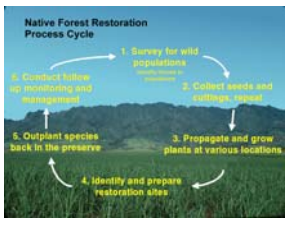

I Hoʻōla I Ka Nahele:

To Heal A Forest

A Mesic Forest Restoration Guide for Hawaii

By Dan Sailer

Preface

Globally unique…a storehouse of endemism … evolutionary laboratory. Most individuals familiar with the natural history of Hawaiian forests are well acquainted with these phrases characterizing the biological heritage of our islands. Individuals from the Hawaiian community offer a different phrase for upland areas, emphasizing the living link between their cultural and natural heritage: *Wao akua*…realm of the gods. Others from the hunting community offer their own metaphor: Icebox in the mountains. While equated with solitude, our forests are a community gathering place; a worksite for some, sacred ground for many, and a playground for many others. Despite the value placed on our forests, many native forest areas are in need of healing.

The idea for this book first began six years ago when I was a student at the University of Hawaii at Manoa. Creating my own course of study in natural resource management, I realized there were no technical manuals for the restoration of any of our disappearing island native ecosystems; only much research on the environmental problems of Hawaii and even fewer published reports on the practical management of those problems. With interest in the field of ecological restoration growing in Hawaii, this book is an effort to satisfy the growing need for information on the basic principles, methods, and techniques of managing mesic forests in particular and terrestrial native Hawaiian ecosystems in general. Many of the technical recommendations in this manual stem from five years of mesic forest restoration work at The Nature Conservancy's Honouliuli Preserve on Oahu. Most of the resource management recommendations are gleaned from the published works and personal communications of those who have worked for over twenty years in the field of conservation biology.

While specifically geared toward resource managers, field biologists, and private landowners, this book is intended to be used by all those who care for our forests for the benefit of our island communities. Two centuries of forest conversion, plant invasion, and ungulate damage have indeed wreaked a devastating toll. I remain hopeful that even two decades of hard work, perseverance, and commitment will go far in restoring our role as stewards of Hawaiian forests.

Acknowledgements

Preparation of this manuscript would not be possible except for the assistance of the following organizations and individuals:

The Wallace Research Foundation for providing funding for this project. Tim Porteous, author of the *New Zealand Native Forest Restoration Manual* upon which this book for Hawaii is based. The past and present field crew members, interns and volunteers at The Nature Conservancy-Oahu Program whose perseverance and humor continue to carry the day. Nat Pak, the primary author of the chapter on working with volunteers. Tamara Melton who first researched and typed the initial drafts of several of the book's chapters. Larry Abbott who assisted with compiling the

photos used in the manual. Pat Bily for his invaluable comments on weed control methods and strategies. Lynette Williams and Jean Ehrhorn who edited the manuscript. And Forest and Kim Starr for providing numerous photos of the weeds of Hawaii used in the weed control table. Unless otherwise indicated, all other photos are from the public domain or taken by the author.

Lastly, I would like to thank my wife and daughter for their infinite patience and encouragement.

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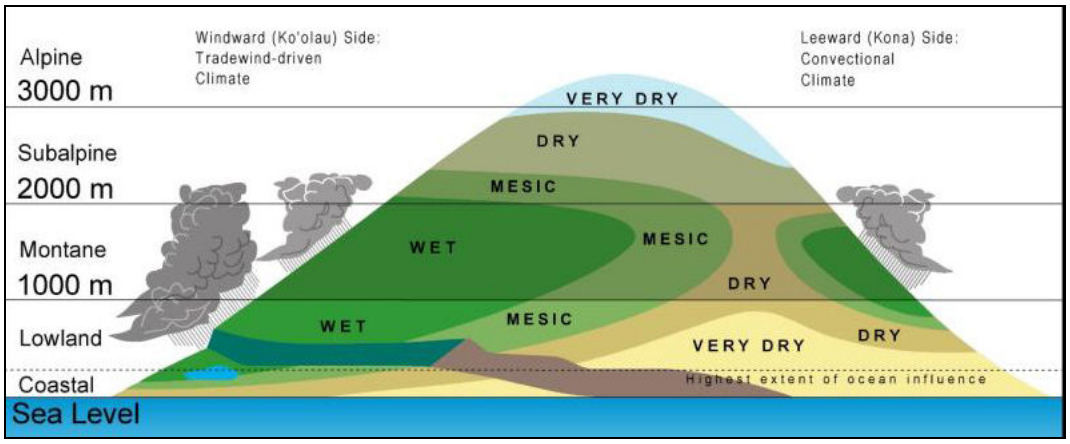
1.0 INTRODUCTION

1.1 VALUE OF MESIC FORESTS IN HAWAII



Our understanding of the value of mesic forests is just beginning, even as they are disappearing. Just the classification 'diverse mesic forests' denotes the existence of a forest type so evenly composed in its makeup that not one tree species dominates the community. A mesic forest is a forest type that is neither wet nor dry, generally receiving 120-150 cm of rainfall annually. As listed in the Manual of Flowering Plants (Wagner et. al. 1999), mesic forests are found in coastal, lowland, and montane areas in elevations ranging from 15-2200 meters.

Table 1A: Native and Alien Dominated Mesic Forest Communities

Coastal Mesic Forests

Hala *(Pandanus)* Forest
Loulu *(Pritchardia)* Coastal Forest
Common Ironwood *(*Casuarina)* Coastal Forest

Lowland Mesic Forests

Ohia *(Metrosideros)* Lowland Mesic Forest
Koa *(Acacia)* Mesic Forest
Olopua *(Nestiges)* Lowland Forest
Lama/Ohia *(Diospyros/Metrosideros)* Mesic Forest
Diverse Mesic Forest
Loulu *(Pritchardia)* Lowland Forest
Papala Kepau/Papala *(Pisonia/Charpentiera)* Riparian Forest
Kukui *(*Aleurites)* Forest
Guava *(*Psidium)* Forest
Common Ironwood *(*Casuarina)* Lowland Forest
Silk Oak *(*Grevillea)* Forest

