Hawaiian Plant Nursery Best Management Practices

The purpose of this document is to provide an overview of considerations, regulations, and methods that apply to the propagation and production of native Hawaiian plants in Hawaiʻi. Techniques and considerations highlighted in the document are meant to promote discussion about native Hawaiian plant production that the grower may not have considered. This document is not intended to provide the specifics of growing all Hawaiian taxa or be the singular document by which native plant nurseries are designed and built. Many techniques and considerations are situational and will need to be adjusted to fit the needs of the individual grower.

In the following sections we will cover some fundamental practices that will help to build and maintain a successful native plant nursery and provide examples specific to the Hawaiʻi Rare Plant Restoration Group's (HRPRG) experiences growing rare and endangered plants in Hawaiʻi. There are many excellent resources available for those interested in starting and maintaining a native plant nursery. One resource that we recommend and cite in the following sections is the United States Department of Agriculture- Forest Service's Tropical Nursery Manual. This detailed resource is available for free online and can be downloaded as a PDF at https://rngr.net/.

Thank you to the HRPRG Horticulture subcommittee (Tiffany Lum, Rhian Campbell, Kay Lynch, Jill Wagner, Tim Chambers, Tim Kroessig, Matt Keir, Lauren Weisenberger) for their input on the various sections and regulatory aspect of the document. Thank you to Dr. Nicole Hynson and Dr. Jerry Koko for their input on the use of mycorrhizal inoculants. Thank you to Jane Beachy for careful review. Finally, thank you to Tim Kroessig and Matt Keir for their work on the HRPRG Nursery Guidelines document, upon which this document was based.

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Section 1: Nursery Design

Greenhouse and/or nursery facilities are key components of plant conservation programs around the world. These facilities propagate, multiply, grow, and maintain plant materials for use in restoration projects. Nursery facilities can also serve as genetic storage sites for rare and endangered plant species that cannot be stored and/or maintained through other *ex situ* methods such as seed storage or tissue culture. Some species of rare plants can be maintained and cultivated for many years in greenhouse facilities, allowing for multiplication of plant material through vegetative propagation and controlled hand-pollination for the purpose of seed production.

Building and managing a nursery facility for the cultivation of rare native plant species requires adequate funding and planning, as well as experienced and dedicated staff. Much of the growing conditions and horticulture techniques utilized in the nursery will be dependent on the location of the nursery and the target plant species being grown. However, there are fundamental protocols and practices that can be applied to any native plant nursery.

The location, site design and layout for a nursery should be carefully considered before purchasing a nursery structure or beginning construction. Here are some important topics to consider in order of importance:

- Location- elevation, rainfall, temperature, vehicle accessibility (materials delivery, moving plants to/from field sites), general accessibility and proximity to non-native species.
- Shade house vs. greenhouse (temperature, air flow and circulation, pest and weed exclusion)
- Water (catchment or municipal water, water pressure and ability to accommodate nursery equipment)
- Electrical access and electrical components (cooling/heating systems, vents and fans, automatic shade, water pumps, irrigation timers, etc.)
- Ventilation and cooling requirements, if any.
- Type of foundation/flooring
- The type of benches and support structures to be used (metal, plastic, wood, a combination)
- Irrigation types- Plant size, type and growth habits will change as plants grow. The greenhouse irrigation system should be flexible to accommodate these changes (mist, overhead, drip, flood, irrigation times, etc.)
- Whether or not quarantine areas or isolation areas are required.

Figure 1.01. The high elevation and cool temperatures year-round make the Pahole mid-elevation an ideal place to grow rare plants.

Layout and Location

Location will be the most important factor in determining whether a nursery is successful or not. Site selection will determine what plants can be grown easily and which species will require more work to germinate and grow.

It is easiest to install the nursery at the site where the plants are going to be planted, as is the case at Hakalau Forest National Wildlife Refuge. Propagules collected from the area are adapted to the climate and conditions found there and grow best in those conditions. Species such as pukiawe (*Leptecophylla tameameae)* are nearly impossible to grow at lower elevations and can only be reliably germinated at mid to high-elevation.

Installing a nursery close to the restoration sites where plants will be going will also reduce the chances of introducing new pests into natural areas and may eliminate pest infestations altogether so long as plants in the area are relatively pest free. If this is the case, phytosanitation will be the key to reducing pest occurrences.

If installation of a nursery onsite is not possible, the next best site to install a nursery would be one which exhibits conditions most similar to that where the original plants are found. Doing so will reduce the amount of guesswork involved with creating favorable growing conditions (shade/light, cooling/heating, etc.) and would allow the grower to focus efforts on propagation.

Once a property is selected/obtained, the next consideration will be where on the property to place the nursery. When selecting a site on the property, the first thing to consider should be access to water, vehicles and power; a site should be selected that allows easy access to all three:

1. Access to water is the first factor to consider; without water, it will be very difficult to operate a nursery. Options exist to get water to a designated area (trucking water in or installing a catchment system) but are less reliable and will increase the cost of the nursery.
2. The second factor to consider is vehicular access; without easy vehicle access, it will be very difficult both to move growing supplies into the nursery as well as to move plants ready to be planted out of the nursery.

3. Access to electricity is the third factor to consider and is not as important as the first two factors since options for off-grid operations such as battery operated components and solar systems exist.

As with any structure of importance, the grower should consider water flow and drainage of the property. The nursery should not be built in areas that are prone to flooding. Flooding will negatively affect any electrical components and may compromise the structure of the nursery. Standing water or frequent periods of saturation in the nursery may also lead to an increase in diseases and pests and should be avoided.

Non-native species should be avoided when selecting a location for the nursery if possible or should be controlled to prevent the incursion of seeds and other propagules into planting stock. Whenever possible, facilities should be planned for sites that do not have much existing vegetation (i.e., paved areas) as opposed to clearing native forest to create a nursery. Utilizing areas that are already free of vegetation is ideal; clearing native forest to construct the nursery should be avoided. Controlling non-native species of plants or pests on a regular basis will require time and effort.

One last consideration is wind: including the amount of wind and the orientation of the nursery facility to the wind. Sighting the nursery in a windy area will increase the chances of damage to the nursery facility whether from the wind itself or from loose objects and other trees. Extra precautions should be taken to secure the covering of the facility if exposed to high amounts of wind, especially during Kona storms and hurricanes. The nursery could be installed in protected areas of the property although this will reduce airflow and may necessitate the use of cooling and ventilation equipment to regulate temperatures in the greenhouse. To facilitate the installation of ventilation equipment, the nursery should be oriented to the direction of the prevailing winds so that the ventilation system is not exhausting air into the prevailing winds (see cooling and ventilation on page 6).

Figure 1.02. An example of a rare plant nursery

Figure 1.03. An example of a shade house

Shade houses

A shade house is essential for the germination of seeds and establishment of seedlings once they have been potted into containers. Shade houses create their own microclimate, reducing evaporation, protecting against extremes of heat, wind, and sun, and reducing rain damage. Shade houses allow higher amounts of airflow, thus reducing the excessive buildup of heat inside, making them the best choice when high temperatures are a concern.

Shade houses are ideal for native plant nurseries due to their relatively low cost to install and the wide range of options to fit any grower's need. A shade house structure in its simplest form can easily be constructed from 'easy up' tent poles and can increase in cost and complexity. Fifty percent shade cloth is the most common material used. However, if multiple shade houses are built, the use of different gradients of shade cloth may be beneficial. Some growers prefer to keep the ends of their shade houses open (non-enclosed) for maximum air circulation. There are shade cloth materials, such as white "Harmony Screen" or Aluminet shade cloth made of reflective material, that do a good job of reflecting radiation in hot regions.

Figure 1.04. Example of a gothic arch greenhouse with polyethylene covering and a solar ventilation fan (Future Forests Nursery Greenhouse, photo courtesy of Jill Wagner).

Figures 1.05a and 1.05b. Examples of a glass greenhouse (figure 1.5a) utilized by Hawai'i Volcanoes National Park Natural Resource staff to germinate rare and common native species and a polyethylene greenhouse (figure 1.5b) utilized by Greenpoint Nurseries above Kurtistown to grow cut flowers. Note the offset roof oriented in the direction opposite from the prevailing winds in figure 1.5b to allow for ventilation without compromising the integrity of the structure during high wind events.

Figure 1.06. Open ended polyethylene greenhouses allow cool air to enter below the benches and allow hot air to rise to the peaks and vent.

Greenhouses

Greenhouses have an impermeable covering installed to protect plants and to give the grower more control over environmental conditions while still allowing an appropriate amount of light through. This is usually achieved by utilizing plastic film, polycarbonate roofing or in some cases, glass.

Polyester coverings are the easiest and fastest to install of all the greenhouse coverings. Polyester coverings can be held in place by sandwiching the film between two wooden boards or can be installed using wiggle wire, which consists of a U-shaped channel and a polyester coated spring wire. Wiggle wire is easy to install and uninstall once the channel is attached and is designed to release the covering when enough force is exerted on the polyester covering in order to prevent damage to the greenhouse structure. Polyester usually requires the least amount of structural support and is usually the cheapest option but will typically last 3–5 years.

Polycarbonate greenhouses require more structure to support individual sheets of polycarbonate and will most likely require working at height to install, which presents a different set of challenges. For these reasons, polycarbonate coverings will be more expensive and require a higher level of expertise to install. Despite the cost, polycarbonate greenhouses have a longer lifespan, in the range of 10–25 years.

Glass greenhouses are the most expensive due to the difficulty involved with installation and the amount of support glass needs. Glass greenhouses are considered the gold standard in greenhouse coverings but due to their fragile nature and high cost, are not recommended in this guide. Other options to cover the greenhouse, such as Solexx, should be explored as they become available.

Greenhouses should be at least 15 ft tall or taller at the peaks of the roof to allow hot air to rise without damaging the crop. Taller greenhouse walls along the sides (typically where the ceiling is lowest) will also allow the grower to maximize the amount of growing space that can be utilized.

Greenhouses can be modified to fit the needs of most plants with the installation of various types of equipment; heaters, coolers, circulation fans, vents, etc. For that reason, it is important to properly plan for future needs, especially when working with rare taxa.

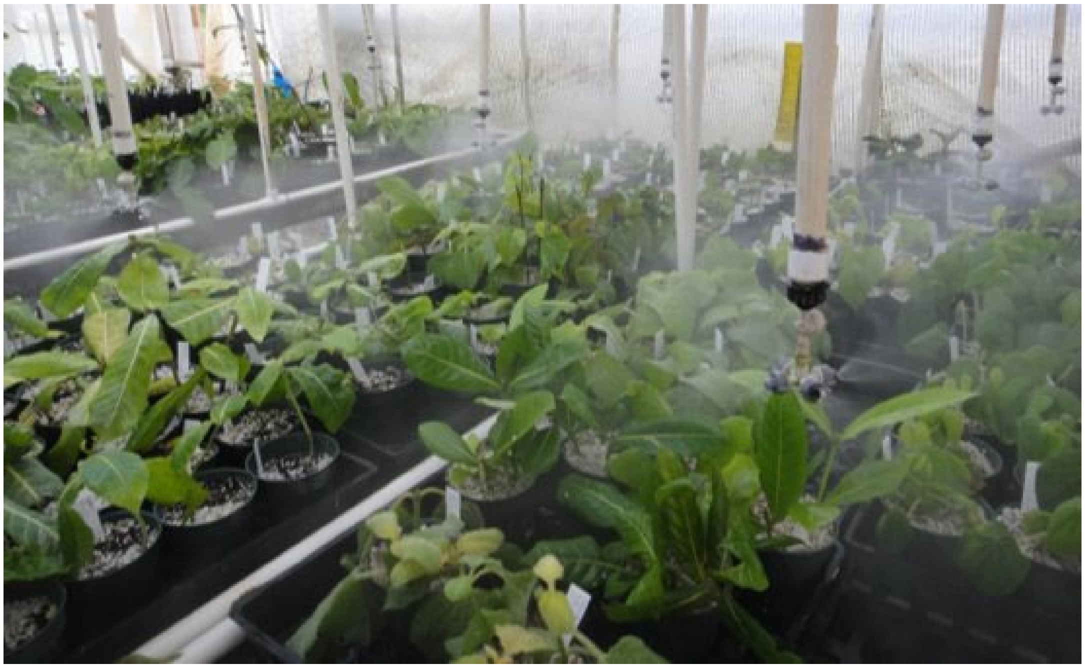


Figure 1.07. The mist bench/propagation area of the Army Natural Resources Program- Oʻahu used to root cuttings and acclimatize seedlings and tissue cultured plants following transplanting. This system uses the Netafim Fognet emitter and check valve assembly.

