope

This genus of nine to twelve species of small, low growing, sub shrubs has a circumpolar distribution in the Arctic and from there southwards in high montane areas (eg *C. mertensiana* as far down as California).

They are characterised by their bright green leaves which are tightly adpressed to the stems and the brilliant white flowers. The fruit is a dry capsule which contains many

seeds - the viability of which is influenced by the length of the particular summer - ie the time between snow melt and the first snow fall and hence the amount of time available for carbon assimilation. The various species are cultivated in specialist conditions such as peat banks and alpine gardens.

The capsules can be collected before they split to release the seeds and then dried in a paper bag and shaken to liberate them. The fresh seed will then germinate without pre-treatment although a more uniform and speedy emergence is achieved after a chill for 21 days at 3°C. Germination will occur prolifically at 20°C.

Cassiopeas demonstrate a particularly integrated mycorrhizal arrangement (the mycelium penetrates and ramifies through most of the plant) and these fungi are an essential component of successful growth patterns and establishment. Thus the inoculation of the medium, preferably with leaf litter from existing plants, is a significant part of the propagation process.

Ericoideae

Empetrum

This genus is attributed, by some authorities to its own Family - **Empetraceae**. It contains up to four species which have a circumpolar distribution in the very north of the Northern Hemisphere. All the species are low-growing subshrubs that act as ground cover in coniferous forest.

The flowers are hermaphrodite and produce the fruit in one season. The fruit is a black, soft, thinly fleshy drupe which contains up to 9 pyrenes ('stones'). The seeds are extracted by gently macerating in water and squeezing to separate the stones; they are then washed thoroughly to remove any remaining flesh and then surface dried for short term storage.

The seeds show low viability - usually about 50 to 60%. The viable seeds are plumper than the unfilled and can be identified visually and are easily separated.

The seeds have a stony endocarp which has traditionally been regarded as impermeable to water; which has engendered recommendations for acid scarification and/or warm stratification. However recent critical observations have determined that this coat is not impermeable. However the

warm stratification is essential for the complete 'maturation' of the imbibed embryo - ie before treatment by chilling can begin effectively.

Seeds will imbibe rapidly in a warm water soak completing water uptake in about three hours.

A protocol to achieve germination consisting of:-

- a) 12 weeks stratification at 20°C,
 - b) 20 weeks chilling at 3°C (which can be conducted in the dark) and
 - c) germination, in light, at 20 to 25°C
- will deliver c90% germination.

Calluna, Daboecia & Erica

These three genera tend to occur in temperate climates and all have species native to the UK - where they principally occur in moorland and heathland. The largest genus - *Erica* - has a wide geographic distribution with a centre of diversity in South Africa chiefly in Mediterranean climate conditions (Fynbos).

The fruit is a dry, five-valved, locular capsule which can be readily collected and extracted in the late summer to autumn. Extraction of the seed can be achieved by crushing and shaking but usually by drying in a paper bag and then shaking to liberate the seed and so produce a sufficiently clean sample.

The South African species, which are native to areas subject to wild fire, will germinate much more effectively if the seed is soaked in a solution of commercial 'liquid smoke' prior to sowing although this is more practically achieved if the imbibed, sown, seed is watered in with the material.

The received wisdom suggests that there are no dormancy constraints to germination in the cold temperate Eurasian species and that they will germinate successfully at suitable temperatures with no pretreatment; however the germination response for these species will also benefit from smoke treatment and will promote a greater proportion of seedlings to emerge.

As would be anticipated, light is necessary for speedy and synchronised emergence.

Bryanthus* and *Elliottia*, *Epigaea*, *Kalmia*, *Kalmiopsis*, *Phyllodoce* and *Rhodothamnus

This group of closely related genera - each of which has only a few species or is monotypic; are all native to temperate to cold temperate climates in the Northern Hemisphere. They all produce dry fruiting capsules in the autumn, these should be collected prior to dehiscence and dried in a paper bag and then shaken to release the seeds - this produces a relatively clean and usable sample. Sometimes capsules persist until the following autumn but the current season's crop should be collected and only fresh seed used.

All the species will show some germination without pre-treatment; however there is widespread evidence and much practical experience that demonstrates that a chill period of 35 days at 3°C enhances the speed of germination and increases the number of seedlings and the synchronisation of seedling emergence at 20°C.

Rhododendron

This very large genus, with a virtually worldwide distribution, consists of around one thousand species which vary in size from substantial trees to procumbent shrubs. They can be evergreen or deciduous and terrestrial or epiphytic. There are very many ornamental species which are suitable for cultivation in temperate climates.

They produce dwarf seeds which are generally quite small and these are produced in dry, locular capsules.

They do not exhibit any dormancy controls although there are some cold temperate species which show improved germination after chilling.

The dry (brown) capsules are collected just prior to dehiscence; drying is continued in a paper bag (of a relevant size) until the seeds can be liberated by shaking - when a clean sample will be produced.

Germination is generally most prolific at 22-25°C, light is required for a least part of the day - there will be no germination in continuous darkness.

This genus is generally obligate in relation to the development of a mycorrhizal association.

Styphelioideae

Epacris*, *Cyathodes* & *Leucopogon

These three genera mostly have a tropical to warm temperate distribution - the relevant, sufficiently hardy, species suitable for cultivation in the UK are mainly found in the Antipodes. They are closely related and previously were attributed to their own Family - **Epacridaceae**.

They are evergreen generally small, low growing, heath-like shrubs. The fruits of ***Cyathodes*** and ***Leucopogon*** are colourful berries while those of ***Epacris*** are five-valved capsules containing numerous seeds.

The brown-black seeds are small and the available reports on successful germination tend to be eccentric and erratic.

In the absence of any immediate knowledge or experience of the germination of the seeds of this group of plants, the only general trends to be extracted from the available reports suggests that the seeds of all of these plants benefit from a period of warm stratification and those at the temperate extreme from a short period of chilling.

Vaccinioideae

Andromeda* & *Zenobia

These two monotypic genera are both natives to damp bog type conditions - ***Zenobia pulverulenta*** limited to the Eastern USA (North and South Carolina and Virginia) and ***Andromeda polifolia*** with an almost circumpolar distribution in the northern parts of the Northern Hemisphere. Both are evergreen shrubs although in cold conditions *Zenobia* may be semi-evergreen.

The fruiting bodies are brown, five locular, dry capsules. Germination occurs most effectively in the range 18-22°C although the speed and synchronisation of emergence was improved in *Zenobia* by chilling for 56 days at 3°C; *Andromeda* shows little response to chilling other than to speed emergence by a couple of days.