Montane Mesic Forests

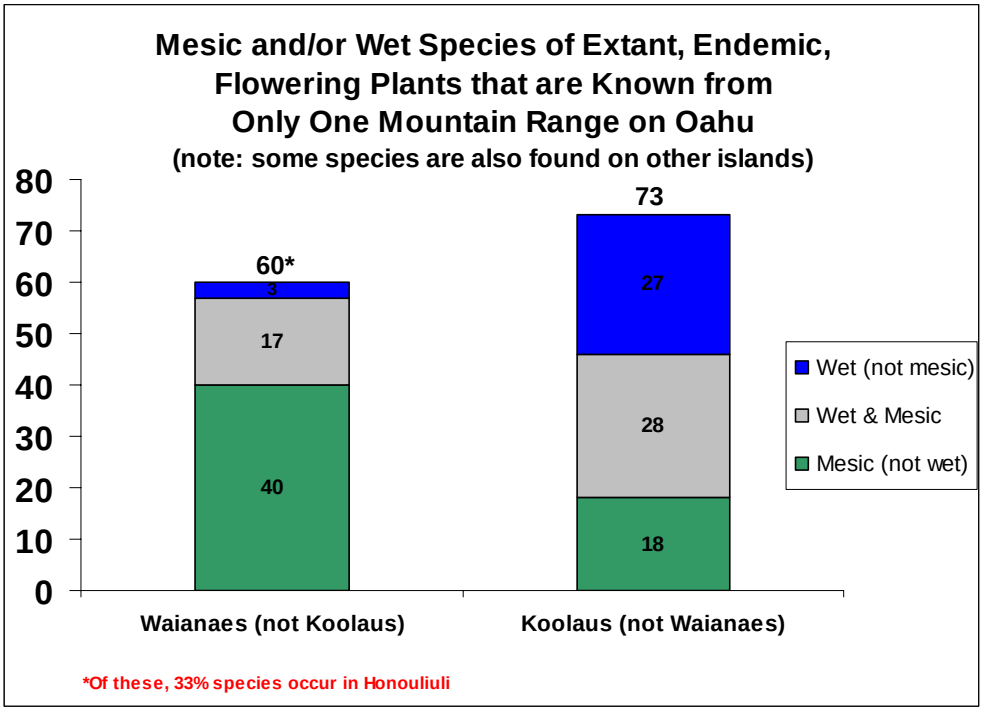
Ohia *(Metrosideros)* Montane Mesic Forest
Koa/Ohia *(Acacia/Metrosideros)* Montane Mesic Forest
Koa/Ohia/Ae *(Acacia/Metrosideros/Sapindus)* Forest
Olopua *(Nestiges)* Montane Forest

*Denotes non-native species

From Wagner et. al. 1999

Within this scattered mosaic of mesic forests lie some of Hawaii's rarest biological riches. Largely because of biogeography and a myriad of microclimates between the dry, lowland vegetative communities below and the wet forests above, mesic forests are storehouses of floral endemism.

The following example from an analysis by Jonathan Price of the floral diversity of Oahu, highlights the number of plant species found in mesic communities.

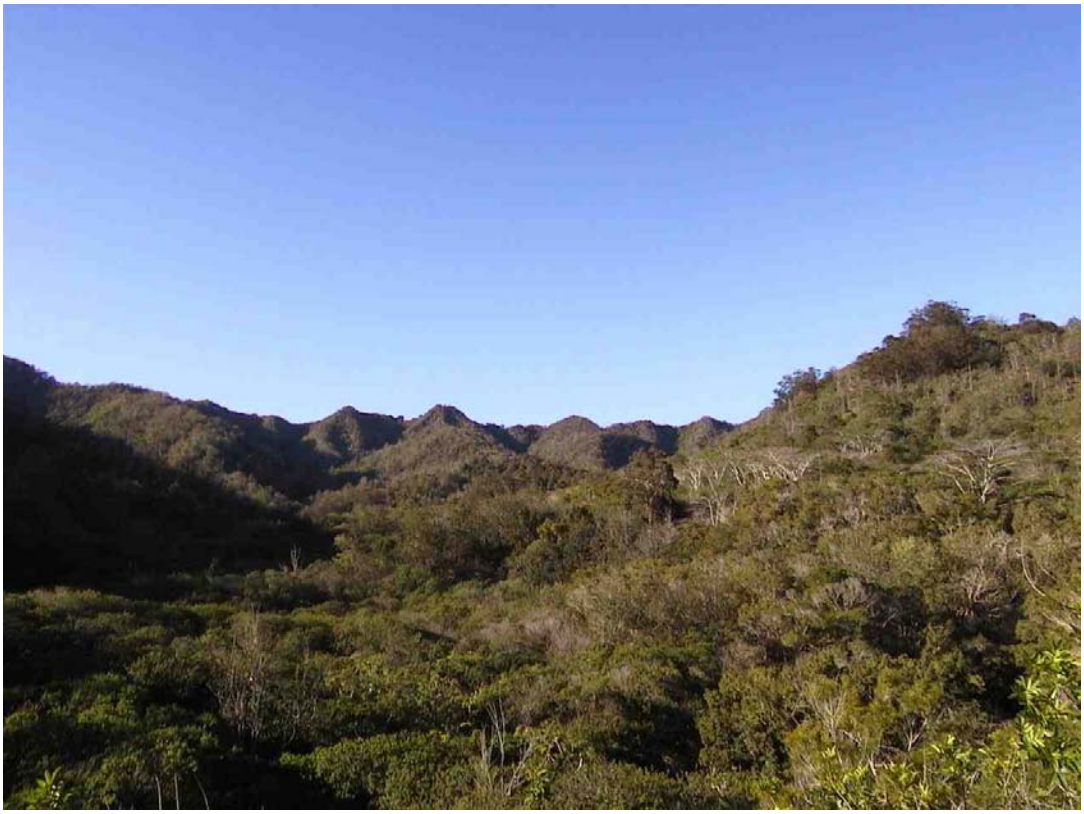


Source: J. Price

If one excludes indigenous and extinct flowering plant species when compiling totals of all native plant species by major vegetation communities, mesic and wet forests clearly contain the bulk of endemic plant species.

TYPE	NUMBER OF SPECIES
Subalpine	96
Wet	494
Mesic	511
Dry	214
Coastal	73

Source: T. Menard



Lowland mesic forest, Honouliuli Preserve on Oahu. Home to over 90 rare and endangered plant and animal species.

Unfortunately Hawaii is infamously known as the one of the 'extinction capitals of the world' as a result of the loss of most of the native lowland dry and mesic forests across our state. Only the mere remnants of a once rich ecological tapestry of plant and animal species remain. Despite their highly fragmented status, protection of mesic forests remains a priority for the following reasons (adapted from Porteous 1993).

- **Refugia for Native Plants and Animals**
  As noted above, mesic forests support a great diversity of plant species. Forest protection is also wildlife habitat protection. The number of rare plant and animals that continue to persist in mesic forest areas alone warrant protection to avoid global extinction.