Mist Bench/Propagation Area

For nurseries utilizing clonal propagation, a mist bench or humidity chamber is essential to ensure the success of cuttings, air-layers and grafts. The main goals of installing a humidity chamber are to:

- Reduce airflow to the humidity chamber to allow for increased relative humidity
- Cool propagules to reduce the chances of drying out due to heat dissipation
- Achieve the smallest water droplet size when humidifying the chamber

Propagation areas can be scaled according to the need of the grower. Smaller boxes constructed out of PVC or small pieces of lumber can be placed on top of existing benches to be efficient on space. Larger structures such as EZ-up tents or full-size greenhouses may be used for larger operations. Propagation areas serve a dual purpose as a hardening off area for newly transplanted seedlings, tissue culture plants or newly removed air-layers, in addition to rooting cuttings. Most structures are covered in plastic on all sides except the bottom to allow water to drain; some structures are covered halfway down the frame to allow for some air movement. The plastic covering should be at least 3mil in thickness and should be clear to allow light to pass through. Shade cloth may be added to reduce the amount of light reaching cuttings while also cooling them.

Timers used for the propagation area must have an interval function, allowing for irrigation to run on intervals as short as 5 seconds for periods as short as 5 seconds. Army Natural Resources Program- Oʻahu (ANRPO) utilizes a Galcon 6 station interval timer, Hunter irrigation valves and Netafim Coolnet fogger assemblies to achieve smallest droplet size. They have tried to use the Aquafog system, which achieves the small droplet size through atomizing water particles through fan blades but realized that the Aquafog system requires a larger space than what is available to them (5ft by 15ft tent). The fog evaporated too quickly during the hottest parts of the day, leading ANRPO to revert to an emitter system. Other systems are available such as capillary mats, fog crystals and others, each with its own benefits and shortcomings.

Figure 1.08. Simplicity benefits growers who choose to hand water their nursery like the Pahole Rare Plant Facility.

Water/ Irrigation

<u>All nurseries must have a backflow preventer installed</u> if the water source is shared with potable water sources (i.e., bathrooms, kitchens, laboratories, etc.) to prevent contamination.

The crop, container (pot) and the size of the crop will determine the type of irrigation required within the nursery. Seed trays, small pots and dibbles are best irrigated with overhead irrigation. Larger plants are watered using drip irrigation to reduce fungi and bacteria presence on the leaves of the crop. The type of irrigation will determine the pressure and flow requirements of the grower.

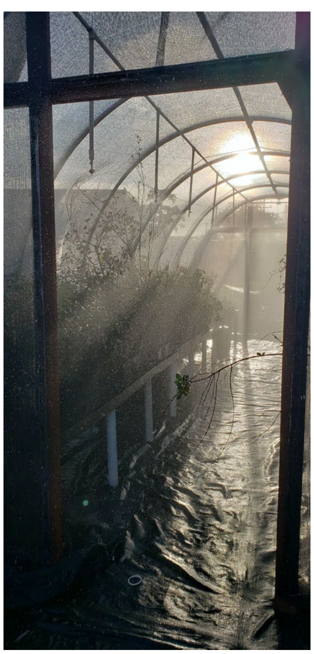
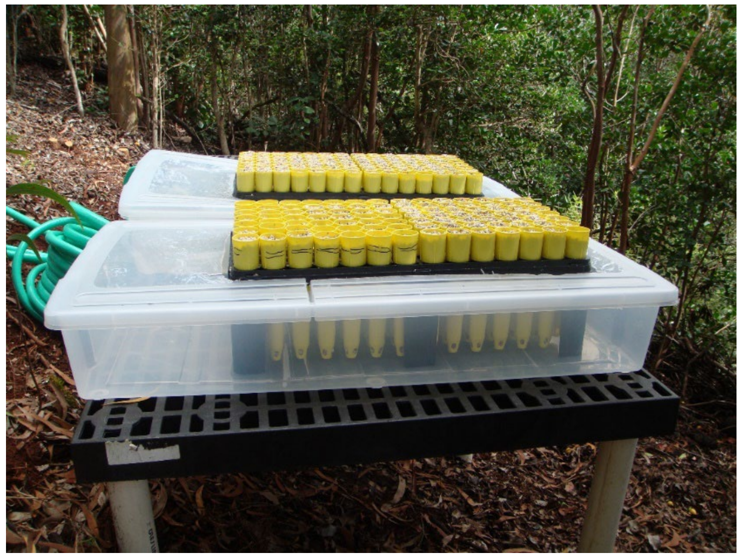


Figure 1.09a and 1.09b. Overhead irrigation in two configurations in ANRPO shade houses utilizing a combination of the Netafim Vibronet emitter and check valve assembly and sprinkler heads.

For overhead irrigation, the grower must ensure that there is adequate flow for the entirety of the system or there will be large areas that do not receive irrigation. Fittings without pressure compensation, such as sprinkler heads, will shrink in coverage or water output the farther from the source the fittings are. Overhead irrigation typically requires higher flow rates and operating pressures and will require larger pipes to accommodate the increased flow rates and pressures. For nurseries where increasing the flow/pressure of the system is not an option, one workaround would be to reduce the flow/pressure requirements by reducing the number of fittings in the system or reducing the size of the system. Overhead irrigation does not always deliver water where it needs to go and is not recommended for nurseries where water is limited.

Figures 1.10a and 1.10b. *Neraudia angulata* grown using 0.125" tubing and Netafim PCJ emitters in the ANRPO nursery at Schofield Barracks (1.10a). *Nototrichium humile* with spot spitters (1.10b) at ANRPO's East Baseyard. Spot spitters are only recommended for use in systems with adequate pressure and flow since they are not pressure compensating, meaning plants furthest from the water source will receive less water than those closest to the source.

Pressure compensating and low-flow fittings, typical of drip irrigation systems, will operate at pressures between 10–30 psi and flow rates of 2–4 gpm, which can usually be achieved by elevating the water source 20+ feet above the output fittings (elevation will only change the water pressure, pipe diameter will affect flow rate). Nurseries utilizing municipal water sources will need to install a pressure reducer to ensure that the pressure does not overwhelm the fittings. If higher operating pressures are required, a pump system will be required. A pump system consists of a pump (1–2hp sprinkler pump), pump relay switch (automatically turns pump on/off with either the irrigation timer or the system pressure) and an optional pressure tank (to allow for a range of operating pressures within the system). Pressure compensating fittings such as Netafim PCJ drippers and Rainbird Xeribug drippers allow uniform watering along the length of the irrigation line, provided the line is no longer than 300ft.


Figures 1.11a, 1.11b and 1.11c. Three different approaches to sub-irrigation. The system in figure 1.11a uses an electric timer and water pump to move water onto the table whereas the system in figure 1.11b is watered manually. Another example of a subirrigation setup at National Tropical Botanical Garden is shown in 11.c (Photo courtesy of Rhian Campbell).

Another type of irrigation available for band pots and other forestry pots is sub-irrigation. Plants sit in individual trays that are filled with water, requiring less pressure and flow than overhead irrigation. The plants uptake the water from the bottom of the pot and after several hours, the trays release the water. Alternatively, a large "tray" can be constructed using lumber and pond liner to accommodate multiple dibble trays, provided the surface is perfectly level. If the water is being recycled, a strainer should be installed before the water returns to the holding tank to reduce the chances of a clogged pump. This type of system reduces fungus and bacteria on the leaves of the plants. Plants can be hand watered from time to time if plants are dry.

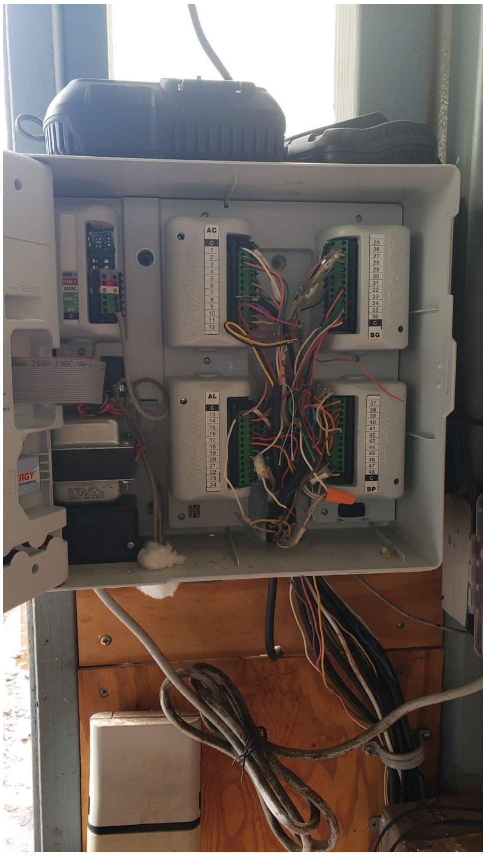


Figure 1.12a and 1.12b. Wiring scheme for the ANRPO main greenhouse controller at Schofield Barracks with AC power, a rain sensor and 48 irrigation zones (1.12a). An example of a battery operated timer (Hunter Node 100) and a 9v solenoid irrigating an outside table at ANRPO's East Baseyard (1.12b).

Irrigation controllers can be categorized into two groups, AC powered and battery operated. AC powered controllers tend to be larger and can operate many stations. Many have a Wi-Fi interface that can allow users to operate the controllers remotely. AC powered controllers require a 120v outlet to operate and may be expensive to install if outlets or electricity is not readily available. AC powered controllers can control many more solenoids than battery operated controllers. The primary benefit of having one AC powered irrigation controller as opposed to many battery-powered controllers is that it is easier to synchronize the watering for the entire greenhouse. For systems with a limited water supply and pressure, it is critical to ensure that the water demand does not exceed the capacity of the water system.

Power is not always an option, and many brands produce battery operated controllers. ANRPO uses Hunter and Rainbird battery operated controllers for sites without electrical service. Battery operated controllers typically require a 9v solenoid and can operate up to 6 valves. Battery operated controllers and solenoids can operate independent of any power source and are a good option for remote locations or where power is unreliable. An added benefit of using battery operated timers is the relatively small amount of wiring to do since electrical resistance will factor in over longer runs of wire.

Electrical components

Electrical needs will vary depending on the size of the growing area and the various needs for the equipment being used. The nursery should have its own electrical service line and panel to accommodate any equipment upgrades needed to support the crops. Ventilation, heating and/or cooling equipment will typically require the most energy. To determine the electrical capacity needs of the greenhouse, the grower can add the amperage of all the electrical equipment to determine if a separate panel and power line is required for the greenhouse or if a subpanel connected to a different building is sufficient.

If electrical service is not an option, it is recommended that the grower investigate solar or battery alternatives for each of the electrical components they intend to install. An off-grid solar system, like a home solar system, could be installed but the cost of installing solar panels, batteries, control modules and wiring would outweigh the benefit of having an integrated system.

Figure 1.13. A semi-underground growing area used during ANRPO's earlier years at Pahole. Note the intake fan at the front of the structure to encourage air circulation.

Ventilation and Cooling

Greenhouses tend to experience higher internal temperatures which may not be ideal for higher elevation species in certain genera, for example *Cyanea, Lobelia* or *Argyroxiphium*. Higher temperatures can also facilitate the growth of bacteria and fungi when coupled with excessive watering schedules. For these reasons, it is recommended that growers install some sort of ventilation system when installing a greenhouse or consider installing a shade house instead.