Chamaedaphne*, *Gaultheria*, *Leucothoe* & *Pernettya

The Leather Leaf is the sole species of the genus ***Chamaedaphne*** (*C. calyculata*). It has a nearly circumpolar distribution in northern latitudes of the Northern Hemisphere. It is a small wiry shrub with white flowers. The fruits are round, dry capsules which are developed in the late summer.

Fresh seed should be used and is sown in the usual way, imbibed in the warm and then chilled for 28 days at 3°C before germinating at 20°C.

The genus ***Gaultheria*** contains about 170 to 180 species which are found in Asia and North and South America. They tend to be small shrubs - often low growing or prostrate - although Salal (*G. shallon*) from the Western fringes of the United States is an upright medium sized shrub. In Australasia the genus is currently separated as ***Pernettya*** but there is apparently no meaningful reason for this distinction. They are chiefly evergreen and occur in temperate to sub-tropical climates.

The fruit is a drupe-like berry usually with a bright red skin but also white, blue, purple, pink and black. The fruits are edible.

The seeds are extracted by maceration. The seeds of all the species would appear to benefit from a short period (28 days) of warm stratification and those from a colder provenance exhibit a faster and more synchronised emergence after a period (35 days) of chilling: a few species from northerly provenances (eg *G. procumbens*) require a chill of as much as 63 days to induce an adequate level of emergence.

The genus ***Leucothoe*** is one of those genera (viz *Wisteria* and *Magnolia*) which have a disjunct distribution in Eastern Asia and the South Eastern United States - which purports to demonstrate the shift of Tectonic plates in the earth's crust. They are evergreen shrubs of no more than medium stature which produce white flowers. Many of the temperate species are cultivated as ornamentals.

The fruit is a dry, valved capsule which contains many tiny, winged seeds - generally the viability is not high. There are no constraints to germination which will occur prolifically at 20°C.

Craibiodendron*, *Lyonia*, *Pieris* and *Oxydendrum

This group of relatively small genera produce fruits which are dry, five locular, more or less globular capsules.

The genus ***Craibiodendron*** consists of about five species of relatively large, evergreen trees occurring in China and

Vietnam, which are not often seen in cultivation in the UK. The capsules contain fewer 'large' seeds than most of the Family.

The genera **Lyonia** and **Pieris** are evergreen shrubs from Eastern Asia and North America. The capsules contain many small seeds - the viability of which is often low, it is therefore necessary to grade the seed - selecting plump seed for processing. There are no constraints to germination, which will occur satisfactorily at 20°C.

Oxydendrum is a monotypic, deciduous, genus from eastern North America. It is a native of wet places and it requires damp conditions for good germination - which occurs most prolifically at 20-25°C.

Agapetes, Gaylussacia & Vaccinium

These three closely related genera all produce edible (in some degree) berry-like fruits which include the Blueberries, Bilberries, Huckleberries etc. Many species are native to cold and cold temperate climates and are cultivated extensively as both ornamentals and fruit crops. However many are also native to tropical and sub-tropical areas.

As all have similar berries the extraction of the seeds is the same ie maceration of the ripe fruits in running water so that the detritus is floated off.

Agapetes (aka *Pentapterygium*) - contains about ten species from the Himalayas. They are scrambling, evergreen shrubs with thin and sparse branches; they mostly occur in warm temperate climates but the spectacular, almost hardy, *A. serpens* can be grown outside in mild areas in the UK, although it is more satisfactorily grown in a conservatory.

The fruits - fleshy berries - are edible but with a bland flavour. Good germination is best achieved with fresh seeds - which are quite tiny. Emergence at 20°C will happen but erratically - better synchronisation and rapidity follows a brief chill of 35 days at 3°C.

The genus **Vaccinium** consists of about 450 species which are distributed chiefly in temperate climates of the Northern Hemisphere although some species are found in places as widely divergent as the Azores, Madagascar and Hawaii. They

are chiefly large bushy to prostrate or dwarf shrubs and are evergreen or deciduous.

The edible fruits (Blueberries, Bilberries, Cranberries, Whortleberries etc) are brightly coloured berries with distinct flavours and are used for a variety of domestic products.

Treatments to achieve the best synchronisation and speed of emergence are particular to individual species.

The seeds of northern species require chilling for 12 wks at 3°C and a high threshold temperature for germination (20°C)

Gaylussacia

The Huckleberries are very closely related to *Vaccinium* and consist of about 50 species - 8 occur in the Eastern United States (mostly in temperate climates), 7 occur in the Andes and the remaining 35 species are found in the mountains of South Eastern Brazil. They can be deciduous or evergreen.

They are distinguished from *Vaccinium* chiefly by the development of an ovary which contains ten ovules and hence the berries contain ten seeds (as opposed to five). The seeds are relatively large, bone-coloured nutlets.

The fruits are fleshy, juicy berries but the number and size of the seeds limit interest as an edible commodity. The seeds are extracted by maceration and usually exhibit a high viability.

The bony endocarp, although 'hard', is not impermeable to water and the seeds will imbibe. However they still require a warm stratification of 30 days at 20°C to 'mature' seed before chilling for 60 days at 3°C. Germination is then prolific at 20°C.

Eucryphiaceae

The genus ***Eucryphia*** is nowadays assigned to its own Family - having, at various times, been placed in the *Cunoniaceae* by several authorities.

The genus contains (currently) seven species - five of which are native to Australia with two in South America. Five species have a provenance suitable for allowing cultivation in the UK - two species from the temperate rainforests of the southern Andes - *E. cordifolia* and *E. glutinosa*; two species from Tasmania - *E. lucida* and *E. milliganii* and one from South East Australia - *E. moorei*.

All the species are evergreen with simple leaves except *E. glutinosa* which can be semi-evergreen to deciduous on its climatic fringes and has pinnate leaves - as does *E. moorei*.

They vary from small shrubs with small leaves to large shrubs or trees - *E. cordifolia* can develop into a columnar tree to forty feet in cultivation. They are generally late flowering with white (sometimes pink) flat to bowl shaped, hermaphrodite flowers - in some species - in *E. glutinosa* the flowers are up to 6cm across and are produced prolifically to give a spectacular display.

The fruit is a dry, valved, dehiscent capsule which dries out in autumn to liberate the small brown winged seeds - often a fair proportion of non-viable seed. The seed has a substantial endosperm with a well defined embryo. There are no constraints to germination which will occur prolifically at 20°C.