- **Reference Sites for Scientific Study, Restoration Activities, and Ahupuaa management**
  An intact, native mesic forest is a living link to the past providing an invaluable guide to efforts focused on restoring viable, functioning forest systems. Remnant native forest areas offer opportunities to understand the complex interrelationships of abiotic and biotic systems in a living laboratory.

- **Watershed Protection**
  Given the recent drought and the growing human population in Hawaii, watershed protection is perhaps one of the most important long-term activities facing natural resource managers in Hawaii. Wet forests are credited with capturing the bulk of

rain water. However, mesic forests play a highly significant role in supplementing groundwater recharge rates and buffering wet forested areas from the effects of ungulate damage, deforestation from land use changes, and fires.

Flyways and banding of Oahu Elepaio birds at Honouliuli Preserve

- **Wildlife Corridors**
  Native invertebrates, birds and bats continue to thrive in mesic forest areas despite significant conversions to non-native forests due to human activities and plant and animal invasions. Native moths, spiders, and pomace flies are a few categories of the invertebrates of mesic forests that are just now beginning to be fully identified and described by scientists. Native forest birds such as the amakihi, apapane, io, and iiwi and the opeapea (Hawaiian hoary bat) continue to utilize mesic forests as important wildlife corridors when making local migrations to feeding areas up and down mountain slopes.

- **Genetic Diversity**
  Because a number of plant and animal species occur in both wet and mesic forests, protection of mesic forests offers the best chance at preserving the full complement of genetic variation within plant and animal species. Loss of genetic variation is a loss of what makes a species uniquely native Hawaiian. With the onset of global warming, species will probably need their full set of genetic variability to adapt over time to a changing environment.

- **Importance to Hawaiians**
  Seeing to Hawaiian spiritual needs…forests also feed the spirits of artists and healing practitioners (Gon 2003). Mesic forest remnants continue to provide sources of medicine, materials, and foods for native Hawaiians.

- **Character of Hawaii's Landscape**
  Mesic forests are also some of Hawaii's most accessible forests for recreational and aesthetic enjoyment. Hiking and hunting remain popular pastimes for Hawaii's locals and ecotourism operations are a growing segment of the tourism industry. Continued degradation or loss of mesic forests areas are very real losses to our quality of life in Hawaii.

We would certainly be wise to protect and restore the native mesic forests that remain given the many ecological services and human values associated with them.

Honouliuli ahupuaa

One need only look carefully at the State Seal of Hawaii to gain inspiration for forest restoration efforts. A phoenix rises from the flaming ashes with native lobelia plants below and native maidenhair ferns above.

The translation of the state motto itself reinforces this need. The motto is most commonly translated as, ‘the life of the land is perpetuated by its righteousness.’ The word ‘pono’ has many meanings. Some would argue the state motto should be ‘the life of the land is perpetuated by its sovereignty.’ In the hearts and minds of Hawaiian conservationists, it may very well be translated as, ‘the life of the land is perpetuated by its native integrity.’

1.2 MESIC FORESTS LOCATIONS IN HAWAII

Kauai: Kauai contains some of the best remaining examples of lowland mesic forests and the island contains an extraordinary number of single-island endemic plant species. The following list highlights areas of remaining diverse mesic lowland forest (Massey pers. comm.).

- Kalalau and Pohakuao Valleys within the Na Pali Coast State Wilderness Park
- Mahanaloa, Paaiki, Kuia, and Poopooiki areas within the Kuia Natural Area Reserve and Na Pali-Kona Forest Reserve
- Koaie Canyon (including Kawaiiki and Hipalau Valleys) within Waimea Canyon State Park
- Olokele Canyon and Kahana Valley on private land.

Oahu: Oahu also has a number of diverse mesic and lowland mesic forest areas. In the Koolau Range, the mesic areas quickly grade into lowland wet ohia forest. In the Waianae Range, larger areas of lowland mesic and even diverse mesic forest remain, but are generally much more degraded.

- Koolau: Hawaii Loa Ridge Trail and adjacent gulches
- Koolau: Halawa Ridge Trail
- Koolau: Makaua Valley/Kahana Valley
- Koolau: Maakua Gulch
- Koolau: Manana/Waimano Valleys

- Waianae: Kahanahaiki Gulch
- Waianae: Pahole Natural Area Reserve
- Waianae: East and West Makaleha Valleys
- Waianae: Palikea Gulch
- Waianae: Makaha and Waianae Kai Valleys
- Waianae: Mohiakea and Haleauau Gulches (above active artillery range)
- Waianae: Honouliuli Preserve (Kaluaa, Ekahanui, Pualii, and Palawai Gulches)

Maui and Molokai: This list is still being researched.

- West Maui: Kapunakea Preserve
- East Maui: Makawao Forest Reserve

Hawaii: As the youngest island, Hawaii does not have the same level of plant biodiversity found on the older islands such as Kauai and Oahu. However it does contain areas of relatively intact mesic forests. This list is also still being researched.

- Manuka Natural Area Reserve
- Hawaii Volcanoes National Park: Mauna Loa Strip Road area and the various kipukas located off the road, in particular, Kipuka Puaulu and Kipuka Ki.

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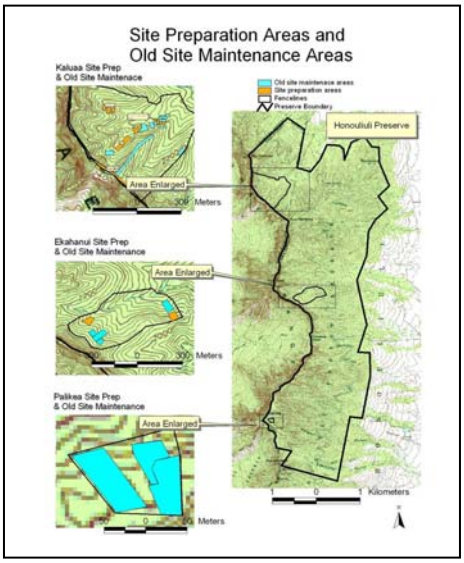
2.0 MANAGING NATIVE MESIC FOREST REMNANTS



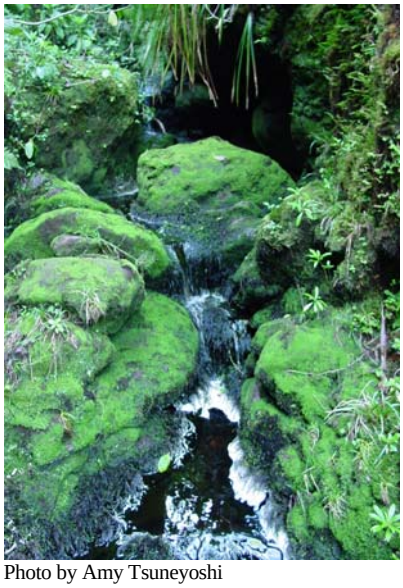


Photo by Amy Tsuneyoshi

2.1 RESTORATION CONCEPTS AND PRINCIPLES

The word *restore* means "to bring back…into a former or original state" (Webster's New Collegiate Dictionary 1977). For the purposes of this book, forest restoration assumes that some semblance of a native forest remains and the restoration process is one of removing the causes for that degradation and returning the forest back to a former intact native state. More formally, restoration is defined as:

The return of an ecosystem to its historical trajectory by removing or modifying a specific disturbance, and thereby allowing ecological processes to bring about an independent recovery (Society for Ecological Restoration International Science and Policy Working Group 2004).