Fan ventilation systems consist of two systems: an exhaust system and a circulator system. Exhaust systems work to move hot air out of the greenhouse. At a minimum, an exhaust system will consist of one exhaust fan venting hot air in the direction of the prevailing winds. More fans may be added along the center of the greenhouse to facilitate air movement towards the exhaust fan. Other options utilize vent fans at the peaks of the greenhouse to move the hottest air out of the top of the greenhouse.

Figure 1.14a and 1.14b. A single circulator fan connected to a GFCI outlet in the ANRPO greenhouse at Schofield Barracks (1.14a). Note the fan's orientation at an angle to circulate air in a circular pattern. Temperature controllers at the peak of the greenhouse and at crop height control when fans turn on/off (1.14b). A ladder is required to change the settings.

Circulator systems move air across the crop to even out temperatures within the greenhouse and cool the crop using transpiration. Circulator fans also reduce pests and disease by increasing air turbidity, making it more difficult for pests and diseases to establish. Solar attic fans are a low-cost option and can be installed in smaller greenhouses to move air to keep temperatures cooler in the greenhouse. Larger greenhouses require larger fans that can move up to 5,470 cf/min. The Schaeffer fans that the Army Natural Resources Program installed in their greenhouse require ~2.1 amps per fan and require a capacity of 14.7 amps to run 7 fans simultaneously during the hottest periods of the day. For more info on greenhouse cooling and ventilation systems, refer to references in Section 4.

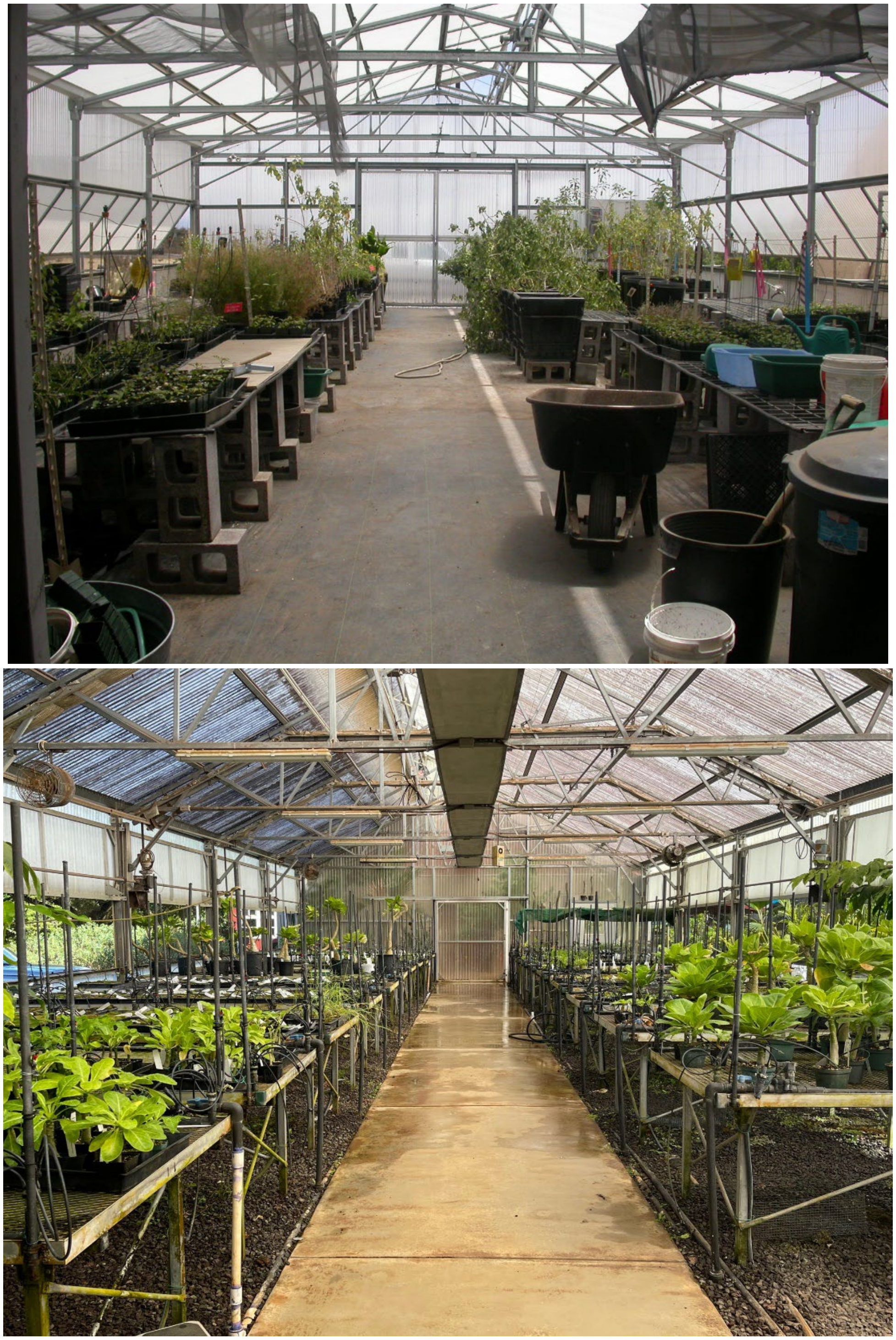


Figure 1.15a and 1.15b. A polycarbonate panel greenhouse used by Pohakuloa Training Area Natural Resources Office (1.15a). Note the motorized vents at the sides and peak of the greenhouse to encourage air circulation. A similar polycarbonate paneled greenhouse is used at the National Tropical Botanical Garden, complete with lights, fans and side and peak vents (1.15b, photo courtesy of Rhian Campbell).

Powered vents on the sides and peak of the greenhouse also facilitate temperature regulation within the greenhouse while still allowing the flexibility to protect the crop from extreme weather events. Unlike fans, vents are harder to retrofit to greenhouses unless properly planned due to the electrical requirements and structural support requirements of vent systems.

Evaporative cooling walls are yet another option to cool greenhouses. Evaporative cooling systems usually require a combination of vents, fans and irrigation. Evaporative cooling systems work by pulling air through a wetted membrane, allowing heat to be absorbed by the water and evaporated off. This system has the tendency to increase humidity in the growing area and may also increase the occurrence of fungi and bacteria. Evaporative cooling systems are rarely integrated into native plant nurseries in tropical areas where the humidity in the growing area may already be high and the benefits of evaporative cooling may not be as apparent.

All systems discussed above can be controlled by a single control board and thermostat such as Microgrow's Procom II system or can be controlled by individual thermostats on each circuit.

If power is not available, solar vent fans are an alternative. Passive cooling methods should be considered, such as installing heavier grades of shade cloth or reflective shade cloth, increasing irrigation, or leaving the sides of the greenhouses open to facilitate more airflow through the structure. The layout of the greenhouse could also influence the air circulation of the greenhouse; no structures should be blocking the side of the greenhouse from which the prevailing wind blows if more air circulation is desired.

Figure 1.16. A hybrid floor design at Waimea Botanical Garden using concrete to provide level walking paths and gravel beneath the benches to encourage good drainage in the nursery.

Substrate/ flooring

The floor and walkways should be covered or paved to achieve three things. The first is to provide the grower with a level, safe working area to grow plants. The second is to build a space that is easy to clean and maintain. The third is to prevent plants from establishing inside of the nursery area. Options for achieving this are outlined below with additional considerations.

Figure 1.17. Newly poured concrete floors in ANRPO's Skeeteretum. Note the overhead communication lines and telephone pole between the two structures (not ideal).

Pavement (Asphalt or concrete)

Pros	**Cons**
Easy to clean	Increased temperatures in the growing area.
Stable	Cost of pouring concrete may be prohibitive.
Long lasting (50+ years)	Permitting may be required for "permanent" structures
Graded to allow for good drainage.	

Figure 1.18. The new ANRPO shade house at their East Base Facility from 2005. As of 1/23/24, the EZ up poles are still standing but have a significant amount of rust, making this setup ideal for short term applications. Note the original weed mat flooring which was eventually removed in favor of gravel after ~10 years.

Landscape cloth ground cover (Weed mat)

Pros	**Cons**
Affordable	Not as long lived. Will eventually rip or tear in highly trafficked areas (~20 years).
Easy to clean	
Permeable to allow for drainage	
Easy to modify/remove	

Figure 1.19. Gravel floors at ANRPO's Pahole Rare Plant Facility.

Gravel

Pros	Cons
Good drainage	Weeds will grow
Ability to level areas as needed.	Difficulty of cleaning
Ability to install underground irrigation or electrical as needed.	Difficulties walking throughout the greenhouse or nursery, depending on size of gravel.
Lowered chances of slipping.	

Figure 1.20. Expanded metal benches filled to the brim at the University of Washington's Center for Urban Horticulture.

Figure 1.21. Four-inch hog panels stacked on top of cinder blocks at the U.S. Forest Service Institute of Pacific Islands Forestry are a cost-effective method of holding plants in 4 in. square pots.

Figure 1.22. Shaped wire supports hold up 6 in. wire panels to serve as bench

Bench Types and Options

There are many options for bench tops provided by commercial nursery suppliers. Metal benches are a popular choice for many nurseries since they have a long lifespan, harbor less algal and moss growth, and are easy to clean. Metal benches are relatively easy to construct using fence panels elevated to a minimum of 18in. (inches) above the ground. Wire fencing with metal wire supports can be found at some local nurseries (Hui Kū Maoli Ola) while other nurseries utilize rolling metal benches (orchid growers) which can be expensive and time consuming to install. Metal benches are not easy to move or modify once installed and installation should be well planned. Expanded metal benches welded to a hollow metal frame have been utilized in other nurseries (U.S. Forest Service in Hilo) as a lighter metal option, but may be expensive.

Figures 1.23. HDPE benches are a good choice for their durability and ability to customize height and arrangement but can be cost prohibitive and degrade over a short period of time. A hybrid setup like this one at Waimea Botanical Garden may last longer or will at least be easy to replace.

High Density Polyethylene (HDPE) Plastic benches with PVC or metal legs are utilized in most State of Hawaiʻi and ANRPO nurseries. Plastic benches also have a long lifespan and are easy to clean but are susceptible to cracking when placed under heavy loads for extended periods of time. Plastic benches are lighter when paired with 2in. PVC legs and can be moved with some effort with one person. They are also easy to modify without specialized tools and are a better option for nurseries with changing crops.

Wooden benches are a low-cost alternative since lumber is relatively easy to obtain and can be relatively cheap. The use of untreated lumber for benches is discouraged due to the relatively short lifespan (6 months with regular watering) and high potential to harbor pests and weeds. A combination of a metal bench top with wood supports may be a good compromise when considering cost, lifespan, and pest mitigation. Fence panels and lumber can be purchased from many vendors and can be cut to fit most spaces.

Hardening off areas

Figure 1.24. Hardening off area in a rare plant nursery

After becoming established in containers, plants may be placed in an area to "harden off" or "acclimatize." This important step allows the plant to develop woody tissue (lignification) in root systems and thicker leaf cuticles to become robust and ready to withstand conditions at the outplanting site. The amount of time plants spend acclimatizing varies by species but generally, plants should acclimatize for a minimum of 2–4 weeks.

A hardening off area can be a separate area outside of the nursery, so long as the plants are elevated at least 18in. above the ground and weeds are controlled. Hardening off can also be accomplished by reducing watering and fertilization within the nursery, although this method will not promote lignification. Adjustable shade cloth is ideal for this step. During acclimatization, plants are exposed to higher levels of light and higher levels of wind. Research also mentions the use of mechanical brushers or mechanical stress to achieve this (Latimer, J.G. 1998) although a separate article has mentioned that the effects vary with watering regimes (Wang et al, 2009) rather than mechanical stress. These methods have not been tested for native Hawaiian plants.

During this time, it is recommended that growers begin to reduce the amount of nitrogen fertilizer the plants receive. Providing a balanced N-P-K fertilizer will help plants balance leafy growth with their root systems. This can be achieved through the application of slow-release fertilizers such as Osmocote and Nutricote which release fertilizers over the course of 2–4 months and continue to release fertilizer after plants have been placed into the ground.

