This chapter has been divided into four sections: cone storage and handling, cone processing (kilning and extraction), seed processing, and seed upgrading. The first three are considered part of the standard cone and seed processing steps applied to each seedlot and illustrated in **Figure 38**–although all steps may not be performed on every species or seedlot. The appearance of processing materials at various representative stages are depicted in **Figure 39**. Seed upgrading may be performed at a later date to improve seedlot characteristics.

## Cone Storage and Handling

Once cones arrive at the processing facility, promptly unload the cone sacks from the transport vehicle and place them onto a racking system (similar to interim storage) until cone processing begins. As in interim storage, protect the cone sacks from the elements, and allow ventilation for further drying (curing) of the mature cones (**Figure 40**). Turn cone sacks to facilitate uniform drying of the cones. The frequency of turning sacks is dependent on cone moisture content. If cones are still quite moist when received it is beneficial to turn the sacks daily, reduce the cone volume in each sack, or spread the cones on trays. Serotinous lodgepole pine is an exception and the cone sacks can be stacked without adversely affecting seed quality (**Figure 41**). Caron et al. (1993) found that white spruce can benefit from cone storage as much as from stratification in terms of germination capacity. In Douglas-fir, Sorensen (1991) showed that low humidity, high temperature cone drying conditions decreased the germination capacity and rate, but that prolonged stratification corrected this reduction. Proper cone storage can have a significant effect on seed quality.

*Cone processing includes cone conditioning, cone cleaning, kilning, and extraction or viable seeds*

During cone curing, moisture content is visually monitored (via cone opening) and a random sample of cones should be obtained to perform a cone and seed evaluation as soon as possible after receipt (**Figure 42**). This will provide information on: cone and seed maturity, presence and extent of fungi, presence and damage caused by insects, and other indicators that will allow staff to prescribe and prioritize subsequent cone handling and extraction activities. An example of a cone and seed evaluation form is presented in Appendix 3.

The *Abies* spp. and other seedlots with high moisture levels may have their cones placed on open, stackable trays in cool (10–15°C) conditions with additional fans for ventilation to facilitate the drying of cones (**Figure 43**). The *Abies* spp. are treated differently as cones disintegrate naturally compared to the cone opening of all other species. The handling practices for cones collected immaturely has been referred to as after-ripening or artificial ripening. This was first suggested by Silen (1958) to expand the window for cone collection in Douglas-fir and was subsequently studied in a variety of species. A thorough review of seed maturity including the artificial ripening of seeds was provided by Edwards (1980). Today, less consideration is given to artificial ripening, except in *Abies* spp., as it is generally accepted that maximum seed quality occurs at the point of natural seed release. A much larger proportion of seeds is also produced from seed orchards today allowing collections to be performed on an individual tree basis at the peak of seed maturation.

Prior to kilning, cones may be cleaned on a vibratory screening machine to remove debris and seeds that have been released from the cones (**Figure 44**). The removed material must then be cleaned to separate the debris from the seeds. Next, dry these seeds to the moisture content of kilned seeds (7 to 8%). The kilned and unkilned seeds can then be combined for further processing. In some seedlots there will be no seeds released prior to kilning, but for other seedlots in which cones have begun flexing, the number of seeds released may be substantial. Cone processing includes cone conditioning, cone cleaning, kilning, and extraction of viable seeds.


**Figure 39** The appearance of processing materials a) unkilned cones, b) kilned cones, c) winged seeds, and d) dewinged seeds of interior spruce (Sx).