The term *native integrity* used throughout this book refers to this continuum of intactness. An area very high in native integrity is fully intact. James Karr (1996) defines biological integrity as:

> The ability to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region.

This standard of biological integrity is admittedly beyond the reach of many restoration projects given some of the irreversible effects of invasive plants and animals as well as a lack of knowledge of how an ecosystem worked in the first place. Nonetheless, the goal of a restoration effort should be a restored native area that is healthy, viable, and self-sustaining requiring a minimum amount of active management in the long-term. The steps needed for a

restoration effort are similar to any problem solving and planning process. Hobbs and Norton (1996) frame the planning process in five basic steps.

1. Identification of the problem: Identify and deal with the processes leading to degradation in the first place.
2. Determine realistic goals, measures of success, and criteria for failure.
3. Develop methods for implementing the goals.
4. Incorporate these methods into land management and planning strategies.
5. Monitor the restoration and assess success.

Along with the target state or product of restoration, Meffe and Carroll (1997) offer several key planning concerns of any restoration project. They are:

- Determining the feasibility of the project and assessing the authenticity of project results,
- Determining an appropriate and feasible scale, and
- Working within realistic cost constraints

The quality of the restored systems (authenticity) and the feasibility of carrying out high-quality restoration work at environmentally significant scales are fundamental issues facing restorationists (Meffe and Carrol 1997).

Ahupuaa of the north shore of Molokai island

The scale of the project can make or break the success of a restoration effort. The National Research Council (1992) gives four considerations for determining the size of a restoration project:

1) The project should be large enough to minimize the deleterious effects of boundary conditions and events on internal dynamics.
2) The project should of such a size that managers can readily add, control, or eliminate, as necessary disturbances to the system.
3) The project should be large enough so that various effects can be measured to assess project success.
4) The project should be an affordable size.

Hand in hand with the above concerns, the financial costs of a project must be realistically matched to the goals and scale of the project. An overambitious project will simply fail because the financing failed to match the project requirements.

Table 2A: Checklist of Appropriate Questions for Planning, Conducting, and Evaluating Restoration Projects

Project Planning and Design

1. Has the problem requiring treatment been clearly understood and defined?
2. Is there a consensus on the restoration program's mission?
3. Have the goals and objectives been identified?
4. Has the restoration been planned with adequate scope and expertise?
5. Does the restoration management design have an annual or midcourse correction point in line with adaptive management procedures?
6. Are the performance indicators – the measurable biological, physical, and chemical attributes – directly and appropriately linked to the objectives?
7. Have adequate monitoring, surveillance, management, and maintenance programs been developed along the project, so that monitoring costs and operational details are anticipated and monitoring results will be available to serve as input in improving restoration techniques used as the project matures?
8. Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparison in conducting the project evaluation?
9. Have sufficient baseline data been collected over a suitable period of time on the project ecosystem to facilitate before-and-after treatment comparisons?
10. Have critical project procedures been tested on a small experimental scale in part of the project area to minimize the risks of failure?
11. Has the project been designed to make the restored ecosystem as self-sustaining as possible to minimize maintenance requirements?
12. Has thought been given to how long monitoring will have to be continued before the project can be declared effective?
13. Have risk and uncertainty been adequately considered in project planning?

During Restoration

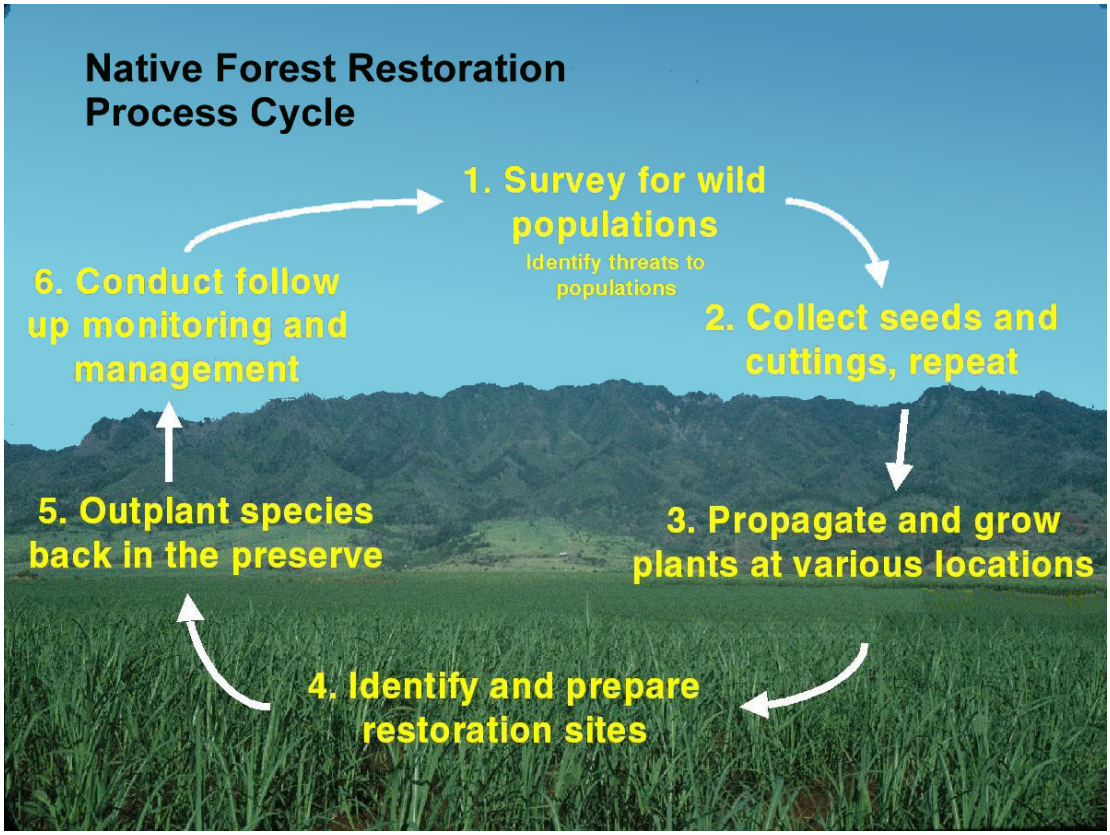
1. Based on the monitoring results, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem?
2. Do the objectives or performance indicators need to be modified? If so, what changes may be required in the monitoring program?
3. Is the monitoring program adequate?