Certain species such as *Erythrina sandwicensis* and *Dodonaea viscosa* seem to prefer higher levels of light and shorter watering regimes in a nursery setting, as these conditions are less favorable for powdery mildew and bacterial rots. These species, and other dry forest plants may benefit from the harsh conditions outside of a greenhouse and may benefit from being grown under hardening conditions.

Hardening off areas can also serve as an inoculation area when implementing mycorrhizae in restoration nurseries. Mycorrhizae do not move well through the air and are instead transported through water, soils, and soil organisms. Mycorrhizae can easily be segregated from the rest of the nursery if the HRPRG phytosanitation checklist is implemented.

Figure 1.25. An example of a quarantine area in ANRPO's Pahole nursery. In this case, the affectionately named "Bug Box" was used to isolate plants for pollination studies.

Quarantine areas

Quarantine areas coupled with routine pest inspections can be helpful in isolating pest problems while they are small. As new plant materials are brought in or are being prepared for planting, they can be placed in a quarantine area to ensure that further contamination of the rest of the crop does not occur. A quarantine area can be attached to an existing shade house or greenhouse if a sufficient barrier exists to stop the spread of insects and pathogens. Insect mesh, polycarbonate or regular construction materials can be used to accomplish this.

Quarantine areas provide an easier opportunity to treat pests. When pests are restricted to the quarantine area control efforts can focus on a smaller area, rather than treating large areas within the nursery. Labeling restrictions on pesticide usage are also easier to follow within a smaller area and many chemicals cannot be used outside of an agricultural setting. Spraying within the quarantine area may limit exposure to non-targets and reduce the amount of pesticide applied, making a quarantine area a good idea for any nursery. Details about nursery inspections and quarantine procedures can be found in the next section; HRPRG Nursery Phytosanitation Guidelines.

Field nurseries

Figure 1.26a, 1.26b and 1.26c. *Pisonia sp.* seedlings on automatic drip tube irrigation (1.26a) in a small clearing in the forest with the water source elevated above the growing area (1.26b). Field nurseries can be more detailed, such as the The Nature Conservancy (TNC) field nursery on Kaua'i (1.26c, Photo courtesy of Rhian Campbell)

Field nurseries established at the margins of restoration sites can provide favorable conditions for the propagation of native plants. Field nurseries can produce large amounts of common and endangered plants with minimal upkeep. Battery operated irrigation timers are attached to water storage tanks which are set beneath a water catchment system. Seedlings are either brought in from the wild or from traditional nurseries; in this case, the field nursery can act as a hardening off area. An area protected from the wind and sun should be selected to mimic conditions in an understory forest. Media can be surrounding forest soil or standard nursery mixes brought in by foot, vehicle, or helicopter. Despite being less accessible field nurseries have several benefits:

- Plants are exposed to the environmental conditions of the restoration site where they will be planted
- Travel expenses of bringing larger plants in by foot or helicopter are greatly reduced
- Reduced risk of bringing in new insect pests or pathogens to restoration areas if plants are grown exclusively at the field nursery

Downsides to consider when deciding to install a field nursery include:

- Limited pesticide applications- labeling for many pesticides used in a nursery/greenhouse do not allow for applications in forested areas.
- Limited accessibility- this will affect the installation and upkeep of the nursery. If hiking materials into the site for example, distance, weight and size of materials will be severely limited.

These topics and many more important considerations are included in the U.S. Department of Agriculture Forest Service's Tropical Forestry (USDA-FS) Manual available online (see references).

Section 2: Plant Propagation

Considerations when deciding to propagate by seed or clonally

Seed propagation

Pros	Cons
Genetically diverse propagules and genetically robust planting stock	Genetic uniqueness not maintained; hybridization is possible especially in a conservation nursery.
Taproot development for tree species	Pollination biology may not be understood for rare species or viable seed may be hard to obtain
Large quantities available for large out-plantings	Germination requirements not always fully understood
Certain species store well for long periods of time	Easily dispersed seed is not always easy to obtain

Clonal propagation

Pros	Cons
Unique genetics are maintained including sex if plants are dioecious	Genetic diversity more difficult to achieve
Many plants can be produced from relatively little material	Material is not always available when plants are not healthy
Maturity of the planting stock can be maintained and time to reproduction is shortened	Pests and diseases can be transferred from stock plant to propagule

Seed Propagation

Figure 2.01. Clipping the fruit of *Cenchrus agrimonioides ssp. agrimonioides* to extract the seed for storage.

Seed storage and preparation

Before sowing or storing seed, many seeds must be cleaned to remove material such as fleshy fruit and husks. In some species, the fruit contains germination inhibitors that will prevent the embryo from germinating. Fruit is the perfect place for fungi and bacteria to begin growth to then move to contaminating the germinating embryo. Seeds should always be removed from the fruit regardless of whether the seed will be stored or immediately germinated. The following techniques are commonly used to clean seed of native trees, shrubs, sedges, and grasses.

Figure 2.02. Soaking *Acacia koa* seed to improve germination times.

- **Soaking**: Species that have fleshy pulp surrounding the seeds should be soaked in clean, cool water for 2–24 hours. This technique aids in softening the pulp, making seeds easier to remove. Fungicide or diluted bleach solution (5 %) may be added to the water to help disinfect seeds although care should be taken when using this on seeds with thin coats as the solution may damage the embryo.

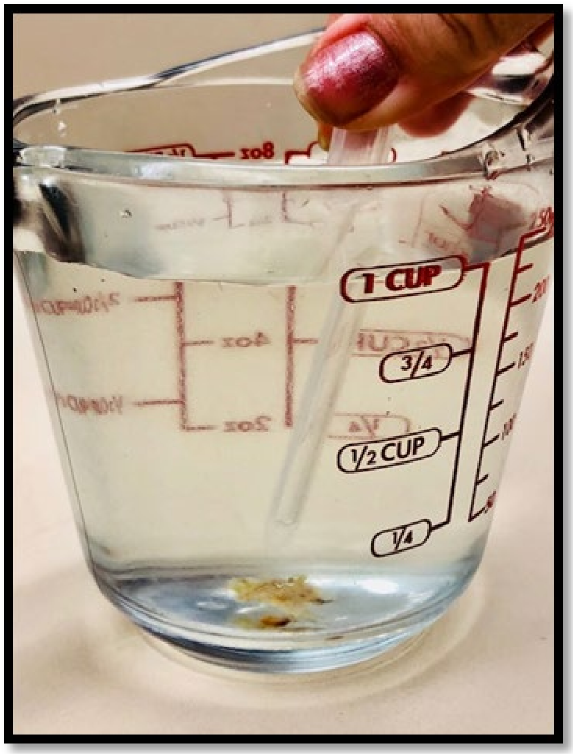


Figure 2.03. Fruit with small seeds can be separated by rubbing the pulp through a strainer into a cup of water, in this case, *Delissea waianaensis*, swirling the pulp mixture and pipetting the now separated seeds to a paper towel where they can dry.

- **Puree**: If large amounts of fleshy fruits with tiny seeds are collected (e.g., *Pipturus albidus*), a small food processor or blender can quickly puree the fruits. The mixture can then be strained through cheesecloth to remove excess water in preparation for drying.

Figure 2.04. The result of rubbing *Sophora chrysophylla* seeds with stair tread, husks are removed without damaging the seed.

- **Friction**: Rub the fruit together to break away husks and separate out the seeds. Many programs use stair tread to help with this, especially with large collections of seed. Winnowing can also assist in removing chaff.

- **Sieves**: Once the fruit has been soaked or rubbed to remove fleshy or dry matter, it is put through a sieve to separate out the seeds from husk material.

Figure 2.05. The column blower being used to separate *Dodonaea viscosa* seed from the fruit. The column blower works well for large batches of dry fruits where the seed is significantly heavier than the fruit.

- **Column Blower:** Once the fruit has been rubbed to remove dry matter, it is put through a column blower which works best when there is a significant difference between the density of the seed and fruit/husk particles.

Figure 2.06a and 2.06b. A drying chamber (2.06a) with several collections of cleaned seed. High end drying chambers can control both the temperature and humidity but similar results can be achieved with salts and air-tight containers. Tri-laminate foil packets are used to store seeds for longer periods of time (2.06b) in their respective storage conditions (0ºC, -18ºC or -80ºC) after drying.

Once seeds are separated from the fruit, they can be dried in a low humidity area or by using silica.

According to the Hawaiʻi Seed Bank Partnership (HSBP), seeds of species native to Hawaiʻi should be dried to ~30% internal Relative Humidity by leaving seeds in a drying chamber for 1–5 months. Drying helps to remove excess moisture that could allow fungi and bacteria to grow while the seed is stored or germinated. Avoid using heat to dry seeds as this may kill the embryo and may also encourage bacterial or fungal growth.

Once the seeds have been cleaned and dried, they can be stored in a cool dry area for later use. Seeds of many rare species can be stored for several years or longer as a form of genetic storage. Seeds of different species differ in the temperature that they can be stored at and how long they remain viable for. The HSBP has resources for those interested in long term storage of Hawaiian species and can be found at https://laukahi.org/ under the Seed Banks tab. Seeds being stored for more than 1 year should be processed and stored following HSBP protocols.

Scarification and seed treatments

Many seeds have natural dormancy mechanisms that prevent premature germination in unfavorable growing conditions. There are many types of dormancy and many more methods of breaking dormancy. More information on the types of dormancies and dormancy-breaking methods can be found in Seeds by Baskin and Baskin (2001). This HRPRG guide focuses on the easy-to-germinate species such as koa (*Acacia koa)* and aʻaliʻi (*Dodonaea viscosa*). Methods for other species of native seed may be found in Lilleeng-Rosenberger's Growing Hawaiʻi's Native Plants. Seeds with a hard protective coat prevent them from imbibing the moisture that is essential for germination. These seeds can be prepared for germination using these methods: manual scarification, hot water scarification, or briefly subjecting seeds to a hot flame. Sometimes it is best to just try one dormancy breaking technique since the use of more than one treatment can cause too much water to enter the seed and cause rotting.

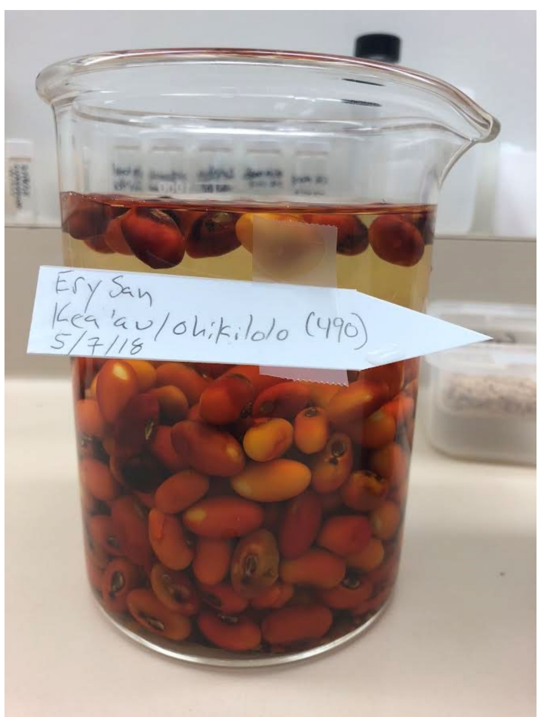


Figure 2.07. *Erythrina sandwicensis* being soaked before being sent to the nursery for germination. Note the lighter areas near the tip of each of the Wiliwili seeds, indicating they have been clipped.

Mechanical Scarification

The goal of mechanical scarification is to create a breach in the seed coat barrier, just enough to allow water to reach the embryo. Care should be taken not remove the entire seed coat. It is also important to preserve the integrity of the embryo. This can be done by making the cut on the side of the seed opposite the embryo. Before the entire batch of seeds are clipped, a few seeds may be cut open to determine the location of the embryo. Note that these techniques are practical for small amounts of seeds as the process is very time consuming.