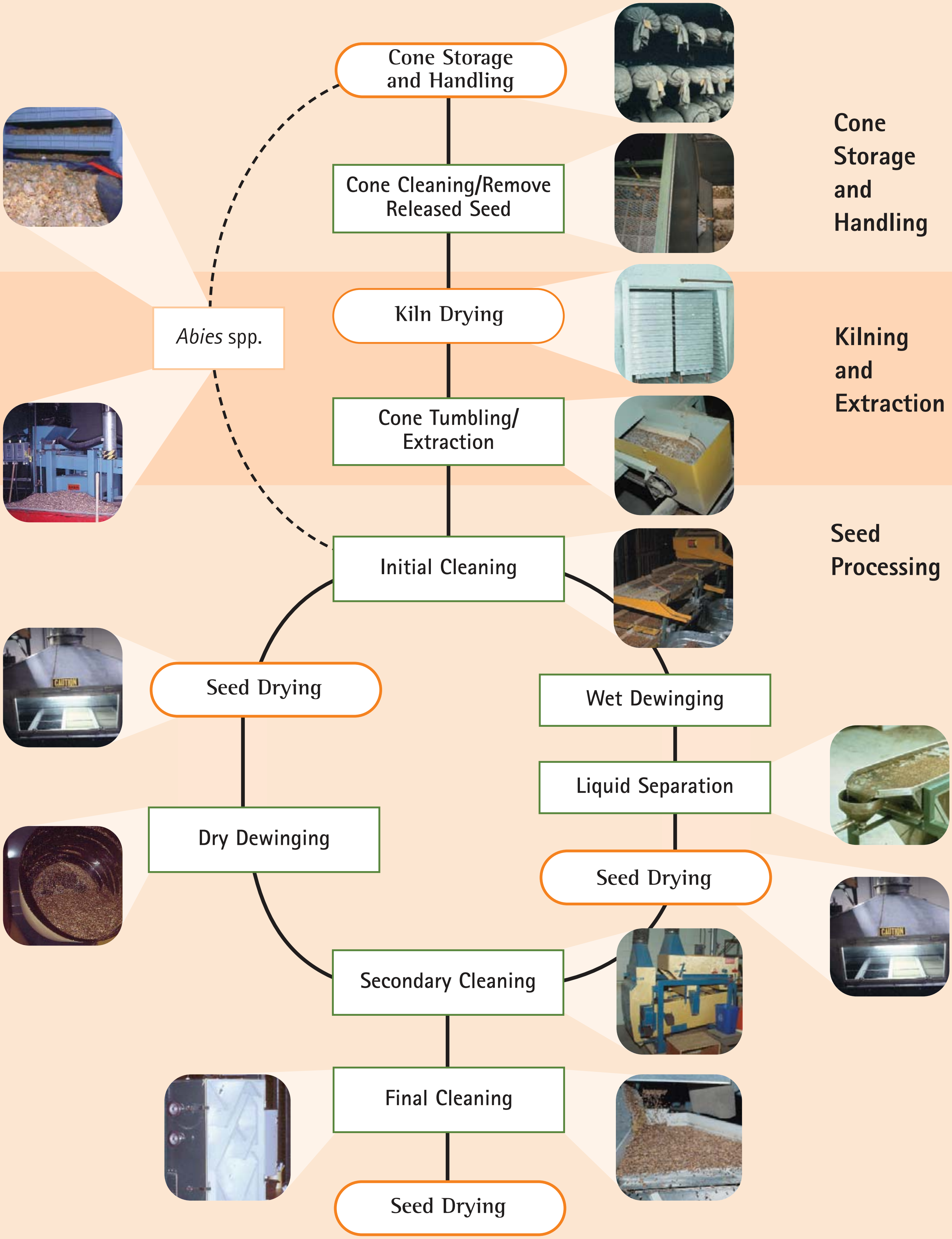


**Figure 38**
Typical cone and seed processing steps and sequence of activities.
Sequence may vary and all steps may not be performed for each seedlot.

Figure 40 A typical cone sack racking system.

Figure 41 Stacking of cone sacks for serotinous lodgepole pine.

Figure 42 Materials used in a cone and seed evaluation.

Figure 43 Conditioning cones of *Abies* spp. in stackable trays with additional ventilation provided by fans.

Figure 44 Two types of equipment used to remove released seeds and debris from cones, before kilning.

## Kilning and Extraction

Kilning refers to drying cones in a controlled, warm, dry environment to flex the cone scales and allow seeds to be extracted. If kilning is applied to very moist cones the outer portion of the cone scale may lose moisture and partially flex causing the scale to set in a semi-open position preventing seed release (Edwards 1985). This condition is called case-hardening. This term is also used to describe cones that will not open due to fungi, insects, excessive pitch covering the cones, and overheating during interim storage or transport.