Post-Restoration

1. To what extent were project goals and objectives achieved?
2. How similar in structure and function is the restored ecosystem to the target ecosystem?
3. To what extent is the restored ecosystem self-sustaining, and what are the maintenance requirements?
4. If all natural components of the ecosystem were not restored, have critical ecosystem functions been restored?
5. How long did the project take?
6. What lessons have been learned from this effort?
7. Have those lessons been shared with interested parties to maximize the potential for technology transfer?
8. What was the final cost, in net present value terms, of the restoration project?
9. What were the ecological, economic, and social benefits realized by the project?
10. How cost-effective was the project?
11. Would another approach to restoration have produced desirable results at a lower cost?

From National Research Council 1992

2.2 RESTORATION PROJECT PLANNING: GOALS AND OBJECTIVES



Learning by doing is adaptive management. The restoration process at work in Honouliuli Preserve.

Defining a restoration project's goals and objectives is perhaps the most important planning decision a restorationist will make. An overall goal that clearly defines what will be achieved will greatly assist all aspects of the project. The objectives of a project are the strategic methods used to achieve the project goal. Having a clear vision of the endpoint of restoration efforts as well as the intermediate steps needed to get there is a fundamental aspect of a restoration project. (Jacobi pers. comm.).

Another way of looking at objectives is to see objectives as describing the desired condition. The desired condition is the goal; the objectives are the description of how one reaches that goal. If the goal is to restore the full biological integrity to an area, the objectives would detail how the full complement of organisms from soil critters to canopy trees would need to be reintroduced. If the goal is to simply prevent further degradation from ungulates, the objectives would detail the steps needed for successful animal control.

Elzinga et al. (2001) describe the value of clear management objectives and list six required components for complete management objectives:

Management objectives:

- Focus and sharpen thinking about the desired state or condition of the resource
- Describe to others the desired condition of the resource
- Determine the management that will be implemented, and sets the stage for alternative management if the objectives are not met
- Provide direction for the appropriate type of monitoring
- Provide a measure of management success

Components of an objective:

1. **Species or Indicator:** identifies what will be managed or monitored
2. **Location:** geographic area
3. **Attribute:** aspect of the species or indicator (e.g. size, density, cover)
4. **Action:** the verb of your objective (e.g. increase, decrease, maintain)
5. **Quantity/Status**: measurable state or degree of change for the attribute
6. **Time frame:** the time needed for the management strategy to prove effective

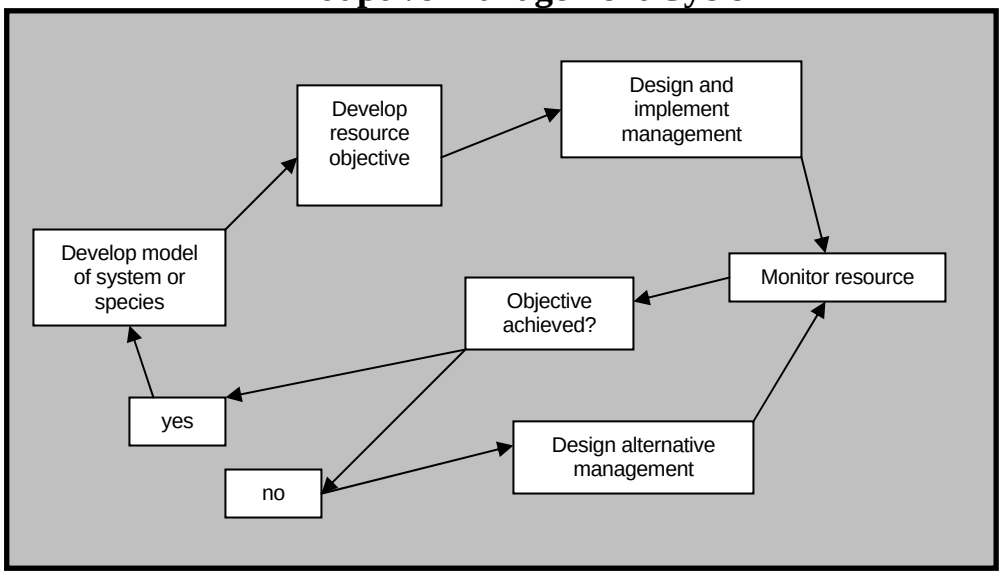
Appendix 6A is an example of a restoration site plan showing how management objectives can achieve an overall goal.

2.3 MONITORING PROGRAMS AND ADAPTIVE MANAGEMENT

The value of a monitoring program cannot be overstated. A good monitoring program will determine if a management objective is met. In adaptive management, learning is as important as doing – monitoring is as important as management if management is to be validated or improved (Elzinga et al. 2001). Adaptive management is more formally defined as the integration of design, management, and monitoring to systematically test assumptions in order to adapt and learn (Salafsky et al. 2001). Monitoring itself is defined as the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 2001). Having stated the importance of monitoring it is beyond the scope of this book to comprehensively discuss all the components of a restoration monitoring program. Readers are referred to an excellent practical handbook designed for field biologists entitled: Monitoring Plant and Animal Populations authored by Elzinga et al. (2001). A full reference can be found at the end of this chapter. Instead, a brief summary of monitoring considerations is presented here as an initial guide to the development of a monitoring program that is fully integrated into the adaptive management process.

Elzinga et al. (2001) underscore the role of monitoring in a successful adaptive management program with the following diagram.