The hard outer seed coat can be broken manually by:

- Clipping the outer coat with a nail clipper or wire cutter
- Scraping the coat with a file or on sandpaper
- Placing the seeds with other coarse material such as cinder and shaking the mixture, using a motorized rock tumbler for larger seeds

Heat Scarification

A better method of scarification for large batches of seed uses heat and varies based on the species and thickness of the seed coat. Three techniques are listed below:

- Heat ten times the volume of water as the volume of seed to be treated, so that the water does not cool too quickly while the seeds are soaking. Bring water to a boil and remove boiling water from heat to cool slightly. Pour water over seeds and let sit for at least 30 seconds up to several days before sowing.
- Briefly immerse the seeds in boiling water then transfer seeds to cold water. Boiling water immersion times will vary by species. Placing the seeds in a mesh bag makes these treatments easier to do. Use experiments to determine the optimum immersion time.
- Flaming seeds can be done by passing seeds through flames using a gas burner or immersing seeds in burning rubbing alcohol for brief periods. Seeds from the Malvaceae family typically respond well to a few seconds of flaming.

Chemically induced germination

Many chemicals can be used to encourage seeds to break dormancy. Chemicals listed below are used to break physiological and morpho-physiological dormancy, influencing the chemistry within the seed. The following are common methods of breaking dormancy. The HSBP is a good resource to use when determining species dormancy type and best methods for germination. Other reasons seeds may not germinate include the absence of a viable embryo, the existence of the fruit protecting the embryo and the decline of viability over time.

- Gibberellic acid: GA3 is the most commonly available formulation of gibberellic acid. Gibberellic acid concentrations are measured in Parts Per Million (ppm) and can be bought in premixed concentrations.
- Potassium Nitrate (KNO_3) can be used to break dormancy
- Ethylene has been shown to play a part in regulating the balance of Abscisic acid (ABA) and Gibberellins and may enhance germination

Sowing and Germination

Figure 2.08. Sowing seeds in a nursery

Figure 2.09. *Freycinetia arborea* seedlings germinating on a layer of vermiculite.

Seed germinating soil can be purchased in bags from landscaping and garden supply stores, or it can be made up using equal ratios of soil, fine cinder, and fine perlite. The main difference between potting soil and seed starting soil is the coarseness of the media; seed starting soil is finer to prevent seeds from getting buried too deeply. Alternatively, mixtures of sand and peat in varying proportions can be used, as well as other materials such as vermiculite for more water retention. The ANRPO greenhouse usually sows seeds onto soil with a layer of vermiculite. Smaller seeds are watered in and buried while larger seeds are covered with a thin layer of vermiculite. For tiny seeds or seeds that are sticky, sterile sand may be added to make handling of seeds easier and to avoid sowing too many seeds in one pot.

Fertilizers containing micronutrients (e.g., Apex™ or Micromax™) may also be added to the seed starting media. Seed media should be well moistened prior to planting seeds. Beware that homemade dirt soil mixes, unless sterilized, may contain weed seeds, nematodes, and fungi harmful to germinating seeds and restoration sites.

Figure 2.10. *Flueggea neowawraea* germinated and growing in an incubation chamber at ANRPO's seedbank. Tags record the six letter species code, seedlot number and founder population reference code.

The following information should be associated with every seed collection being sown in the nursery. This information may help to determine effective seed treatments for future collections. While the information does not need to be written on the plant tag, it is important to maintain records for tracking each seed lot.

- Seed lot number
- Seed cleaning method including any insecticidal or fungicidal treatments
- Drying techniques before storage
- Recommended seed storage method
- Germination treatments
- Germination rates

Figure 2.11. Sowing seeds in containers

Any container can be used for sowing seed so long as there is sufficient drainage. Trays or containers that do not have enough drain holes will hold too much water, resulting in rotted seeds. The following containers are the most common in Hawaiʻi's native plant nurseries.

- Plastic seed trays usually measuring 10in. x 20in. (available from horticultural suppliers and nurseries). These trays are not divided, so are best for sowing large batches of seed or for seeds with staggered germination times. Seedlings should be divided in a timely manner to avoid the roots becoming intertwined with other seedlings.
- Cell trays are divided to assist in keeping seeds separated and ease transplanting after initial growth.
- Nursery pots
- Dibble tubes (shown above)
- Other household containers (pie tins, grilling trays, glad containers, etc.) may be used after punching holes through the bottom using an awl or drill.

Fill the seed sowing container with soil mix, then smooth and press down the material. Keep seed distribution as even as possible. Fine seeds should be sown on top of the media, firmly pressed down and watered in to ensure adequate seed-to-soil contact. Larger seeds are pressed down into the media in a similar manner, then covered with additional media to an appropriate depth and lightly pressed down. A common mistake is to bury seeds too deep. Tiny seeds only need to be scattered on the top of the soil and gently pressed into the media with a flat surface. Larger seeds should be buried no more than the width of the seed itself. After sowing, moisten the seed media again by misting it with a fine spray of water or place the container in a tray of water, allowing the media to soak up the water. Containers should then be placed in indirect light to avoid drying out and excessive heat. The seed trays should never be allowed to dry out and should be kept moist for optimum germination rates. Spray as needed with fungicide, algaecides, and insecticides to prevent disease and insect problems which kill young seedlings.

In cool, high-elevation climates, the temperatures of the seed flats can be raised by a variety of methods. Commercially available warming trays placed under the flats are an expensive method but get the job done. An alternative, cheaper method is to place Plexiglas over the flats, covering the plexiglass with newspaper to provide shade for the seedlings. As soon as germination begins, the covers and newspaper should be gradually removed.

Seed propagation and storage is also covered in Chapter 17 of the USDA's Tropical Forestry Manual. Chapter 9 discusses seed germination and sowing and provides guidance on seed germination techniques.

Clonal Propagation

An intermittent mist or fog tent or other humidity chamber is required for the vegetative propagation of any species (Hartmann et al, 2002). High humidity is required to ensure that cuttings and other vegetative propagules do not dry out once they are separated from their root systems.

In addition to a mist bench, most cuttings or air-layers must be treated with a type of rooting hormone. Most commercially available rooting hormones utilize Indole-3-Butyric Acid (IBA) to induce callusing and eventually rooting. Other rooting hormones are available through certain vendors or other commercial formulations of rooting hormone (**See appendix 5A**).

Figure 2.12. Various rooting stages/successes of *Eugenia koolauensis* using the plant hormone Clonex (0.03% IBA).

Figure 2.13. A successful rooted cutting of *Rockia sandwicensis*.

Cutting collection

Determining optimal material for rooting cuttings will always depend on the species, timing, and climate. Nursery protocols must be developed for each species. More information on other factors such as types of cuttings, stage of growth and time of year can be found in Plant Propagation Principles and Practices by Hartmann et al, beginning on page 341. There are some advantages to propagation by vegetative cutting over air-layering. Propagation by cuttings is better for soft material or for material where the phloem and xylem are not easily distinguishable. Propagation by cuttings is also best for producing more plants with limited plant material or for plants that do not have much material to propagate from. Downsides to propagation by cuttings include higher chances of rot for species that take longer to root and lower chances of success in Hawaiian native hardwood species, especially when the incorrect hormone is applied. These are general guidelines for collecting vegetative material from native Hawaiian plants.

- Look for plants with signs of vigor; long internodes, green stem tissue and many healthy leaves.
- Cuttings should be thin and firm.
- Material should be taken from lower areas of the mother plant. This includes watersprouts, basal shoots and suckers which tend to have physiological juvenility.
- Cuttings should not be flowering or fruiting. If only flowering material is available, the flowers should be removed before propagation.
- Cuttings should be pest and disease free.
- For best results, cuttings should contain at least two to four nodes.
- Use a sharp cutting tool and clean all hand tools between plants.
- The health of the parent plant is important. Cuttings taken from healthy plants will have a higher chance of rooting. Cuttings taken from upright branches tend to make better material for maintaining in containers than branches growing downwards, because the habit is usually maintained in cultivation.

Figure 2.14. Cuttings taken in the field are placed in Ziploc bags to maintain the water content in the cuttings.

When transporting cuttings to the nursery for propagation, these guidelines should be followed to increase the chances of survival.

- Place cuttings in a sealable bag (e.g., Ziploc) or other sealable container to maintain high relative humidity.

- Leave cuttings as large as possible.
- Add clean water to a container or bag to increase humidity, enough to wet all surfaces of the plant material. Paper towels and other materials placed with the cutting to pack plant materials are not necessary. Packing with moss and other bryophytes is discouraged due to the impact on the site and due to the opportunities for unwanted organisms to travel with the bryophytes.
- Keep cuttings cool and out of direct sunlight (National Tropical Botanical Garden (NTBG) often refrigerates cuttings if they must sit overnight).
- Protect cuttings from overheating and crushing or other physical damage.
- Transport cuttings to the nursery for processing as soon as possible to give nursery staff the best opportunity to successfully root the cuttings.

Figure 2.15a and 2.15b. Successful air-layers of *Alectryon macrococcus* (2.15a) and *Gardenia mannii* (2.15b). Note the white colored roots beneath the plastic in figure 2.15b, indicating this air-layer is ready to be removed and placed into soil.

Air-Layer Collection

Air-layering techniques and principles are discussed in Hartmann and Kester's Plant Propagation, beginning on page 539. Air-layering takes time and practice to perform proficiently so practicing on easier species is advised before air-layering rare species. There are several advantages that production by air-layering provides over production by cuttings; air-layering results in larger plants, air-layers are more likely to root since they will not be separated from the parent plant until after rooting takes place, lower chances of rot since the air-layer will not be subjected to a high humidity environment and the air-layer can always be redone, so long as the donor material is still alive. Downsides of air-layering wild plants include ease of access to appropriate material to install an air-layer (material is too high in canopy or would result in larger plants that are difficult to transport), impacts from wounding the parent plant during installation and removal (unavoidable with any clonal propagation) and timing and accessibility issues (as it relates to root formation and revisiting parent plants for collection). The following are tips for installing air-layers.

- Look for signs of vigor; long internodes, green stem tissue and many healthy leaves. Air-layers should be installed in the semi-hardwood portions of the stem.
- Ensure that the cambium is completely removed from the girdled area, or the plant may heal over and fail to root.

- Ensure that the wrapping is secure and will not let additional moisture in or out. Many air-layers fail because of drying out.
- Use a sharp cutting tool and clean between plants to reduce the chances of infection.
- Air-layers should be collected when roots have reached the bottom of the moss and the root mass is enough to support the shoot material above it when removed from the plant. Roots are typically visible through the wrapping and can be felt protruding from the moss or other media.

When transporting air-layers to the nursery for propagation, these guidelines should be followed to increase the chances of air-layer survival.

- Place the air-layer in a sealed container if possible. Placing large air-layers in a sealed container isn't always necessary so long as the air-layer can get to the nursery quickly.
- Hike out the whole air-layer if it isn't too difficult. If you must cut it, leave as many leaves on the air-layer as possible.
- Reduce the number of leaves on the air-layer by approximately ½ after removal from the mother plant. This step is not necessary if the air-layer will fit into a sealed container or if the air-layer can be transported to the nursery in a timely fashion.
- Add water to a container or bag to increase humidity, enough to wet all surfaces of the plant material.
- Keep air-layers cool and out of direct sunlight (NTBG often refrigerates material if they must sit overnight).
- Protect air-layers from overheating and crushing or other physical damage.

Nursery Materials

Growing media

A mix of ½ Sunshine #4 Professional Growing Mix, and ½ perlite has been used extensively in Hawaiʻi and has been proven to be a suitable growing media for most, if not all native Hawaiian plants. Alternatives to peat moss are encouraged where possible to reduce the effects of peat harvesting on climate change and encourage the use of more sustainable options. Other products such as coconut coir, Sunshine #1 and other potting mixes can be used as well with varying results. As with pesticides, growing media mixes should be tested on a small portion of the crop in case phytotoxic effects are observed (*Gardenia mannii* has been noted to perform poorly in media with coconut coir at ANRPO, NTBG has noted similar phytotoxic effects in several species). It is recommended to purchase all media ingredients separately to maintain the ability to adjust growing media mixes to suit the needs of the crop. Dry forest species and species susceptible to rot out can handle well-drained media (2:1 Perlite: Sunshine#4), but may require more irrigation. Vermiculite may also be added to increase water-holding capacity. A balanced slow-release fertilizer such as Osmocote or Nutricote can also be mixed directly into the potting mix.