There are two main types of kilns used to remove moisture and induce flexing in conifers: rotary and batch (Figure 45). The essential elements in any kiln design are (a) heat for evaporating moisture, (b) air circulation to conduct heat, (c) control of temperature and humidity to prevent injury to the seeds (Rietz 1941), and (d) a tray or shelf system to expose cones to the air current in batch-style kilns. A rotary kiln is a temperature controlled chamber that rotates cones in a large wire drum allowing released seeds to fall through the drum and exit the kiln environment. The rotation speed and duration of the kiln can be adjusted. Each rotary kiln can process only one seedlot. The batch type kiln, similar to lumber kilns, introduces cones on dollies and exposes the cones to controlled heat and humidity for a specific duration. Rotary kilns offer the advantage of automatically removing released seeds from the hot, dry environment (combining kilning and tumbling), but batch type kilns allow greater flexibility in the number and size of seedlots that can be treated at one time. An initial investigation of the effect of kiln temperatures on germination indicated that germination was not reduced by the range of kilning temperatures used in seven BC conifer species (Rappaport 1996).

*Kilning refers to drying cones in a controlled, warm, dry environment to flex the cone scales and allow seeds to be extracted*

The duration and settings for temperature and humidity form the basis of the batch kilning program. In general temperature is ramped up to one of three peak temperatures: 30°C for the low dormancy species (western redcedar and western hemlock), 60°C for serotinous lodgepole pine and black spruce, and 40°C for all other coniferous species that are kilned. The kiln usually runs on a 17 hour timeline overnight with temperature ramping up gradually, over a two to five hour period, to the peak temperature. This temperature will be maintained for several hours and then ramped down in the morning to the ambient temperature. Relative humidity in the kiln will initially be high, corresponding to the relatively high cone moisture content, and will then decrease over the kilning period as cones lose moisture. The kiln control parameters are important as low initial relative humidity, high initial temperatures or a sudden change in cone moisture content can cause casehardening of the cones.

*...to avoid contamination clean equipment thoroughly between seedlots*

The loading and unloading of the kilns can differ between facilities. In some, the loading of kilns will still be performed manually, while mechanization has been incorporated into others (**Figure 46**). The most important consideration is to avoid contamination of materials between seedlots; a thorough cleaning of all equipment must occur between seedlots (i.e., by vacuum). This applies to kiln loading and unloading, and to all other phases of cone and seed processing. If cone opening has occurred in the sacks then one should ensure all released seeds are also incorporated into the processing cycle (i.e., turn cone sacks inside out to check for released seeds). If burlap sacks are turned inside out before filling, the inner seam will probably not "catch" seeds and **efficiency** of extraction can be improved. Not all burlap is the same (e.g., weave differences) and sack construction can also vary—be aware.

Following kilning in a batch-style kiln, the seeds are extracted from the cones in a large mesh cylinder referred to as a tumbler (**Figure 47**). The speed of rotation and angle of the cylinder are usually adjustable to allow for optimization by species. Seeds will fall through the mesh screen and onto a conveyor belt that will collect seeds and debris in a plastic bag. Spent cones

**Figure 45** The two main types of kilns used for opening cones a) batch-type and b) rotary.

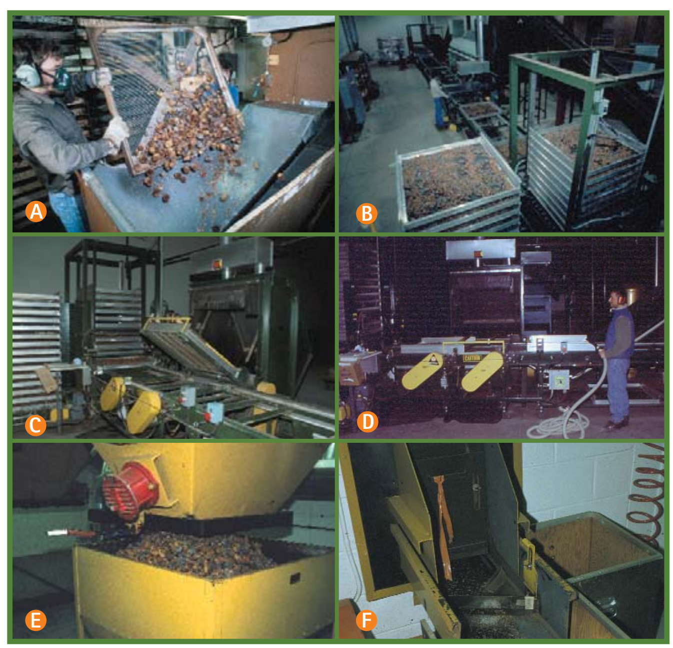

**Figure 46** Kiln loading and unloading a) manually, b) mechanized stacking of batch-style kiln trays, c) mechanized destacking of batch-style kiln trays in preparation for tumbling, d) cleaning of equipment between seedlots, e) loading of rotary kiln, and f) collection of seeds outside rotary kiln.

traverse the length of the mesh cylinder and for small-coned species they are vacuumed out of the processing plant to an outside holding area. For large-coned species, cones are manually removed from the extraction area.