Adaptive Management Cycle



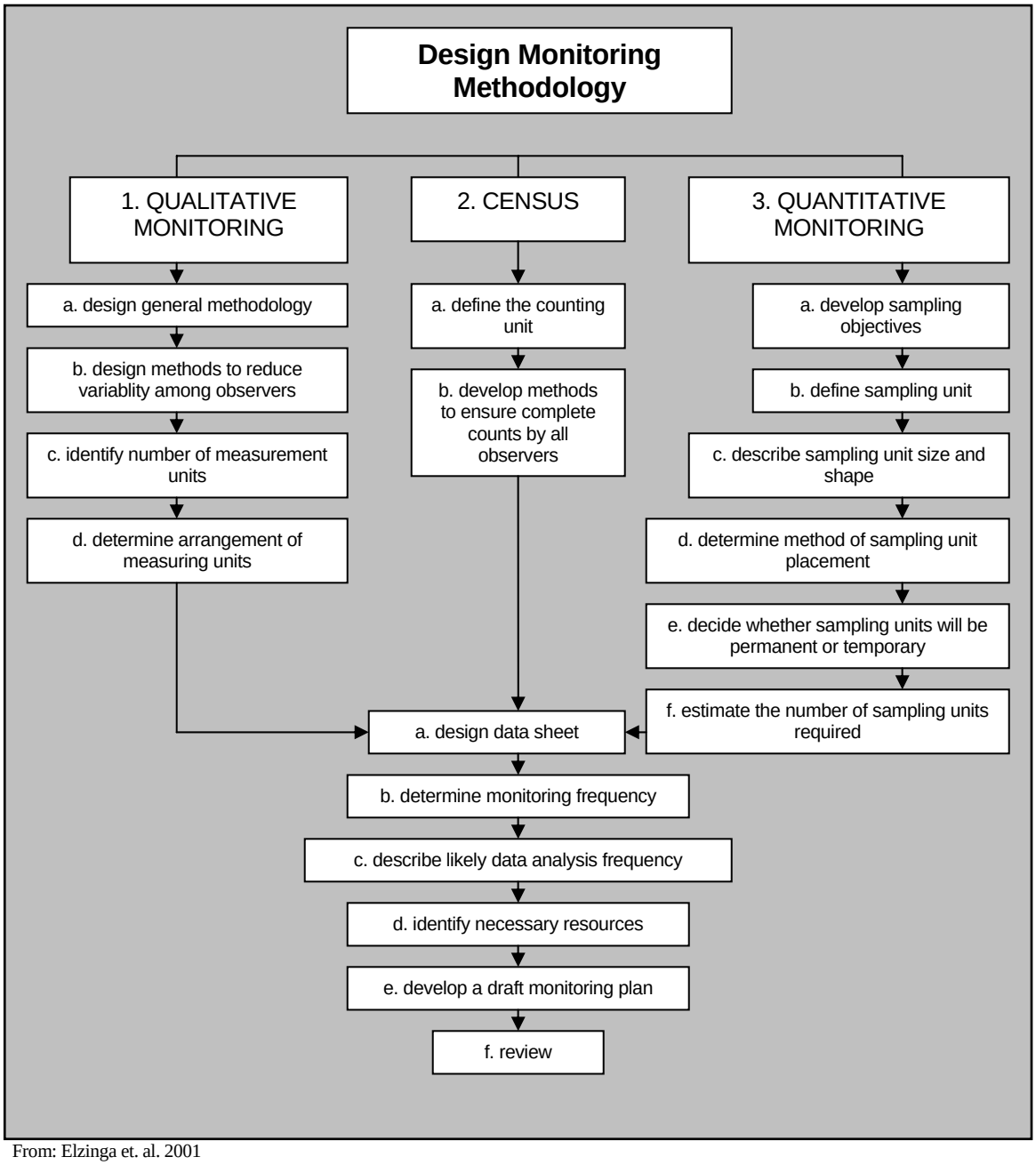
The major steps in the management/monitoring process are also summarized by Elzinga et al. (2001). They are:

A. Complete background tasks
B. Develop management objectives
C. Design and implement management
D. Design monitoring methodology
E. Implement monitoring as a pilot study
F. Implement and complete monitoring
G. Report and use results.

Seven of the most important background tasks include:

1. Compiling and reviewing existing information
2. Reviewing upper level planning documents
3. Identifying priority species, populations, communities
4. Assessing the resources available for monitoring
5. Determining the scale
6. Determining the intensity of monitoring (qualitative, quantitative, demographic)
7. Reviewing the monitoring project internally or by an external team

A crucial stage in the monitoring process is designing the monitoring methodology. Elzinga et al. (2001) summarize the three types of monitoring-qualitative, census, and quantitative (sampling) with the following flow diagram:



From: Elzinga et. al. 2001

2.3.1 TYPES OF MONITORING RELEVANT TO FOREST RESTORATION

The types of monitoring employed will reflect the management goals and objectives for the areas to be restored. Status assessments commonly answer the question, "How is the biodiversity that we care about doing?" Effectiveness measurements answer the question "Are the management actions having their intended impact?" (Salzer and Salafsky 2003). Baseline monitoring commonly assesses the status of resources of value. Weed control, ungulate control, and revegetation programs all require their respective monitoring programs to determine if management actions are effective. The following examples are common to most forest resource management monitoring programs in Hawaii.

- **Baseline inventory and status of resources:** Often the first planning step is to determine what native resources are present and to assess their condition and value relative to other areas. This baseline of information will help guide the construction of ecological models as well as the development of management goals and objectives. The term 'baseline monitoring' is used for the activity of specifically measuring variables before management begins. Compilation of plant and animal species lists, rare animal and rare plant distribution maps, native and non-native community vegetation maps, vegetation composition studies, and damage assessments before restoration activities are some of the most common products of baseline monitoring efforts. Ground based or aerial surveys along transects and GIS analysis of aerial or satellite maps are some of the more common methods used to quantitatively or qualitatively assess natural areas. Without adequate baseline information, the success of future restoration efforts cannot be adequately measured.
- **Weed Monitoring:** Species lists, weed distribution and weed density maps are the most common products of ground and aerial survey monitoring of forested areas. Ground or aerial weed surveys are commonly done along belt transects to ensure adequate coverage of the target area. GPS units are commonly used to map occurrences and a GIS database is used to map and analyze weed data. The number of transects and the frequency of weed surveys are determined by the weed management goals and objectives for the area. Factors which influence these goals and objectives include the human and financial resources available, the size of the area, the type of terrain, the conservation value of the area, and the types or invasiveness of weeds already present. Quadrat plots can also be used to quantitatively monitor weed frequency, cover, and density.
- **Ungulate Monitoring:** To determine levels of animal activity, belt transects are commonly used. A type of qualitative sampling, observers record animal sign (browse, scat, tracks) at specified distances along a given transect length. Aerial transects can also used for direct observations of animals that prefer open areas (e.g. mouflon sheep). Where feasible, transects should be systematically placed throughout a survey area, with transects oriented perpendicular to contours following a compass line (Elzinga et. al. 2001). In Hawaii, determining accurate estimates of ungulate activity and sizes of ungulate populations is notoriously difficult and labor intensive. Difficult terrain, the large size of management units, and unpredictable patterns of ungulate movement are usually responsible for inaccurate estimates of ungulate numbers. Scouting often proves to be more effective at detecting animal activity when ungulate densities are low. Pig catch rates

in snares or traps are also used to quantitatively measure the effectiveness of removal efforts, but catch rates must be coupled with some type of ungulate activity monitoring program to ensure the complete removal of ungulates from an area.