Thymelaeaceae

Daphne

This text represents the material from which an article appeared in 'The Plantsman'

The problem of 'hard' seedcoats in seed propagation

Philip McMillan Browse

The seeds of many woody plants develop, during the normal process of maturation, a seed coat condition which prevents the uptake of water (imbibition) so that further progress towards germination is prevented until the condition is degraded and the seed coat becomes water permeable. This situation is recognised as a seed dormancy mechanism.

Many of these conditions of the seed coat are well developed, long term in effect and difficult to overcome artificially; under natural conditions they can take many years before there is a sufficient degradation to allow water to permeate - such seed coats are described as being 'hard seeded'. However in seeds of plants from cold temperate climates this condition rarely needs more than three to four years to degrade by natural methods.

The 'hard seed coat' condition is a developed strategy which may have evolved for any one of several reasons - *inter alia* to protect the seed as it passes through the digestive tract of an animal which has devoured the fruit or to spread germination over several seasons as the variations in the natural processes of seed coat degradation proceed or to be degraded by the passage of heat as part of a fire ecology strategy.

The variety of mechanisms, by which these tough or hard seeded conditions are achieved, are many and diverse - having evolved independently they vary in structure and process virtually family by family - even genus by genus - from the horny or stony seed coats of many leguminous subjects through the hard, somewhat woody, seed coats of *Acer campestre* and the trifoliolate Maples to the softer leathery, external seed coats found in species of *Tilia*.

The mitigation of this problem by the plant propagator is therefore difficult as there is 'no one size fits all' solution.

The conventional artificial treatments for this type of seed coat condition have involved the degradation of the seed coat to the stage that will permit imbibition. This has generally been achieved by:-

- a) scarification - is usually achieved by agitating the seeds with an abrasive grit or passing the seeds through sand or emery paper rollers until the seedcoat is sufficiently reduced; if the seeds are large enough to handle individually they can be chipped or cracked by hand;
- b) caustic digestion - usually using concentrated acid - a hazardous operation and one in which the end point is critical and not easily monitored;
- c) weak acid digestion - normally using dilute solutions of organic acids involving an extended time scale but with less chance of major damage;
- d) warm stratification - with or without an activator - usually a tedious long term process - often with a variable end point as it is difficult to get all the seeds treated uniformly and
- e) hot water and soaking - a technique which may require several iterations.

These processes are all lacking, in various degrees, in precision and are less than suitable for modern commercial seed propagation systems where accurate protocols and production blueprints are increasingly the required norm.

The obvious solution, thus, is to avoid the problem. This can be achieved by collecting and then processing the seed towards germination before the seed coat condition develops to an intractable condition. This simply requires an understanding of the stages through which the seed matures and gauging when the embryo is mature, the food reserve is complete and thus the stage at which the seed coat begins to 'harden' as the seed is isolated from the physiological influences of the parent plant.

A Case Description - *Daphne mezereum*

The genus *Daphne* consists of deciduous and evergreen shrubs and is highly prized for its fragrant flowers and in several species the early season of blossoming. It is native to the Northern Hemisphere across Eurasia.

Flower production, of many species, is early in the year (eg the winter flowering species *Daphne odora* and *D. mezereum*) and is usually prolific. Where pollination occurs fruit production is also substantial. The chief limitation, to the production and development of seeds in the UK, is that the early flowering habit exposes the flowers or the fertilised ovules to freezing temperatures which causes tissue death. Similar conditions may also limit pollination by inducing the absence of suitable pollinators.

However if climatic conditions are suitable then seed production is prolific on an annual basis. This propensity for seed production is also probably associated with the relatively short lived nature of many of the species. Several, especially among the deciduous species, are also prone to infection with a virus disease which causes leaf chlorosis and a major reduction in vigour. However it would appear that this infection is not seed transmitted.

Many of the rarer sorts of *Daphne* and the cultivars, which are not readily propagated by stem cuttings, are often grafted and for this purpose rootstocks are required. The usual species used for this activity - at least for the larger sized species - are the deciduous *Daphne mezereum* and the native, evergreen *D. laureola* - both of which are fairly reliable in seed production in the UK.

The deciduous, early flowering *Daphne mezereum* produces its flowers in February and March on leafless shoots before the leaf buds break. It has been a popular garden shrub for three or more centuries and as such has produced variants of flower colour from white through pink to a deep red. The progeny testing of certain of these colour variants, by growers in the Dutch nursery stock industry, has produced strains which comes more or less true to flower colour.

The fruit is a single seeded berry which matures in the early autumn and is taken and dispersed by birds - particularly Blackbirds. These show a voracious appetite for the fruits and if they are required for conventional propagation should therefore be harvested before the birds start to clear them.

As the fruits ripen the skin becomes red (often yellow in white flowered forms) and the flesh soft. With time if the fruit remains on the bush it gradually dries and becomes black and falls to the ground.

Even with its early season of flowering the production of seed follows the normal sequence of development and time scale and matures early in the summer - although the production of the fruit takes most of the remainder of the summer. The mature fruit does not ripen until the early autumn (usually about September).

The seed has, by this stage, developed a hard seed coat. This 'hard' seed coat condition (which is impermeable and prevents the uptake of water - even with a prolonged soaking) has evolved to protect the seed in its passage through the gut of the bird. The seed coat is much reduced by this process and it is normally degraded sufficiently for water to be able to penetrate into the seed and for imbibition to occur as soon as it is expelled. Although this arrangement works well with Blackbirds the action during the passage through the gut of other species is not always sufficient to reduce the seed coat and a further year's decomposition in the soil may be necessary to allow water penetration.

If the fruits are not taken by predators they simply fall to the ground and remain in the soil. Under these conditions the seed coat degradation process, to a stage at which imbibition will occur, may take as much as three to four years for a complete response. This provides the plant propagator with a definite problem if the often hazardous artificial degradation procedures (such as the use of concentrated acid) are to be avoided.

In this particular species, once the seed is imbibed the embryo still demonstrates an endogenous dormancy control which is, currently, mitigated by a period of chilling.

This species then represents a classic example of the possibility of collecting the seed at an early stage in fruit development in order to avoid the development of this intractable seed coat condition.