Extraction is a critical point in processing. If all viable seeds are not removed from the cones at this point in time it can have a large impact on yield. If it is determined that sufficient viable seeds still remain in the cones and are extractable, the seedlot, or a portion of it, may be rekilned to improve cone opening and extraction efficiency. It is important to determine through cutting tests whether unextracted seeds are viable, as many 'empty' seeds are routinely retained in the cone. Excessive tumbling should also be avoided as it introduces additional debris to the seedlot, reducing processing efficiency and possibly damaging seeds.

**Figure 47** a) A cone tumbler and b) a close-up of the wire mesh screen used to separate seeds from cones.

## Seed Processing

Following the removal of seeds from the cones, seed processing is initiated. Seed processing deals with the purification of seeds, reduction in moisture content, and removal of non-viable seeds. Initial cleaning is the first step in seed processing and is primarily concerned with the removal of debris from a seedlot that may damage the seeds or impede processing. A **'scalper'** or multi-screened vibrational seed cleaner uses metal screens of varying opening size, shape, and arrangement to separate seeds from debris (**Figure 48**). Examples of debris are cone scales, foliage, pitch, rocks, and other inert matter (**Figure 49**). Choice and order of screens as well as vibrational speed are based on the species and type of debris in each seedlot and are important decisions for efficient and successful seed cleaning. The stickiness of seeds can also be problematic for seed processing or nursery sowing. Minimize stickiness by placing the seeds in a cool environment prior to use or use scientific grade talc or a seed flow lubricant during processing or sowing.

*Seed processing deals with the purification of seeds, reduction in moisture content, and removal of non-viable seeds*

**Figure 48** a) Initial cleaning performed on the scalper and b) a close-up of the seeds running over the screens.

The seeds separated during initial cleaning will then be dewinged to remove the seed wing from its attachment to the seed coat. Dewinging generally occurs in a rotary drum or cement mixer in which rotation speed and angle can be controlled and water can be added if required (**Figure 50**). The seed wings are blown off in the dewinger or separated later in the aspirator or on the gravity table. The dewinging stage has prompted the development of various pieces of