Figure 2.16. Root-training nursery pots, also called book pots. Note the use of crates to keep the pots standing upright.

Figure 2.17a and 2.17b. *Acacia koa* grown in dibble tubes in figure 2.17a require a specialized dibble rack to stand upright which will need to be ordered from the U.S. continent, adding to production costs. Plants grown in 4" round pots such as the *Myrsine lessertiana* in figure 2.17b do not require specialized trays or containers.

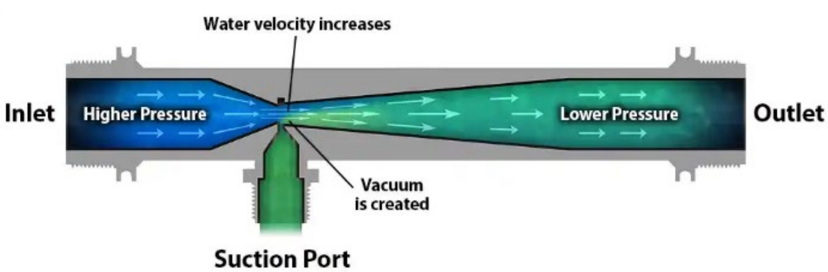
Pots

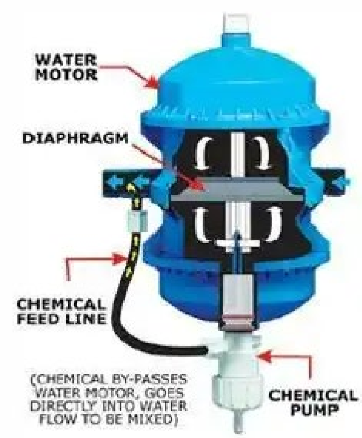
Selecting pots for each crop should consider the needs of the plants throughout the production cycle and with the intended goal in mind, i.e., living collection or outplanting (including planting conditions in the field site). For living collection plants, the container size and the growth rate will determine how quickly the plant should be transplanted. Plants should be continuously transplanted in the nursery to maintain plant health and vigor. For plants going to field sites, the grower should consider several things: soil type, soil depth, and transportation limitations. Rocky soils present a unique challenge when attempting to outplant; it is much easier to plant smaller plants into rocky soils, but larger plants may survive better since they have a greater ability to establish under the right conditions (deeper roots can help plants reach higher moisture zones faster). In areas with shallow soil horizons, short pots may be required to ensure that the roots of the plants are not overly disturbed during planting. Transportation to the field site will always be a factor since larger plants will be more difficult to transport no matter the method being used.

Round nursery pots of various sizes can be used for plants both in living collections and for planting. Species without a defined taproot or plants that are unable to produce a taproot due to vegetative propagation methods are best placed into round pots. This includes herbaceous species and species propagated from cuttings and air-layers. Round pots will stay upright better than tree pots and are able to capture rainwater better due to the larger surface area at the soil surface. Plants grown for extended periods of time in round pots may be at a higher risk of root binding and care should be taken to loosen the root ball when planting. Round pots are the most commonly available pots in Hawai'i and will be the cheapest local option since shipping costs will be lower.

Tree pots of various sizes are commonly used for species with distinct taproots and for species requiring more depth at planting (tree pots are available from Stuewe & Sons Inc.). The tall, narrow shape of the pot, and in some models, vertical grooves in the pots, train roots down towards the large drainage holes at the bottom which assist in aeration. For most species, the influence of light and air flow at the bottom of the pot are enough to prune roots that manage to escape the pot. Tree pots will require a wire mesh rack or crates to keep them upright on benches (an increased cost for the nursery). Tree pots themselves are also expensive due to the need to import them from the U.S. continent.

Dibble tubes of various sizes can be utilized for species with short production cycles. Dibble tubes must be placed into dibble tube racks and could be irrigated using any method, but overhead irrigation seems to make the most sense due to the smaller surface area relative to the depth of the pot. Sub-irrigation is another method used to water dibble tubes. Dibble tubes are also very useful for growing large quantities of "plugs" for grass species.





Figures 2.18a and 2.18b. Examples of the Venturi principle injector (2.18a; courtesy of irrigationking.com) and a piston type chemical injector (2.18b; courtesy of Solutiontrade.co.in).

Nutrients and Fertilization

A regular weekly or monthly fertilization regime may help crops grow larger and faster. Native plants, especially seedlings tend to respond well to organic fertilizers with lower amounts of nutrients, such as organic kelp fertilizer (1-1-0.5 NPK). ANRPO applies a hydroponic 20-20-20 fertilizer with some micronutrients to its crops once a week. Chlorosis, abnormal growth, or premature abscission of plant parts may be indicators of a nutrient deficiency. Iron and calcium are two nutrients not commonly found in most fertilizers and may need to be applied to specific species, especially species in the mint family (Lamiaceae).

A chemical injector can greatly ease the application of fertilizers (and some pesticides when labels allow) by incorporating the fertilizer into the water supply. Note that a backflow preventer should precede the installation of the chemical injection device on the water line to avoid contaminating potable water. A concentrate can be loaded in a separate container and will be taken up by the injection system at a specific rate. Piston based injectors (Chemilizer, Dosatron) apply the chemical at a set rate which can be used to calculate the mix rate of the chemical concentrate. Injectors that utilize the Venturi effect (e.g., Ortho Dial N Spray®) will also achieve the same effect but will not always apply the fertilizer at a consistent rate since the uptake depends on the pressure difference on each end of the device.

Utilizing Beneficial Microorganisms

As the study of plant-microbe interactions has expanded, so too has the use of beneficial microorganisms in commercial nurseries. Commercially available sources of mycorrhizal fungi are not recommended for various reasons both practical and ecological, one of the biggest is the lack of information on the contents of such products and how they may or may not reflect the local microbial communities. The composition of viable spores or other forms of inoculum within the commercial inoculants is unknown and growers cannot be sure that they are not introducing “weedy” species of fungi to their host plants and ecosystems, which may have unintended negative impacts on both. Furthermore, commercial inoculants may not always be effective due to the lack of live spores in the mix or inoculants may not be able to associate with the target host plant.

Given that >89% of native Hawaiian plant species form symbiotic associations with arbuscular mycorrhizal fungi (AM fungi) it’s not surprising that even many common species of Hawaiian plants such as koa and aʻaliʻi perform better with mycorrhizal fungal inoculation, than without. For rare plant species with obligate mycorrhizal mutualisms, inoculation may be required and may be an important factor in the grower’s ability to propagate and maintain the species in cultivation. If mycorrhizal inoculation is required, many methods can be employed to inoculate plants with local mycorrhizal fungi, for example from the intended planting site or from existing congeneric or conspecific wild plant populations. Soil from the site can be applied directly to the plant in the nursery or for AM fungi, trap cultures can be generated to increase mycorrhizal fungal inocula, more so, spore slurries of AM fungi can be generated from trap cultures thereby limiting the potential for introducing non-targeted fungi such as pathogens. Live roots from field sites can be collected and applied to the host plant as well, reducing the time and space required of trap cultures. In order to comply with HRPRG phytosanitation standards, mycorrhizal fungi and other inoculants cannot be added to general nursery mixes or irrigation systems, must only be applied to specific plants and must be separated and clearly labeled to prevent introducing microbes to new areas.

When considering moving mycorrhizae between sites, it is recommended that the grower complete a molecular soil survey of the site to inventory all existing species of microbes. If this cannot be completed, it is recommended that growers move mycorrhizae from pristine habitats to poor quality (Native species composition) habitats, not the other way around to reduce the risk of introducing “weedy” mycorrhizal fungi into more pristine habitats. A study by Kajihara et al. (2022) suggests that native Hawaiian host specific species of AM fungi are more abundant in remnant forests therefore supporting the use of live soil from pristine habitats when working with rare plant species. A study by Gomes et al. (2018) found that “AM species composition was not related to invasion status of the vegetation nor the local environment, but stratified by watershed,” indicating that soil microbes should not be moved between watersheds without first determining the composition of AM fungi among watersheds. In some cases, the benefits to rare plant success through mycorrhizal inoculation may outweigh the potential risks of introducing mycorrhizal fungi to a novel ecosystem, so these cost/benefits should be carefully weighed and rely on the scientific literature for guidance.

Transplanting

Materials need for transplanting:

- Clean pots (for seedlings, 1–2in. pots; for bigger plants, one size bigger than pots which plants are already in)

- Moist media (mixture depends on plant)
- Plant tags and pencils
- Small digging tools
- Plant trays for organizing and carrying large numbers of small pots
- Liquid fertilizer or transplanting hormone (optional)

For seedlings, transplant after the first 2–4 true leaves appear. For older plants, transplant before the plant outgrows the pot. This will be a decision subject to experience and judgment. A rule of thumb that nursery growers use is if roots are protruding from the drain holes, the plant is ready to transplant. The plant should be transplanted just as roots are reaching the bottom of the pot to avoid root pruning and coiling. Care should be taken to maintain the existing soil line, ensuring that the transplant is not planted too deep or too shallow. When transplants are planted too deep, they may be subject to higher incidents of disease. When transplants are planted too shallow, they risk drying out from overexposure of the roots.

Figure 2.19. Kaleo Wong briefs the 50 or so middle school volunteers helping to plant *Hibiscus brackenridgei ssp. mokuleianus* at Koko Crater Botanical Garden, part of the Honolulu Botanical Gardens system.

Preparation for planting

Plants may be placed into the hardening area as discussed in the first section of this document. There they will undergo physiological changes to help them prepare for life in the field.

U.S. Department of Agriculture Forest Service's Tropical Forestry Manual: Chapter 15- Hardening provides some information and guidance about preparing plants for transport and outplanting. Chapter 17 includes more information about outplanting nursery plants into natural areas.

Healthy plants selected for planting should be pest free and not exhibit any signs of disease or viruses. Once plants are selected, all plants must be inspected and cleaned. A visual inspection of the plant stems and leaves is performed. If high levels of pest infestations are observed, plants will be removed from the planting selection and will need to be treated following IPM protocols. Once plants have been visually inspected, dead leaves and stems are removed, any seedlings are removed and the top 2cm of soil are replaced. The plant is then removed from its pot to examine the root ball for insect or mollusk pests. If pests are found at this stage, the plant must return to the nursery until it can be considered pest free. Plants may be considered cleaned and inspected for no more than 3 weeks prior to leaving the nursery. If more time has passed, the plants will need to be reinspected and recleaned.

When plants are ready for shipping to outer islands, they should be inspected for pests, securely packed so they are adequately protected during transport, and otherwise moved with caution. Hawai'i Department of Agriculture requires that plant material be inspected before being moved inter-island. Plants being shipped to the U.S. mainland are subject to regulations and inspections by the USDA. The figure in section 3 outlines the inspection process for all plants grown for outplanting and should be adjusted to fit the needs of each island.

Section 3: Nursery Phytosanitation: Pest and Pathogen Control

Sanitation is a key step in outplanting (reintroductions or augmentations) to prevent the introduction of foreign organisms into natural areas. This section outlines phytosanitation considerations that must be addressed in order for a nursery to operate effectively as a site for growing plants destined for planting into natural areas.

A checklist included in **Appendix 5c** (Nursery Checklist for State of Hawaiʻi Threatened & Endangered Species Permit Compliance) provides the standards by which the HRPRG Horticulture subcommittee operates and will be used by regulating agencies to issue permits and ensure compliance.

Before outplanting, all plants must be inspected. Only plants that are apparently weed-free, pest-free, and pathogen-free may be used for outplanting. If plants do not meet the standards stated in the guidelines at the time of inspection, they cannot be used. Plants must be treated so that all weeds, pests, and pathogens are eliminated before the plants can be considered for outplanting.