Once the embryo has matured and the food reserve is in place, the seed coat begins to develop and isolates the seed. At this stage the seed coat is still soft and permeable and has not 'hardened' to the impermeable state. However the embryo and food reserve may still be losing water as part of the maturation process and this may well be a critical stage - as collection before the seed becomes

quiescent (ie fully matured) could be detrimental. It is necessary therefore to err on later rather than early collection if there is any doubt.

In *Daphne mezereum* the seed has matured by the beginning of June and is effectively complete and isolated from the parent. At this time the fruit tissues are immature and the fruit is little more than a very thin layer of tissue enclosing the seed. The fruit appears as a very small, bright green, spherical, pea like structure. If it is collected at this stage and extracted from the tissue of the fruit it will be found that the seed coat has not hardened appreciably and the seed will be able to imbibe. However it will be important to keep the seed moist to prevent any further development of the seed coat.

A short period of warm stratification will cause the fleshy material of the berry to decompose then the seeds can be rubbed clean, the embryo, in this condition, can and does imbibe and the seed can be transferred to cold stratification. This will allow the mitigation of the endogenous dormancy control which is eliminated by a period of chilling.

The chilling period is not well documented but experience suggests that a period of 63 days at below 3°C should be sufficient to achieve the elimination of the endogenous dormancy condition - as long as the seed is fully imbibed. Chilling for a period of 84 days seems to be the norm for most species - according to the 'handed down wisdom' and it might well be prudent to adopt this figure as no detriment to the subsequent germination phase is incurred by the extended period of exposure. Germination does not begin until a reasonably high temperature is experienced; a temperature of 18 to 20°C will ensure a rapid, uniform and synchronised emergence.

Although it is only in recent decades that this procedure has been reasonably widely adopted the original work was undertaken and published by A J van der Graf in the Boskoop Year Books just after the Second World War.

The principle of collecting seeds with an effectively similar and comparable status (eg *Viburnum lantana*, *Acer campestre*, the trifoliolate Maples, Asiatic *Hamamelis* species and *Fraxinus excelsior*) is in practice much the same - simply assess the development of the seed and

collect and treat as soon as the seed has matured and before the seed coat has 'hardened'.

Some Anacardiaceae

This Family of woody plants is characterised - as far as the seedling propagator is concerned - by the development of hard seed coats which can develop to such an extent that seed coat reduction, to achieve germination, is an issue. The seeds have a hard pericarp which often has a waxy outer layer - this combination prevents imbibition effectively. It is relatively easy to remove the wax - dissolving it in organic solvents such as chloroform or acetone, however the reduction of the seed coat is not so tractable.

Rhus, Toxicodendron, Cotinus Schima

Pistacia

The Pistaches (***Pistacia***) are classified as part of the Family *Anacardiaceae* and are related to *Rhus*. They are a genus of ten to twenty species - the number being dependent on the determination of the parameters for species recognition. They are found in the warm temperate climates of the Northern Hemisphere chiefly in North Africa and Eurasia - most are adapted to succeed in summer drought conditions and saline soils. They are usually shrubs to medium sized trees and can be evergreen or deciduous. In general they all emit an aromatic smell which is acrid or bitter in its basal qualities.

The best known species is *P. vera* - a native of Iran but now widely planted worldwide in suitable situations, it produces the edible seeds known as Pistachio nuts. *P. lentiscus*, *P. terebinthus*, *P. palaestina* (all occur in the region from Iran to the Western Mediterranean) and are tapped commercially for various emissions - turpentine, mastic etc. *P. atlantica* has a wide distribution across North Africa and the Western Mediterranean into Mesopotamia - it can be a dwarf shrub to a medium sized tree depending on the particular environment. *P. chinensis* and *P. integerrima* are natives of continental climate areas in Eastern Asia and have a more northerly distribution than their western allies, they are deciduous and are noted for the development of autumn foliage colour. These latter two species are the only reasonably hardy species.

All the species are dioecious. The flowers are produced in clusters during early summer, they do not have petals and are generally inconspicuous. The fruits are small drupes

(about the size of a petit pois) which mature during late August and September - initially they are red but ripen to brown or blue, however those fruits that remain red do not usually contain a viable seed.

The flesh is not palatable to humans but is taken by birds which devour the fruits quickly - they are a rich source of food for them. The seeds have a 'hard' seed coat which protects the seed in its passage through the digestive process, which however is not a problem even when extracted artificially unless the seeds are subsequently dried excessively.

The seeds have short longevity (less than a year in nature) but can be stored dry for a couple of years at low temperature.

The fruit pulp contains inhibitors to germination so that extraction needs to ensure that this is completely removed (maceration, fermentation and rigorous washing). Void seeds can be floated off during the process, leaving a viable clean sample.

Germination of imbibed seeds is fairly straight forward, under nursery conditions the optimum (ie speediest and most uniform emergence) response occurs after chilling the sample at 3°C for 30 days and germinating at 20+°C with emergence in 7/8 days.

The more northerly species, especially the Chinese Pistache, respond to chilling for 42 days at 3°C - although, without a chill, seeds of all species will germinate but emergence is much slower and is erratic over several weeks beginning after about 30 days when germinated at 20°C.

Hamamelidaceae

NH N. America, Caucasus to Eastern Asia
Genera with a principally temperate distribution
Early flowering
Fruits capsules +/- violently dehiscent
Seeds usually complete and mature quite early in the season
ie well before the capsule starts to mature

Corylopsis
Disanthus
Distylium
Exbucklandia
Evergreen trees with large foliage reddish when young
Infl 7-16 fls in lf axils small herm
Fr a 4valve capsule
Ea valve 2 locular ea loc 5-7 seeds only basal 2 fertile
narrowly winged

Fothergilla
Hamamelis
Loropetalum
Matudaea
Parrotia
Parrotiopsis
Rhodoleia
Sinowilsonia
Sycopsis

Fothergilla 2 spp native to the SE US, and SE China?
fall colour
White bottle brush flowers monoecious
Dense terminal spikes- apetalous with prominent filamentous
stamens
Fruit beaked, strongly dehiscent

Juglandaceae

This relatively small Family contains eight genera and about fifty species of trees (and sometimes shrubs). It is native across the Northern Hemisphere but edges south of the equator down the Andes in South America; it is not present in Africa or Australasia. It has a temperate to sub-tropical distribution with five, deciduous genera (**Juglans**, **Pterocarya**, **Cyclocarya**, **Platycarya** and **Carya**) having all or some species with a distribution in temperate climatic areas.