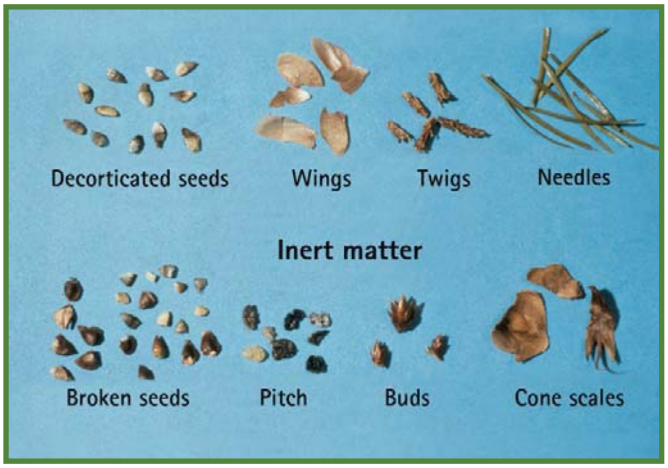


**Figure 49** Examples of debris commonly found in seedlots before processing.

equipment including augers and brush dewingers. For small seedlots dewinging is often accomplished by hand. For species of spruce and pine, wet dewinging is employed as the addition of moisture causes the wings of these species to enlarge and cleanly detach from their connection with the seed coat. Species which are wet dewinged also subsequently undergo a very brief water bath which helps to separate particles denser than water (i.e., rocks and pitch) which sink to the bottom of the liquid separation tank (**Figure 51**). Prior to further processing the wet dewinged seeds are dried to a storage moisture content target of approximately 8%. For the other Pinaceae species dewinging is performed 'dry' (most efficient at seed moisture contents less than 15%) and wing removal results from mechanical friction and breaking the connection of the wing and the seed coat. In some species, drying of seeds prior to dewinging results in the wing becoming more brittle and breaking from the seeds more easily. Seeds from species in the Cupressaceae (western redcedar and yellow-cedar) are not dewinged. Wet dewinging results in much 'cleaner' looking seeds that will not release more debris (wing material) over time, but not all species respond to 'wet' dewinging. Improvements to dry dewinging have included the use of foam inserts or other foreign objects into the drum to increase frictional forces and improve dewinging efficiency. Dewinging is a stage in which the probability of seed damage is higher and it is important that the activity be as brief as possible to accomplish the required product. In particular, species with resin vesicles can be damaged and require additional care during all stages of cone and seed processing. Secondary cleaning may or may not be performed depending on the purity of the seedlot after dewinging. It may be performed on the scalper, sizer (basically a smaller-sized scalper), or on a fanning mill which includes **aspiration** in an air column with scalping. Secondary cleaning reduces debris volume in preparation for final cleaning and can be used to size seedlots. Seed sizing has been a subject of great debate as conflicting results have been found concerning its benefits. In the southeastern United States, seed sizing is performed on loblolly pine and the increasing uniformity of germination speed may justify the sizing practice (Dunlap and Barnett 1983, Barnett 1989). Sizing also appears practical in the southeastern US as quantities of seed per size class (or family) may reach 20 kg or more. For BC species that have been studied there does not appear to be justification for seed sizing and the small request sizes often faced do not improve the feasibility of this practice. Sizing may sometimes be performed to improve final cleaning

*Minimize stickiness by placing the seeds in a cool environment prior to use or use scientific grade talc or a seed flow lubricant*


**Figure 50** a) Dewinging performed dry in the large batch machine and b) wet dewinging being performed in a cement mixer.

**Figure 51** Two different pieces of equipment used for liquid separation.

*Dewinging is a stage in which the probability of seed damage is higher and it is important that the activity be as brief as possible to accomplish the required product* separation efficiencies. For Sitka spruce it was determined that although seed size differences between parent trees are significant they were minor compared to the effect of pretreatment, having little importance operationally (Chaisurisri et al. 1992). Douglas-fir seed size showed significant differences between families, but correlations between seed size and germination capacity and rate were weak (St. Clair and Adams 1991).

In a study looking at sorting seven interior spruce families into four fractions, the smallest seeds (passing through a 1.37 mm holed screen) had the lowest germination capacity and rate (Perkins 1998) and removal of these seeds which occurred in all families would have little impact on genetic variability, but may significantly improve seed quality. The decision to size seeds is complex and will depend upon species attributes, quantity of seeds, nursery seeder used, and finally, as the bottom line, the cost effectiveness of sowing sized request fractions which can vary greatly by nursery.

*Cutting tests are used to calibrate settings and determine if acceptable separations are occurring*

Final cleaning is the final removal of debris particles, which should have been minimized through previous processing, and the removal of empty, immature, and non-viable seeds. Two pieces of equipment can be used for final cleaning: aspirators or the gravity table. The aspirator or pneumatic separator uses an adjustable air column to separate seeds based on terminal velocity which is influenced by specific gravity, size, shape, and surface texture (Edwards 1979). Aspirators may have several, usually three, outlets for seed discharge. These are commonly referred to as light, mid, and heavy seed fractions. Cutting tests are used to calibrate air flow settings and determine if acceptable separations are occurring. The machine is set up to separate the heavy seeds considered filled and viable from the light fraction consisting of empty seeds and debris. The mid fraction is usually a combination and commonly has to be re-run, with adjusted settings, to separate out the viable seed. Various configurations on this central concept have been constructed (**Figure 52**) and the 'aspirator' is a common piece of equipment found in most seed processing facilities. A review of air separation and a detailed description of one configuration of a laboratory aspirator is presented in Edwards (1979).