HRPRG Phytosanitation Guidelines for Restoration Nurseries

Threats to be monitored and controlled before outplanting include arthropods, alien plant species (weeds), mollusks, plant pathogens, small mammals, and other pests. These threats are major problems that affect the overall health of the plants and may cause harm to the environment if transported into natural areas. The table below summarizes the threats and control methods needed to eliminate them.

Control Methods	Nursery Pests and Pathogens							
	Virus	Bacteria	Fungi	Nematodes	Arthropods	Slugs/Snails	Weeds	Animal Pests
Nursery design		X	X	X	X	X	X	X
Plant media preparation and handling			X	X	X	X	X	
Plant and nursery sanitation	X	X	X	X	X	X	X	X
Pest and disease control program	X	X	X	X	X	X	X	X
Nursery and plant inspection	X	X	X	X	X	X	X	X
Threat monitoring and control	X	X	X	X	X	X	X	X

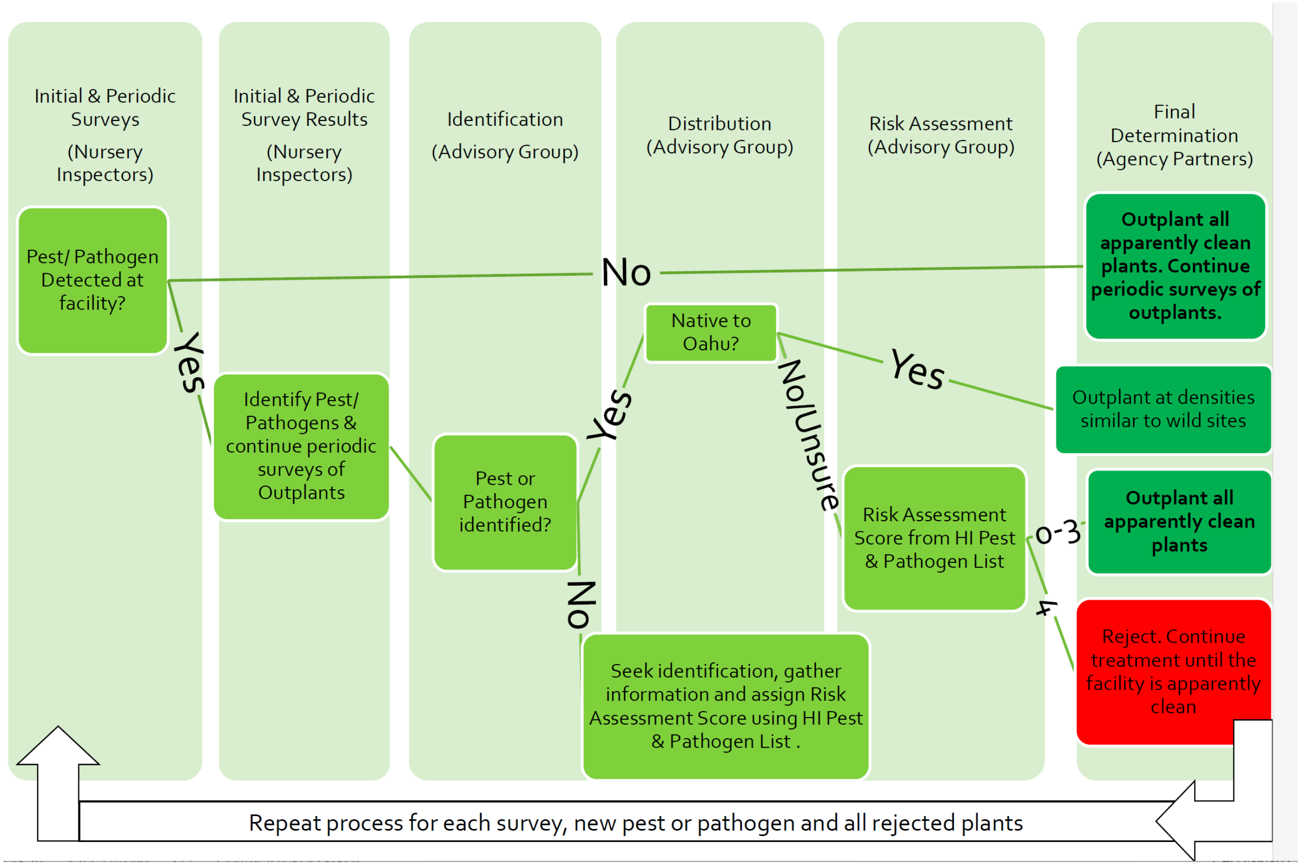


Figure 3.1. Suggested workflow for inspecting plants with unknown pests or pathogens

Nursery Inspections

As part of the Integrated Pest Management plan for the nursery, an inventory of all pests, pathogens and weeds should be made. This list should be used as a checklist for phytosanitation inspections before planning to transport plant material to a field site for planting. Pests that are found in or around the nursery facility but are not present at the field site should be given special consideration, because of the higher risk they may pose to native ecosystems.

The nursery and all plants will be subjected to inspection by the project lead or other private inspector as part of the outplanting process. All plant material should be carefully inspected before being moved to a field site for planting. Areas and plants not designated for project use will still be subjected to inspection, since they may still serve as possible sources of pests and pathogens. Plants grown by contractors must be inspected before acceptance; and contracts should be designed to allow contaminated plants to be rejected at the discretion of the nursery or buyer.

Inspections should be conducted by qualified and knowledgeable staff monthly throughout the planting season. All plant parts should be examined from the growing tips, with special attention given to leaf undersides (abaxial surfaces), all the way down to the roots. The plant roots must be inspected by carefully removing the container from the root ball and examining on all sides for pests. Traps and baits may also be utilized to detect and control pests that are difficult to observe. Increasing the frequency of inspections and the number of people inspecting will increase the likelihood of finding pests before they become a problem both in the nursery and in the field.

When possible, plants to be outplanted should be isolated from the rest of the nursery stock, placed on a surface with a barrier to prevent crawling pests from accessing the plants, inspected and then treated for insects, disease, weeds, and any other unwanted pests. Once nursery pests and pathogens have been identified, thresholds must be established to determine when and which treatments will be applied to reduce or eradicate pests and pathogens.

Various local, national and international services can aid in pest and disease identification. The University of Hawaiʻi's CTAHR Agricultural Diagnostic Service Center requires basic contact and collection information and charges $7 for each submission. Specialists in the Cooperative Agriculture Pest Surveys at the Hawaiʻi Department of Agriculture require detailed collection information for the identification of insect pests; a sample form is provided in Appendix 5d. The U.S. Department of Agriculture's Tropical Forestry Manual: Chapter 14 provides guidelines on pest management for nurseries and many other resources are available for pest and pathogen control online.

General Sanitation

- Water hoses must be stored off the ground to reduce the transmission of nematodes and bacteria.
- Plants must be grown in sterilized or disinfected pots, containers, or beds. Disinfection can be achieved with a 15–20% solution of bleach or 70% alcohol.
- Plants must be grown on clean surfaces and supports.
- Plants must be elevated at least 18 in. above the ground or floor level. Plants being utilized for breeding purposes or living collections do not need to be 18 in. above the ground although plants will generally be healthier when they are elevated above the ground. This can be attributed to the increase of drainage, airflow beneath the pots and additional effort for organisms to go against gravity and the flow of water.
- Plants must not be placed over other plants (hanging containers or secondary benches) to prevent contamination to plant material by the downward movement of water, spores, soil or plant material.
- The grower must sterilize/disinfect tools regularly, especially when moving between groups of plants or benches.
- The grower must keep all growing areas, benches, and work surfaces clean to minimize pests. This includes vehicles, plant boxes and other transportation equipment.
- All dead, diseased, or infected material on plants and in pots must be removed and disposed of daily.
- A 3-meter-wide buffer zone around any growing area or greenhouse building should be maintained and kept free from any vegetation to minimize pest and disease infestations.
- Plants should be grown in an enclosed area to prevent weed seeds from blowing into pots. Open sided nurseries may be used to increase airflow but plants will need to be thoroughly inspected and cleaned to remove unwanted airborne seeds prior to outplanting.
- Sprayer heads should be cleaned with 15% bleach or isopropyl alcohol at least once per year.
- Plants must be spaced appropriately in order to maintain air circulation between plants. Air circulation helps to minimize pest and pathogen problems. Horizontal airflow can be implemented to overcome the tighter spacing required by higher production nurseries and can be achieved with the installation of circulator fans. Circulator fans should be oriented to move air in a circular pattern

within the greenhouse to achieve the best results.

- Propagules must be free from pathogenic bacteria, fungi or viruses. Use appropriate methods to clean propagules (i.e., 5% bleach solution, fungicides) before bringing them into the nursery.

Media and Media Additives

- Media must be clean and free of living plant material at the time of initial planting or transplanting.
- Recycled media or media incorporating compost must be heated to a minimum of 131ºF for 3 days to be considered clean (USDA Agricultural Marketing Service, National Organic Program 5021). Sterilization of soil products is recommended.
- All media and media mixes must be stored in closed bins or containers.
- Commercial mycorrhizal inoculants must not be used in soil mixes.
- If mycorrhizal inoculation is required, it must be obtained from locally collected sources. Within the nursery, containers with inoculated media must be segregated from non-inoculated containers on separate benches and thoroughly disinfected afterwards. Care should be taken if inoculating with mycorrhizae to prevent the introduction of new mycorrhizal strains to areas where not previously known.
- Mycorrhizal inoculations must only be performed using inoculants from the planting site. Each planting site must have its own inoculum until it can be determined that the same microbe communities exist at all sites.
- *Ex situ* plantings should be periodically monitored post-planting to detect any weed seedlings (or other pests) emerging from the root ball area of the plants

Integrated Pest Management and Threat Control Program

An effective threat control program implements the principles of integrated pest management (IPM) which at its simplest consists of a cycle of two actions: monitoring and treatment. Pest management relies heavily on the proper identification of pests and thorough inspection of the nursery. Once pests are detected, thresholds must be established to dictate when and what to spray. This step helps to reduce the overuse of one chemical and can reduce the chances of pesticide resistance occurring in any particular pest. An example of an IPM plan for a small nursery (~15,000 plants produced/year) should look something like the following:

1. Identify pests through frequent nursery inspections.
2. Determine the extent of the pest infestation.
    a. Low abundance: 1–100 plants in nursery showing signs of infestation. Use of a quarantine area at this level will reduce the spread of the pest throughout the nursery.
    b. Medium abundance: 101–500 plants in nursery showing signs of infestation
    c. High abundance: 501 or more plants in nursery showing signs of infestation
3. Develop treatment plan based on level of infestation. If pesticide use is required, utilize a rotation of pesticides of different chemical classes to achieve control and reduce the risk of pesticide resistance. The OHP Chemical Classification Chart (2023) and The Pesticide Book by Ware and Whitacre (2004) are excellent resources with more than enough information to help find the correct chemical.

a. Low abundance: remove or control by hand
b. Medium abundance: short spray program to target specific pest
c. High abundance: Develop and implement multistep treatment program.

4. Monitor on a weekly basis and return to 2 until pest is at low level or undetectable.

Plants that are observed to be heavily infested with any pest or plants in questionable health must not be planted into field sites, even if pests have already been observed at the planting site. A plant planted in poor health will not survive the establishment phase of planting and will be a wasted effort.

The use of pesticides is governed by state and federal regulations. Ensure pesticide use is in compliance with the law and follow all label directions. If there are any questions, contact the State of Hawaiʻi, Department of Agriculture Pesticide Division (DOA) for further information. Nurseries must abide by the following:

- All staff must be properly trained in the use of sprayers and pesticides.
- All staff must be provided proper Personal Protective Equipment.
- All spray equipment must be provided and maintained by the nursery.
- All pesticides must be stored according to local regulations and label requirements. Secondary containment for all pesticides, especially liquid formulations, is recommended.
- If restricted pesticides are used, the applicator must be a certified pesticide applicator or supervised by a certified applicator.
- The grower must have a monitoring and treatment program for each threat category.
- Records of all spraying schedules must be kept for a minimum of two years. The information recorded must include: plant species treated, threat/pest treated, last time sprayed, and chemicals and rate of application

Planting

- Plants must be inspected and cleaned before leaving the nursery to be outplanted. Once plants have been visually inspected, dead leaves and stems are removed, any seedlings are removed and the top 2cm of soil is removed. The plant is then removed from its pot to examine the root ball for insect or mollusk pests. Once replaced into its pot, the top layer of soil is replaced with new media. Plants may be considered cleaned and inspected for no more than three weeks prior to leaving the nursery. If more time has passed, the plants will need to be reinspected and recleaned.
- If high levels of pest infestations are observed, plants must be removed from the planting selection and will need to be treated following IPM protocols.
- Clothes, gear, tools, etc., must be free of foreign soil and plant material. All equipment should be cleaned and treated with 70% alcohol to ensure that surfaces are free of microorganisms.
- Mulch must be produced from materials on-site if being utilized.