- **Outplanting Monitoring:** Survival, vigor, and recruitment are some of the more common measurements of outplanting success. Census, qualitative and quantitative methods are used to determine these three variables. Sampling may also be needed if the number of reintroduced plants is excessively large.
- **Restoration Site Condition Assessments:** This technique evaluates the condition of the habitat through repeated subjective observations; assessments focus on a single activity, potential disturbances (i.e. weed control), or site characteristics (Elzinga et al. 2001). Photopoints or photoplots are commonly used to track gross vegetation changes over time. Site assessments are most effective when observers articulate their qualitative assessment quantitatively (Elzinga et al. 2001). An example of a restoration site assessment data sheet is given at the end of Chapter 6 as Appendix 6B.

2.3.2 COMMON MONITORING PITFALLS

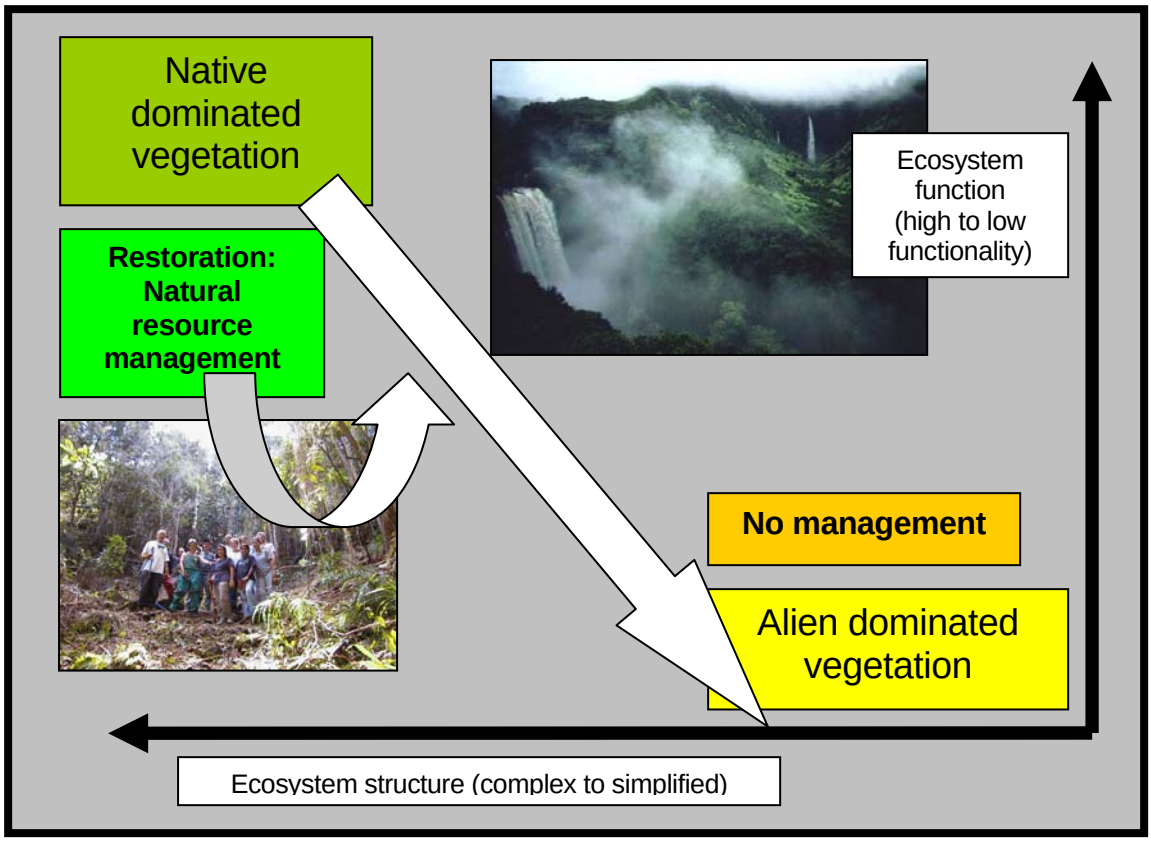
Monitoring programs are often fraught with difficulty given the complexity of the ecological systems at work and the limited time, financial resources, and competing priorities of resource management staff. Besides problems of observer bias and poor sampling design, some of the more common mistakes of the monitoring process are listed below:

1. Failure to adequately define management objectives which form the foundation of the adaptive management process.
2. Failure to adequately budget financial and human resources to a monitoring program.
3. Funding basic research in the name of monitoring (Salzer and Salafsky 2003).
4. Failure to set up a pilot monitoring program first to refine monitoring methods.
5. Collecting way too much data instead of taking action (Salzer and Salafsky 2003).