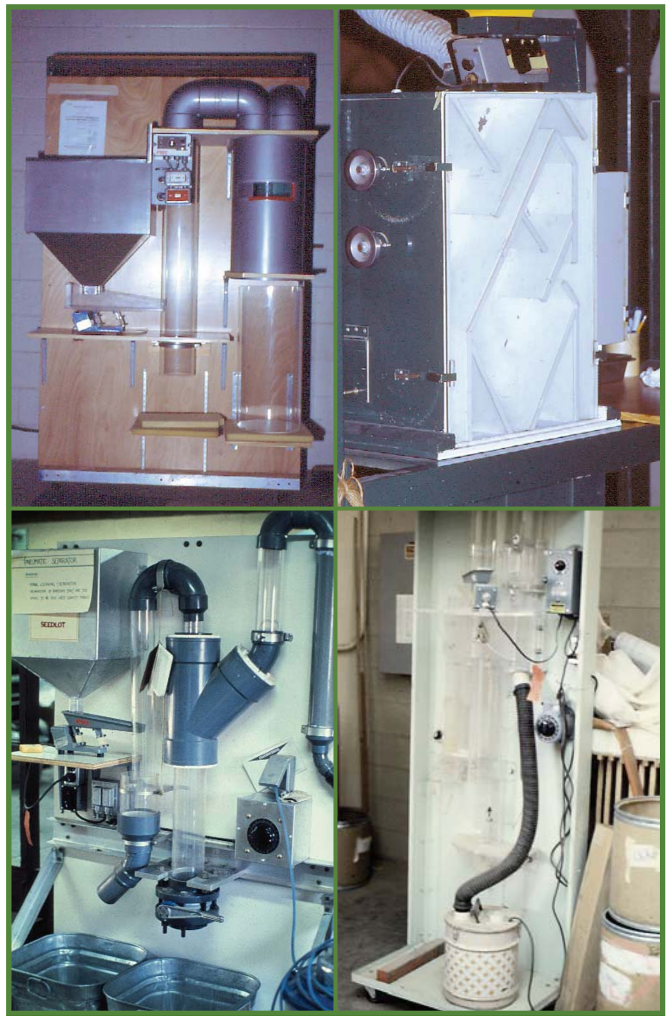

**Figure 52** Various configurations of aspirators used for final cleaning.

The gravity table, originally used in the mining industry, is the primary tool used for final cleaning at the BC Ministry of Forests Tree Seed Centre (**Figure 53**). Seeds are separated across an inclined deck that moves in two directions—up and down, and backwards and forwards. An air current is also present from below the deck. Although it requires a great deal of dedication and seed knowledge on the part of the technician it can produce excellent separations. The gravity table is initially overwhelming as the operator has many variables to control.

The air current blown through the gravity table deck is strong enough to lift the light seeds slightly off the surface. These

**Figure 53** The gravity table used for final cleaning.

light seeds, not in contact with the deck will run to the lower end of the deck due to the force of gravity. The heavier seeds, in contact with the deck, will be moved upwards with the reciprocating (two-dimensional) motion of the deck. The outcome of light seeds running down the deck and heavier seeds running up the deck initially seems counter-intuitive until one recognizes that different forces are used to move these fractions in their respective directions. Separations are performed on the gravity table by placing dividers on the discharge end of the deck separating the seeds into heavy, mid and light fractions similar to the aspirators. The placement of dividers is determined through cutting tests and it is common that more than one 'run' is required for each seedlot or fraction thereof. Separate runs on the gravity table usually include changes to settings and adjustment of dividers based on additional cutting tests.

*...dead filled seeds and viable seeds will both imbibe moisture in a similar manner, but upon drying the dead filled seeds will lose moisture much more rapidly and allow for a separation to occur*

Following final cleaning the seedlot is blended to ensure a homogenous product. A seedlot must meet the registration requirements for purity (97%+) and moisture content (4.9 to 9.9%) before the seedlot is placed into long-term storage at -18°C. After final cleaning it is common for some species (e.g., *Abies* spp. which have not undergone any kiln drying) to require further drying before storage. Once registration requirements of moisture content and purity have been met the seedlot will be sampled for seedlot tests: germination, seed weight, x-ray, and possibly fungal assays.