The genus is characterised by large, aromatic, alternate, pinnate leaves - often up to 100cm long. The pith is generally soft or more usually hollow - sometimes chambered and in one genus it is solid. All the species are monoecious with the male flowers being of a 'catkin' type structure and the female flowers being squat and pointed. Pollination is by wind.

The fruits vary in structure being winged in those which are wind distributed and fleshy in animal dispersed types. Seeds store their food reserves largely as fats or oils which has implications for storage conditions and potential longevity.

The genus contains several economically important species - Walnuts, Butternut, Pecan and Hickory.

Carya

Juglans

Platycarya

Monotypic genus *Platycarya strobilacea* native to Eastern Asia - China Korea and Japan although some authors accept two additional species by separating the more extreme variants - however the variants are clinal in their distribution.

In the wild a scrubby shrub but in cultivation when grown on good soil with adequate space will grow into a tree to 12m.

Solid pith

Monoecious Fls May -June

Male catkins erect cylindrical 2-15cm long surrounding the female flowers - female flowers erect, rigid, cone-shaped

structure 2.5 to 5cm long, smell of apples; matures from yellow green to bright chestnut and then to dark tan as the seeds are dispersed

Fruit a woody cone made up of spirally arranged scales

Seeds - a two winged samara

24hr soak, Stratify for 84 days @ <3 C germinate @ 20C

Pterocarya

Wingnuts 6spp

Asiatic deciduous trees, pinnate leaves chambered pith

Monoecious

Inflorescence catkin like, fls greenish

Male catkins borne singly

Fraxinifolia Caucasus SW Asia 50cm long rhoiifolia

Japanese 20cm stenoptera E china 20cm - temp dist

Fruit

Single Seed a nut with two opposite lateral wings

Soak 24 hours, strat for 35 days @ 3C, germ @ 20 C

Sten narrow and erect wings

Cyclocarya

Monotypic C paliurus E and C China

Decid to 30m, lvs pinnate

Separated from Pterocarya - male catkins in clusters (not singly) & a continuous wing surrounding the nut as opposed to two lateral wings

Some Oleaceae

A large genus -
Subdivisions of the Family
Jasmineae - Jasminum, Menodora
Fraxineae - Chionanthus, Fraxinus
Forsytheae - Abeliophyllum, Forsythia
Oleae - Ligustrum, Olea
Syringeae - Phillyrea, Syringa

Chionanthus

The Fringe Trees (***Chionanthus***) are a genus of two species of deciduous shrubs or small trees - one of which is native to eastern North America (*C. virginicus*) and the other (*C. retusus*) is native to Eastern Asia (China, Korea and Japan). Sometimes the genus is described as containing 80+ species but this number is arrived at by the inclusion of evergreen, subtropical and tropical species which are usually consigned to the genus *Linociera*.

They take their name from the drooping, feathery, axillary panicles of scented, white flowers - which are produced during mid-summer and are characterised by the thread like extensions of the corolla lobes.

The plants are functionally dioecious and so fruit production, with viable seeds, will only occur where both male and female plants are growing in reasonable proximity.

The fruit is a single seeded drupe which in *C. retusus* ripens to blue-black and is 1.0 to 1.5cm long and in *C. virginicus* ripens to purple and is 1.5 to 2.0cm long. These drupes are relatively small initially and are green in colour - they will normally ripen in the early autumn.

The seeds have a hard seed coat which protects the contents from damage during passage through the gut of the vector - which is either a bird or a rodent. The seed coat does not however become water impermeable.

In nature the seedling does not usually emerge until the second spring after dispersal - a condition normally associated with hard seed coats but in these species is due to the presence of epicotyl dormancy requiring a period of chilling to initiate the emergence of the epicotyl. As both species have a considerable north-south distribution in the

Northern Hemisphere it is probable that the period of chilling will vary according to provenance and that the more southerly distributions will require less chilling.

The fruits should be collected by picking from the tree before they are taken by birds - or earlier if treatment to foreshorten the dormancy effect is to be undertaken. The seeds are extracted by macerating the fruits and then fermenting them in warm water for three days or so, when the seeds will sink and the dross and liquid can be decanted off. The seeds can then be washed clean and kept in the short term under water conserving conditions at low temperature.

The imbibed embryo responds initially to a period of warmth, during which time the embryo will develop to radicle emergence and as this stage is reached the epicotyl will show signs of development but further growth is quickly arrested until the embryo has experienced a period of chilling. After a suitable period of chilling the epicotyl is no longer constrained and will grow and emerge when it is exposed to warm temperature.

Under artificial treatment - if the imbibed seeds are stratified and initially exposed to warm temperature (20+°C) for 90 days and then transferred to chilling (3°C) for a further 70 days, sown and given an environment of 20°C - the seedlings will emerge in seven to ten days. This protocol does not normally produce radicle emergence to any great degree so that sowing is not complicated by any extensive root development. However the sample (especially if it is from a southerly provenance) should be examined regularly so that if radicle emergence and root development does occur earlier in the treatment, it can then be transferred to the chilling phase and so avoid subsequent difficulties.

This total time scale (ie in days) required for collection, extraction, warm stratification, chilling and germination; can then be related to the nominated time (ie date) proposed for emergence and by counting back will determine the date for harvesting the fruits.

Fraxinus

The Ashes (***Fraxinus***) have a distribution throughout the temperate climates of the Northern Hemisphere but this

reaches south to the sub-tropics in Central America. In common with many other genera, the nomenclature in the genus *Fraxinus* has been significantly re-aligned as a result of modern genetic analysis and several 'well known' specific names have disappeared and these entities now appear in wider spectrum species. Many of these absorbed 'species', however, represent sufficiently divergent genetic entities (even if only marginally different in the critical genetic markers) and are worthy of propagation in their own right, as they represent real differences in morphological and cultural characteristics - viz *F. syriaca* and *F. sogdiana* (both now given as part of *F. angustifolia* subsp *oxycarpa*). Currently the genus is cited as containing 43 species. They are generally deciduous, medium to large trees but the sub-tropical species are semi-evergreen.

The flowers are borne in dense panicles during the spring and are followed by similarly dense clusters of fruits in the autumn - individually these consist of elongated, one seeded samaras which mature in the autumn.

The nursery production of ash seedlings is, more often than not, complicated by the presence of more than one dormancy factor. The sequence of protocols required for the pre-treatment of *Fraxinus* seed, in order to achieve germination success, can therefore be complex and may be governed by as many as four factors in the following succession -

- a) a hard seed coat (a pericarp which is impermeable to water),
- b) an underdeveloped embryo (ie an immature embryo that is in a differentiated condition but which requires a period of warmth to mature morphologically and physiologically),
- c) an endogenous dormancy (requiring a period of chilling to mitigate) and
- d) a particular minimum threshold temperature for the germination and emergence of the embryo.