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Section 4: References and further resources

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Section 5: Appendices

5A- Commonly available Rooting Hormones

Rooting hormones fall in a class of plant hormones called Auxins. There are other chemical compounds that could stimulate root production that are untested such as 2-4D (found in pasture herbicides) and ethylene. This list highlights the hormones commonly used for native plant propagation.

Brand Name	Hormone/Concentration	Type	Comments
Dip n Gro	IBA (1%), NAA (0.5%)	Liquid	Good for large quantities of cuttings or for woodier species. Alcohol base so should be taken up by plant material better. Can be diluted to lower concentrations for certain species.
Clonex	IBA (0.3%)	Gel	Good for harder to root species and native species in general. The gelling compound seems to keep the plant material in contact with the auxins for longer, perhaps increasing the rooting success. Other concentrations are available in other countries.
Hormodin	IBA (various concentrations)	Powder	Also ideal for woodier species although met with less success than clonex. Cheaper and easier to obtain.
DynaGro K-L-N	IBA (0.7%), NAA (0.1%)	Liquid	

5B- Commonly used pesticides:

As stated in many pesticide labels, the pesticide intended for use should be tested on a subset of the crop in case the pesticide is phytotoxic to the crop(s). The following pesticides have been used on native species with little or no phytotoxic effects. If weed control is also being performed in the nursery area, consider separating storage areas of herbicides and pesticides to reduce the chances of accidental exposure.

Brand Name

Active Ingredient	Brand Name	Pests controlled	Chemical Class	Signal Word	Comments
Potassium salt of fatty acids	M-pede, Safer Soap	General insecticide/ fungicide/ miticide	Multiple	Warning	Organic and very effective. No limit on applications except to sensitive plants.
Neem oil, mineral oil, petroleum oil or horticultural oil	Trilogy, Volck oil	General insecticide	Multiple	Caution	Organic. No limit on applications. Other neem products exist but may not mix well.
S-Kinoprene	Enstar AQ, Enstar II	General insecticide/ miticide	7a- Insect growth regulator	Caution	Works for most greenhouse pests.
Botanical pyrethrins	Pyganic 1.4ECII	General insecticide	3a- Pyrethrins	Caution	Works well, respirator required for application.
Dinotefuran	Safari 20SG	General insecticide	4a- Neonicotinoids	Caution	Systemic, same class as imidicloprid.
Ethylene bisdithiocarbonate	Dithane DF Rainshield	General fungicide	M3	Caution	Seems to be systemic and works well.
Sodium bicarbonate	Kaligreen	Powdery Mildew	No classification	Caution	Specifically for powdery mildew.
Tebuconazole	Bayer Tebuconazole	General fungicide	3	Caution	Used in garden setting to treat rust in Eugenia.
Potassium phosphite	Rampart, Agri-Fos	General fungicide	33	Caution	Systemic

Active Ingredient	Brand Name	Pests controlled	Chemical Class	Signal Word	Comments
Bifenazate	Floramite	Spider mites and mites	No classification	Caution	Works well as single treatment.
Myclobutanil	Eagle 20EW	Rust and other diseases	3	Caution	Works well for Ohia rust

5C- Nursery Checklist for State of Hawaiʻi Threatened & Endangered Species Permit Compliance

Facility & Equipment

- ☐ Benches and other growing surfaces must be clean and free of weeds and other plant material
- ☐ Benches must be elevated at least 18in. above ground
- ☐ Plants must not be grown underneath other plants (hanging baskets)
- ☐ Tools and work areas must be clean including tables, vehicles, and transportation equipment
- ☐ All equipment and personal protective equipment (PPE) must be maintained in good working order
- ☐ Water hoses must be stored off ground
- ☐ Adequate storage of nursery supplies must be maintained to prevent infestation by weeds, pests, and pathogens
- ☐ An un-vegetated buffer of at least 3 meters around the growing area should be maintained
- ☐ Electricity should be available to power all equipment
- ☐ Nursery facility should be in a region where the taxa being grown are known to occur and/or the facility must be able to maintain appropriate temperature and rainfall conditions
- ☐ Facility should be able to withstand prevailing local weather conditions and high-wind events and/or must have access to a secure site to shelter plants during hurricanes, wildfire, and other natural disasters
- ☐ The floor of the growing area should be covered with a material sufficient to prevent weeds from becoming established

Supplies & Media

- ☐ Commercial inoculants must not be used
- ☐ Media components must be stored in closed containers and must be free of plant, insect, and microbial pests
- ☐ Mycorrhizal inoculations must only be performed using inoculants from the planting site; each planting site must have its own inoculum
- ☐ Mycorrhizal inoculations must be separated from the general nursery
- ☐ Pesticides must be stored according to local regulations and label requirements
- ☐ Pots and growing containers must be clean and disinfected between uses

Phytosanitation Practices

- ☐ All plants used for plantings must be inspected and cleaned. Only plants that have passed inspection may be used for outplanting in natural areas to prevent the spread of harmful organisms to wild populations and native ecosystems.
- ☐ An accurate pesticide and fertilizer spray history log must be maintained
- ☐ Clothes, field gear, tools, and planting supplies must be clean and free of soil and plant material
- ☐ Integrated Pest Management control plan must be developed and implemented
- ☐ Monthly inspections of plants and facilities must be completed during the planting season. Records must be maintained for review

- ☐ PPE must be provided to staff
- ☐ Staff must be properly trained to identify pests/pathogens and apply pesticides
- ☐ Each facility should maintain a list of all pests and pathogens observed on plants and within the facility.

5D Sample Inspection Form and HDOA sample submission form

Nursery Phytosanitation Survey Record

Nursery Facility:	Date:
Species Inspected:	Outplanting Site:

Loc.	Plant	Pest/Pathogen Name (include life stages present)	Abundance/ Damage Level #pests: very low (0–5) Low (6–15), moderate (16–50), heavy (>50)	Symptoms, Comments, Recommendations

Inspector: Date:

STATE OF HAWAII DEPARTMENT OF AGRICULTURE PLANT PEST CONTROL BRANCH 1428 S. KING ST., HON., HI 96814-2512	SPECIMENS SUBMITTED TO TAXONOMY LAB FOR IDENTIFICATION		1e. TAXONOMY #
			1f. PQ #
	1a. COLLECTED BY: Chris and Max, ANRPO	1b. DATE: 2/7/23	1g. USDA #
	1c. SUBMITTED BY: Chris	1d. DATE: 3/23/23	1h. OTHER COLL. #

COLLECTION SITE

2a. ORIGIN OF SAMPLE IF OTHER THAN HAWAII (Quarantine)	2d. NAME AND ADDRESS OF PROPERTY OWNER	
2b. LOCALITY OF COLLECTION: ANRPO Schofield Barracks Greenhouse,	2e. ISLAND: Oahu	2f. STATE: HI
2c. TYPE OF PROPERTY (Nursery, farm, residence, etc.): Nursery	2g. LATITUDE	2h. LONGITUDE

HOST DATA

3a. SCIENTIFIC NAME OF HOST: Neraudia ovata

3b. COMMON NAME OF HOST: Ma'aloa

3c. PLANT PARTS AFFECTED
- [x] Leaves, Upper Surface
- [ ] Leaves, Lower Surface
- [ ] Petiole
- [ ] Stem
- [ ] Trunk/Bark
- [ ] Branches
- [ ] Growing Tips
- [ ] Roots
- [ ] Bulbs, Tubers, Corms
- [x] Buds
- [ ] Flowers
- [ ] Fruits or Nuts
- [ ] Seeds
- [ ] None
- [ ] Other:

3d. PLANTS AFFECTED OF TOTAL PLANTS
Number: 200
Percent: 100

3e. PLANT SYMPTOMS: Mottled yellowing on leaves similar to spider mite damage, damage to emerging leaves on cyaneas.

PEST DATA

4a. PEST INFESTATION LEVEL
- [ ] Light
- [x] Medium
- [ ] Heavy

4b. LIFE STAGE COLLECTED
- [x] Alive
- [ ] Dead
- [ ] Eggs
- [ ] Larvae
- [ ] Pupae
- [x] Adults
- [ ] Cast Skins
- [ ] Nymphs
- [ ] Frass

4c. SAMPLING METHOD (Hand coll., trap, sweep net, etc.): Hand coll

4d. TYPE OF TRAPS & LURE: None

NOTES

5a. REMARKS (Collector's observation, notes, etc.): Tenatively identified as poinsettia thrips by Lynne, wings look correct under dissecting microscope. NerAng seemed to have heaviest infestations. Pylon seemed to be effective in eliminating population.

5b. TENTATIVE DETERMINATION: Echinothrips americanus

TAXONOMY LAB ONLY

6a. - [ ] SEND TO SPECIALIST
- [ ] SENT TO SPECIALIST

6b. # SENT TO SPECIALIST
_____ Pinned
_____ Vials
_____ Slides

6c. NAME OF SPECIALIST

6d. DATE SENT

TAXONOMY LAB ONLY

FINAL DETERMINATION

7a. ORDER: FAMILY		7f. NOTES
7b. GENUS/SPECIES/AUTHOR		
7c. COMMON NAME		
7d. DETERMINED BY	7e. DATE	

TAXONOMY CATALOG

8a. RECORD: [ ] U.S. [ ] STATE [ ] ISLAND [ ] HOST	8b. SPECIMEN LABELS: [ ] Needs Coll. Label [ ] Needs ID Label [ ] Coll. Label Complete [ ] ID Label Complete	8c. PARTIALLY ENTERED BY	8e. COMPLETELY ENTERED BY
		8d. DATE ENTERED	8f. DATE ENTERED
8g. [ ] Add to Collection	8h. DATE ADDED TO COLL.	8i. # ADDED TO COLLECTION: _____ Pinned _____ Vials _____ Slides	

PPC-24 5/7/2018

5E List of Vendors and Suppliers updated 12/6/22

The following list of products and companies are meant to give the grower ideas of places to start their search for supplies. HRPRG does not advocate for the utilization of the following products and/or companies.

Island	**Type of Product**	**Company**	**Website or address**
Hawaiʻi (Kona), Maui, Oʻahu	Irrigation supplies	Pacific Pipe	http://pacificpipe.net/
Hawaiʻi (Hilo)	Irrigation supplies	Central Supply	https://www.centralsupplyhawaii.com/
Hawaiʻi (Kona)	Irrigation and landscape supplies	Siteone Landscape Supply	https://www.siteone.com/en/
Hawaiʻi (Hilo), Kauaʻi, Oʻahu	Landscape/nursery supplies and chemicals	Nutrien Ag Solutions	https://nutrienagsolutions.com/
Hawaiʻi (Kona, Hilo), Kauaʻi, Maui, Oʻahu	Landscape/nursery supplies and chemicals	BEI Hawaii	http://www.beihawaii.com/index.html
Hawaiʻi (Hilo)	Nursery supplies	Nursery Things	626 Kealakai St, Hilo HI 96720
Ships statewide	Plant tags	Forestry Suppliers	https://www.forestry-suppliers.com/
Oʻahu	Greenhouses and nursery supplies	Island Grower Supplies LLC	https://islandgrower.com/
Hawaiʻi (Hilo)	Greenhouses, nursery and irrigation supplies	Greenhouse Specialists Inc	http://greenhousespecialists.com/