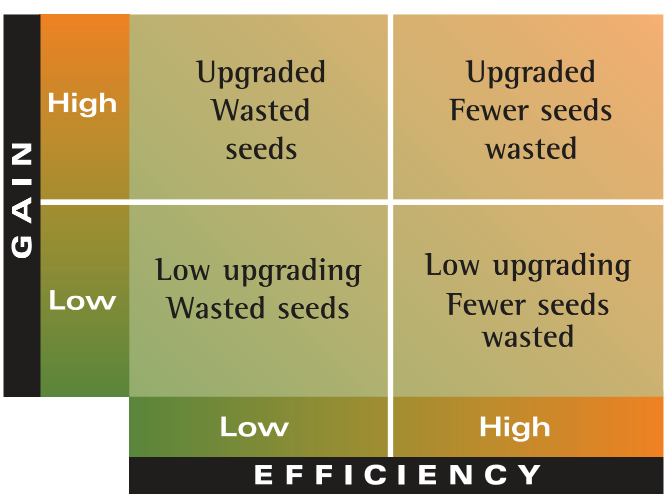


**Figure 54** Tradeoffs between upgrading gain and efficiency.

## Seed Upgrading

Seed upgrading refers to a variety of methods used to improve the quality of a seedlot. Seed upgrading often refers only to improvements in germination capacity, but upgrading or enhancing seed quality will be used here to also describe improvements in seed characteristic such as purity, moisture content, and possibly rate or uniformity of germination. In upgrading, and to some extent in conventional seed processing, one is dealing with a tradeoff between the **gain** in a particular trait (i.e., germination capacity) and the efficiency (i.e., yield, which is the amount or proportion of viable seeds retained) of the separation as illustrated in **Figure 54**. The optimum situation occurs when we achieve a high gain and a high rate of treatment efficiency. This occurs when a discrete difference exists in some characteristic, such as density, between the seeds we want to retain and remove. If gain or efficiency is reduced, the decision to upgrade will be an economic one due to the cost per increment of gain. Another important aspect is initial seed quality. If initial quality is high there will be little difference between the product before or after upgrading. It is generally recognized to be easier to improve a lower quality seedlot (e.g., from 75% to 85%) than to take a high quality seedlot from 92% to 96%. There appears to be diminishing returns to seed upgrading if initial seed quality is already high.

Separation of seedlots into discrete categories requires the identification of clear parameters. When dealing with immature seedlots possessing a great deal of variability, upgrading becomes difficult or impossible within reasonable efficiency limits. A procedure that has gained a great deal of international attention with conifers is the incubate-dry-separate (IDS) method. While many other methods rely on the physical characteristics of seeds this procedure separates seeds based on physiological principles. The basic principle is that dead filled seeds and viable seeds will both imbibe moisture in a similar manner, but upon drying the dead filled seeds will lose moisture much more rapidly and allow for a separation to occur. The live seeds actively bind moisture and more energy is required to remove this moisture compared to dead filled seeds. A thorough review of the procedure can be found in Bergsten (1993). Several research papers have been published illustrating how this method can improve seedlot quality (Simak 1984; Bergsten 1988; Downie and Bergsten 1991; Downie and Wang 1992; Poulsen 1995; Vanangamudi et al. 1993).

In BC, the IDS and related techniques have received a great deal of research and attention for improving seedlot quality (Edwards and Banerjee 1989; Banerjee and Scagel 1992; Kolotelo 1993). Results have generally been good when trying to improve poor quality seedlots, but many seed owners are looking to IDS, or related technologies, to raise germination capacity to accommodate single-seed sowing (≥95% germination capacity). Although the technology can provide this level of improvement, not all seedlots can be upgraded to this level efficiently. One may have a great deal of flexibility in efficiency if the goal is single-seed sowing as one can afford to throw away approximately half the seeds by reducing the sowing factor from two to one seed per cavity.

Although no nurseries in BC currently use the IDS technology, there are nurseries which engage in upgrading prior to sowing. Many nurseries simply soak the stratified seeds in a water bath and skim off the floating material consisting of debris and seeds which are lighter than water when imbibed (**Figure 55**). Success with this technique is mainly a matter of luck in having undesired seeds and debris float while the viable seeds sink. It is a quick and easy method that will not work for all species or all seedlots within a species. The technique will ensure that all the seeds are evenly and adequately hydrated prior to sowing and this will help the crop germinate rapidly and uniformly.

Another method, the PRE-VAC technique, is used to remove seeds that have seed coat damage (Downie 1999). The procedure works by placing dry seeds in a water-filled chamber, creating a vacuum to evacuate air from cracks in the seeds and then releasing the vacuum. The water will more easily enter the mechanically damaged seeds causing them to lose buoyancy and sink. This allows for a separation to occur. The method is specific to mechanically damaged seeds and although uncommon using conventional processing today, it is a viable method of improving past seedlot errors.

**Figure 55** Separation of debris and empty seeds through the soaking of stratified seeds.