Section **Ornus**

The **Flowering Ashes** are a group of some fifteen species of small to medium sized trees which occur across temperate Eurasia. They include the following species which can be seen in cultivation in the UK:- *F. bungeana*, *F. chinensis*, *F. floribunda* (includes *F. insularis* previously *F. retusa*), *F. griffithii* (includes *F. ferruginea*), *F. lanuginosa*, *F. longicuspis*, *F. ornus*, *F. paxiana*, *F. sieboldiana* (includes *F. mariesii*) and although strictly not part of the *Ornus* Section *F. cuspidata* and *F. spaethiana* are included here.

These species are characterised by the large, billowing panicles of, usually scented, white flowers which are produced in May-June - just after leaf production. All of the species of this Section occur in Eastern Asia except for *F. ornus* (the Manna Ash) which occurs in Southern Europe and adjacent Asia. Although the following Chinese species are rarely found in cultivation they would have ornamental value - *F. baroniana* and *F. malacophylla* although there provenance suggests that they would require a mild climatic niche.

Although species of this Section do not generally show complex dormancy conditions (most of them are from reasonably benign climate areas), little is known of the conditions that they require for successful germination - it would be as well to err on the generous side for the practical treatment until more information is available:-

- a) collect the seed at an early 'green' stage to prevent any hard seed coat development;
- b) warm (20°C) stratify for 35 days to ensure that the pericarp is permeable and that the embryo is fully mature;
- c) chill (3°C) for 28 days and
- d) germinate at 20°C.

Section ***Fraxinus***

This section consists principally of large trees which produce tight clusters of numerous inconspicuous green or yellowish green flowers before the leaves - which in turn produce substantial clusters of fruits. It includes *F. angustifolia* (includes *F. oxycarpa*, *F. sogdiana*, *F. syriaca*), *F. excelsior*, *F. mandschurica* (and var *japonica*), *F. nigra* and *F. platypoda*.

The seeds of *F. excelsior*, *F. mandschurica* and *F. nigra* develop a hard pericarp in some degree at dispersal and require either warm stratification to induce water permeability or they can be collected 'green' - they also have immature embryos at this time and will require a period of warm stratification to mature the embryo - 84 days at 18°C. These three species also show endogenous embryo dormancy and require a chilling period of 90 days at 3°C for mitigation.

F. angustifolia and its variants are generally from warmer provenances and do not exhibit extensive dormancy conditions. A treatment of 28 days at 20°C followed by 28 days at 3°C will permit acceptable germination at 20°C.

Section **Melioides**

This grouping of Ashes is native to the New World and contains the following species which would potentially grow reasonably successfully in the climate of the UK:- *F. americana*, *F. caroliniana*, *F. latifolia*, *F. pennsylvanica*, *F. profunda*, *F. texensis*, *F. uhdei*, and *F. velutina*.

The Shamel Ash, *F. uhdei*, has a southern distribution in the US and Central America and is only suitable for cultivation in milder niches of the UK. It has no dormancy controls and imbibed seed germinates uniformly at temperatures in excess of 20°C. *F. americana* (White Ash) and *F. pennsylvanica* (Green Ash) both develop a hard seed coat condition by the time of dispersal and should be warm stratified or preferably collected 'green' to avoid this: in addition they have an endogenous dormancy which will be eliminated by chilling at 3°C for 84 days. *F. caroliniana* (Swamp Ash), *F. profunda* (Pumpkin Ash) and *F. texensis* (Mountain Ash) exhibit an endogenous dormancy which is mitigated by a chill of 56 days at 3°C. *F. velutina* (Velvet Ash) is reported as needing only a chill of 84 days. *F. latifolia* (Oregon Ash) also requires a chill of 84 days but also needs an initial warm stratification of 42 days which would suggest that it has an immature embryo as there is no hard seed coat issue.

Section **Dipetalae**

This Section is also native to North America and contains three species - *F. anomala* (from montane areas in the South West), *F. dipetala* (montane California and N. Mexico) and the widespread Blue Ash (*F. quadrangulata*) from the Mid-West, the East and Canada.

F. anomala appears to have an immature embryo which requires 42 days of warm stratification to mature and which is then followed by a chilling requirement of 70 days at 3°C. *F. dipetalae* has a mature embryo but requires a similar 70 day chill before germination. *F. quadrangulata* however develops a hard seed coat which requires warm stratification for 60 days or collection 'green' - this is then followed by a chilling requirement of 63 days.

There are five warm temperate to subtropical species which occur from the extreme SW USA to mid Central America and are placed in the Section **Pauciflorae**. They are unlikely to succeed in the UK.

Some notes on Proteaceae

The Protea Family is a large genus of woody plants which occur in warm temperate (chiefly Mediterranean climate areas) to mainly sub-tropical and tropical climate areas. They vary from prostrate creepers to medium (sometimes tall - eg *Grevillea robusta*) sized trees.

The Family consists of about 80 genera and contains from 1600 to 2000 species. They are distributed in the Southern Hemisphere mainly around the Pacific Rim. The most important economic edible crop is the Macadamia nut but those genera with a warm temperate distribution contain many species of ornamental use and especially as cut flower crops - including *Banksia*, *Isopogon*, *Grevillea*, *Telopea*, *Protea*, *Leucospermum* and *Leucadendron*.

Most of the relevant temperate species - especially in Australia and parts of Southern Africa - are native to areas with acidic, arid, depauperate soils with little or no humus content and these characteristics can have important implications for the successful production, of the relevant species, of a crop of seedlings.

Of the genera with a temperate climate distribution - many are also native to areas with fire ecologies which often has a profound effect on their germination strategies. This is rarely as a result of degradation (by cracking or splitting) of the seed coat (as a result of temperature shock) but more commonly by the effects of smoke or the leaching of soluble charates on physiological controls within the seed.

Although the basic germination processes of the seed are not unusual - the success of the production of a crop of liners is dependent on the post germination 'cultivation' employed as the seedlings of most species are susceptible to particular issues. Thus:-

- a) the great majority of species benefit from an acid growing medium,
- b) virtually all are, in some degree, susceptible to phosphorus toxicity and the medium should be low in this nutrient,

(however this does not imply that the plants do not require phosphorus - they do - but they adopt a variant strategy in obtaining their needs)),

c) most are susceptible to *Phytophthora* root rots (water moulds) and consequently the medium should be well drained
d) as many of the species grow most satisfactorily in inorganic soils with very limited quantities of organic matter this factor should be reflected in the growing medium

In relation to these latter two issues:-

Although most recommendations suggest that crop production should require the use of fungicides - to control water mould infections - it is best to grow without such aids and ensure that the crop is grown using relevant cultivation techniques and under hygienically suitable conditions - and so avoid such invasions.

The seedlings generally produce a tap root and a fibrous root system - thus the containers used for crop production should allow for this development - the seed often germinates erratically therefore it is prudent to sow in a tray and move on to the liner container very soon (as soon as the first true leaves appear) - so that the root system is not damaged.

Many species germinate at lower temperatures than might be expected

Germinating medium needs to be well drained but also sufficiently water holding to maintain sufficient water uptake for the seed.

The seedlings are susceptible to 'damping off' - therefore maintain reasonably dry atmospheric conditions and avoid waterlogging of the medium without allowing it to become dry.

Mycorrhizal associations are made soon after germination.

It would appear that the seedling is capable of producing a root exudate which deters competition and therefore it would be prudent to either sow into individual containers or transplant very soon after germination; it is probably such a situation which causes the decline and death of seedlings when grown fairly closely together in a container without separation and moving on.

Embothrium

strat germn at c15C

Gevuina

monotypic (the previously included tropical species are now assigned to Bleasdalea)

Lomatia

Banksia montane species 63 days at 3 C. many species have serotinous cones germ @ 25C

Dryandra (nowadays inc Banksia)

Grevillea

Hakea

Isopogon

Petrophile

Telopea

Knightia

Leucadendron

Leucospermum

Mimetes

Protea

Serruria

Rosaceae (3)

Rosa

Neillia

Holodiscus

Physocarpus

Styracaceae

Styrax, Pterostyrax Rehderodendron Halesia Alniphyllum
Sinojackia

Ulmaceae

Ulmaceae (the Elm family) is currently made up of six genera which are widely distributed through the temperate zones of the Northern Hemisphere and occasionally elsewhere - except Australasia.

Chiefly trees, Evergreen or deciduous

Includes the following genera which are found in cultivation in temperate climates

Hemiptelea, *Planera*, *Ulmus* and *Zelkova*

These six genera have been separated from *Aphananthe*, *Celtis* and *Pteroceltis* which are now included in ***Cannabaceae***.

Fruit an indehiscent samara, nut or drupe

Zelkova

Deciduous Smooth barked monoecious fls

several spp *Z. serrata*

F. serrata req 63 days @ 3°C

Ulmus c37 spp but many species have a wide distribution and many geographic subsp occur

Decide to semi-evergreen ie carry leaves to following bud break

The Propagation of Temperate Woody Plants from Seed

Index of Genera discussed

Angiosperms

Conifers

Cycads

This list indicates the Families and their constituent genera which have been assessed and completed to date and the information is recorded here - this is a work which is continually being revised and updated as the notes in the files on additional Families are put in order and assessed.

The information is published here when all the available information on a Family has been aggregated - there is therefore a huge amount in the pipeline and if information on a particular genus is sought - an enquiry could well produce a positive response if the material has already been accumulated and is accessible and available! Some of the Families are virtually complete and hopefully will be added soon. An e-mail will elicit a response.

The list indicates the name of the Family in which the genus currently resides (depending on one's view of the taxonomy!) and thus where the information is recorded.

Genus	Location
Abies	Pinaceae
Acacia	Legumes
Acer	Aceraceae
Acradenia	Rutaceae
Actinostrobus	Cupressaceae
Adenocarpus	Legumes
Aesculus	Hippocastanaceae
Agathis	Araucariaceae
Agathosma	Rutaceae
Agapetes	Ericaceae
Akebia	Lardizabalaceae
Albizia	Legumes
Alectryon	Sapindaceae
Alnus	Betulaceae
Amelanchier	Rosaceae (1)
(Amentotaxus)	Taxaceae
Amorpha	Legumes
Andromeda	Ericaceae
Anthyllis	Legumes

Aphananthe	Cannabaceae
Araucaria	Araucariaceae
Arbutus	Ericaceae
Arctostaphylos	Ericaceae
Aria	Rosaceae (1)
Aronia	Rosaceae (1)
Atherosperma	Atherospermataceae
Athrotaxis	Cupressaceae
Austrocedrus	Cupressaceae
(Austrotaxus)	Cupressaceae
Berberis	Berberidaceae
Betula	Betulaceae
Bignonia	Bignoniaceae
Billardiera	Pittosporaceae
Boronia	Rutaceae
Boquila	Lardizabalaceae
Bowenia	Cycadales
Broussonetia	Moraceae
Bryanthus	Ericaceae
Calliandra	Legumes
Callitris	Cupressaceae
Calluna	Ericaceae
Calocedrus	Cupressaceae
Camellia	Theaceae
Campsis	Bignoniaceae
Camptotheca	Nyssaceae
Caragana	Legumes
Carmichaelia	Legumes
Carpinus	Betulaceae
Cassia	Legumes
Cassiope	Ericaceae
Castanea	Fagaceae
(Castanopsis)	Fagaceae
Catalpa	Bignoniaceae
(Cathaya)	Pinaceae
Cedrus	Pinaceae
Celastrus	Celastraceae
Celtis	Cannabaceae
Cephalotaxus	Cephalotaxaceae
Ceratonia	Legumes
Ceratozamia	Cycadales
Cercidiphyllum	Cercidiphyllaceae
Cercis	Legumes
Chamaecyparis	Cupressaceae
Chamaedaphne	Ericaceae
Chamaespilus	Rosaceae (1)
Chaenomeles	Rosaceae (1)

Chilopsis	Bignoniaceae
Chigua	Cycadales
Choisya	Rutaceae
Chorizema	Legumes
Chrysolepis	Fagaceae
Citrus	Rutaceae
Cladastris	Legumes
Cleyera	Theaceae
Clianthus	Legumes
Clytostoma	Bignoniaceae
Coleonema	Rutaceae
Colutea	Legumes
Coronilla	Legumes
Cormus	Rosaceae (1)
Cornus	Cornaceae
Correa	Rutaceae
Corylus	Betulaceae
Cotoneaster	Rosaceae (1)
Crabi dendron	Ericaceae
Crataegus	Rosaceae (1)
Crowea	Rutaceae
Cryptomeria	Cupressaceae
Cunninghamia	Cupressaceae
Cupressus	Cupressaceae
Cyathodes	Ericaceae
Cycas	Cycadales
Cydonia	Rosaceae (1)
Cytisus	Legumes
Daboecia	Ericaceae
Dacrydium	Podocarpaceae
Daphniphyllum	Daphniphyllaceae
Davidia	Davidiaceae
Decaisnea	Lardizabalaceae
Desmodium	Legumes
Dioon	Cycadales
(Diosma)	Rutaceae
Dipteronia	Sapindaceae
Diselma	Cupressaceae
Distictis	Bignoniaceae
Docynia	Rosaceae (1)
Dodonea	Sapindaceae
Doxantha	Bignoniaceae
Drimys	Winteraceae
Eccremocarpus	Bignoniaceae
Eleagnus	Eleagnaceae
Elliottia	Ericaceae
Epacris	Ericaceae

Empetrum	Ericaceae
Encephalartos	Cycadales
Enkianthus	Ericaceae
Epigaea	Ericaceae
Erica	Ericaceae
Eriobotrya	Rosaceae (1)
Eriostemon	Rutaceae
Erythrina	Legumes
Eucryphia	Eucryphiaceae
(Euodia)	Rutaceae
Euonymus	Celastraceae
Eurya	Theaceae
Fagus	Fagaceae
Fitzroya	Cupressaceae
Franklinia	Theaceae
Gaultheria	Ericaceae
Gaylussacia	Ericaceae
Geijera	Rutaceae
Genista	Legumes
Ginkgo	Gingkoales
Gleditsia	Legumes
Glyptostrobus	Cupressaceae
Gordonia	Theaceae
Gymnocladus	Legumes
Hardenbergia	Legumes
Heteromeles	Rosaceae (1)
Hippophae	Eleagnaceae
Holboellia	Lardizabalaceae
Hovea	Legumes
Ilex	Aquifoliaceae
Indigofera	Legumes
Juniperus	Cupressaceae
Kalmia	Ericaceae
Kalmiopsis	Ericaceae
Kennedyia	Legumes
Keteleeria	Pinaceae
Koelreuteria	Sapindaceae
Laburnum	Legumes
Lapageria	Philesiaceae
Lardizabala	Lardizabalaceae
Larix	Pinaceae
Laurelia	Atherospermataceae
Laureliopsis	Atherospermataceae
Lepidozamia	Cycadales
Lespedeza	Legumes
Leucothoe	Ericaceae
Leucopogon	Ericaceae

Libocedrus
Liquidambar
Liriodendron
Lithocarpus
Lyonia
Maackia
Maclura
Macrozamia
Magnolia
Mahonia
Malus
Manglietia
Maytenus
Mespilus
Metasequoia
Michelia
Microbiota
Microcachrys
Microcycas
Mimosa
Morus
Nandina
Neocallitropsis
Nothofagus
Notholithocarpus
(Nothotsuga)
Nyssa
Ononis
Ostrya
(Ostryopsis)
Osteomeles
Oxydendron
Pandorea
(Papuacedrus)
Pernettya
Petteria
Phellodendron
Philesia
Photinia
Phyllocladus
Phyllodoce
Picea
Pieris
Pilgerodendron
Pinus
Piptanthus
Pittosporum

Cupressaceae
Altingiaceae
Magnoliaceae
Fagaceae
Ericaceae
Legumes
Moraceae
Cycadales
Magnoliaceae
Berbericaceae
Rosaceae (1)
Magnoliaceae
Celastraceae
Rosaceae (1)
Cupressaceae
Magnoliaceae
Cupressaceae
Podocarpaceae
Cycadales
Legumes
Moraceae
Berberidaceae
Cupressaceae
Nothofagaceae
Fagaceae
Pinaceae
Nyssaceae
Legumes
Betulaceae
Betulaceae
Rosaceae (1)
Ericaceae
Bignoniaceae
Cupressaceae
Ericaceae
Legumes
Rutaceae
Philesiaceae
Rosaceae (1)
Podocarpaceae
Ericaceae
Pinaceae
Ericaceae
Cupressaceae
Pinaceae
Legumes
Pittosporaceae

Platyclusus
Podranea
Podocarpus
Podylaria
Poncirus
Prumnopitys
Prunus
Pseudolarix
(Pseudotaxus)
Pseudotsuga
Pseudowintera
Pteroceltis
Pueraria
Pultenaea
Pyracantha
Pyrostegia
Pyrus
Quercus
Raphiolepis
Rhododendron
Rhodothamnus
Robinia
Sambucus
Saxegothea
Schima
Sciadopitys
Sequoia
Sequoiadendron
Shepherdia
Sinofranchettia
Skimmia
Sollya
Sophora
Sorbus
Spartium
Stangeria
Stauntonia
Stranvaesia
Stewartia
Taiwania
Talauma
Tasmannia
Taxodium
Taxus
Tecoma
Tecomaria
Ternstroemia

Cupressaceae
Bignoniaceae
Podocarpaceae
Legumes
Rutaceae
Podocarpaceae
Rosaceae (2)
Pinaceae
Taxaceae
Pinaceae
Winteraceae
Cannabaceae
Legumes
Legumes
Rosaceae (1)
Bignoniaceae
Rosaceae (1)
Fagaceae
Rosaceae (1)
Ericaceae
Ericaceae
Legumes
Adoxaceae
Podocarpaceae
Theaceae
Sciadopityaceae
Cupressaceae
Cupressaceae
Eleagnaceae
Lardizabalaceae
Rutaceae
Pittosporaceae
Legumes
Rosaceae (1)
Legumes
Cycadales
Lardizabalaceae
Rosaceae (1)
Theaceae
Cupressaceae
Magnoliaceae
Winteraceae
Cupressaceae
Taxaceae
Bignoniaceae
Bignoniaceae
Theaceae

Tetraclinis

Tetradium

Torminaria

Torreya

Tsuga

Ulex

Ungnadia

Vaccinium

Viburnum

Virgilia

Widdringtonia

Wisteria

Wollemia

Xanthoceras

Zamia

Zanthoxylum

Zenobia

Cupressaceae

Rutaceae

Rosaceae (1)

Taxaceae

Pinaceae

Legumes

Sapindaceae

Ericaceae

Adoxaceae

Legumes

Cupressaceae

Legumes

Araucariaceae

Sapindaceae

Cycadales

Rutaceae

Ericaceae