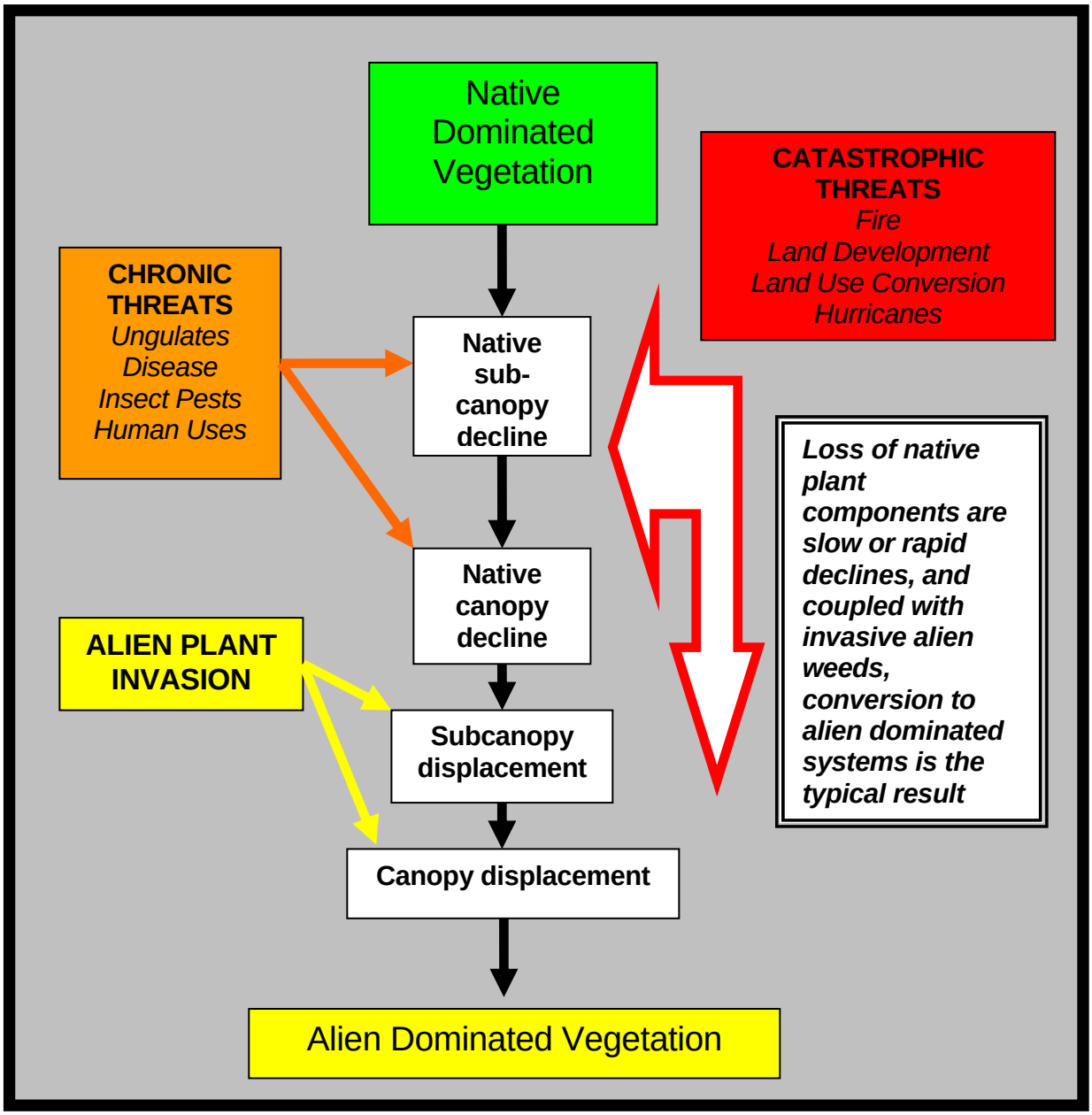
6. Failure to analyze data, report and communicate results, and use recommendations to guide management decisions.

2.4 VALUE OF ECOLOGICAL MODELS

An ecological model is a tool that diagrams the often complex relationships and components of an ecological system or the ecology of a species. Models can be purely theoretical or based entirely on known facets of an ecosystem or organism. Most ecological models contain a combination of theoretical assumptions and information distilled from actual data. Models can be as complex as the systems they depict or as simple as necessary to convey the processes at work. For example, some complex models contain multiple nested compartments and numerous feedback loops. Other models are simple flow diagrams depicting only the key components of a system. The following two figures are examples of very simple models illustrating the plight of native forests.



Given the degree of threats, even the most pristine forested areas are at risk for eventual conversion to alien vegetation over time without aggressive and consistent human intervention. Ecologically simple, monotypic alien forests with potentially lower capacities for ecosystem functions like nutrient cycling and watershed recharge are the result of alien plant domination.



Elzinga et al. (2001) describe three important benefits of ecological models:

1) They provide a summary of your understanding of the species, community, or ecosystem of concern.
2) Models also identify the gaps in your knowledge and understanding of the species or system at hand.
3) Models help identify mechanisms and potential management options.

The construction of simple, management oriented ecological models is most useful at the onset of restoration planning, but they should be refined as one's understanding of the system at work grows. Constructing an ecological model often stimulates thinking that can

greatly inform the development of focused management and monitoring objectives (Elzinga et al. 2001).

2.5 REFERENCE SITES

Lowland mesic ohia and lama stands, Kaluaa Gulch, Honouliuli Preserve

As noted in **Table 2.1** the selection of a reference site can greatly clarify the desired endpoint of restoration efforts. Reference sites serve as comparison areas which help set quantitative targets in objectives, and can therefore be of considerable value, but should be used with caution. (Elzinga et al. 2001). A reference site generally contains an intact, functioning system free from the degradation affecting the restoration site at hand. Ideally, a forest restorationist would merely need to mimic the natural patterns of plant distribution and composition in their revegetation efforts for project success. Unfortunately, because no two natural areas are alike, an exact match is not likely. Also, because nature is never static, reference sites are usually undergoing changes themselves; reference sites then become a moving target. Nevertheless, keen observation and analysis of what makes an intact native area resistant to invasion and self-sustaining will go far toward informing restorationists of the most important threats that require control, as well as identifying any crucial missing components at restoration sites. On a practical level, reference sites can also serve as sources of seed material for propagation efforts and 'starter stock' for mychorrhizal inoculations of media for propagation work.

2.6 LINKING FOREST FRAGMENTS

Mesic forests are often sandwiched between dry forests and shrublands below and wet forests above. Commonly a patchwork of forest types grading into each other, mesic forests are a fascinating example of a vegetative community assembled from native species found in both dry and wet forests. All too often though, native mesic stands are dissected by invasive plant communities, ranchlands, and non-native forestry plantation stands. Another challenge the restorationist faces is how to link up disparate stands of native forest to form a more contiguous native stand. One basic strategy for linking forest fragments is to remove the threats which caused the fragmentation to begin with and re-vegetate the areas between

the remnant fragments with native trees and shrubs. At Hakalau National Wildlife Refuge, the primary management goal is to provide a high quality habitat for native forest birds. An intensive and successful forest regeneration effort began with fencing the area from cattle, sheep, and pigs. This was followed by a massive koa replanting effort in former pasture areas to provide wildlife corridors between more mature intact koa and ohia stands. Endangered birds such as the akiapolaau have already begun utilizing those corridors for foraging and nesting areas (J. Jeffrey pers. com.).

2.6.1 THREATS TO MESIC FORESTS

Nearly every terrestrial native ecosystem in Hawaii is threatened by changes in land use, invasive plants and animals, or fire, and mesic forests are certainly no exception. Conversion of mesic forests to subdivisions is an irreversible change and resource managers can often do little to prevent private landowners from exercising their right to realize economic gains from their properties. Resource managers do however have the means to properly manage mesic forests on protected lands by controlling weeds and animals that are damaging to native resources. Identifying and prioritizing threats, implementing management of invasive plant and animal threats, and preventing forest fires are the primary duties of a resource manager. The management of these threats is discussed in Chapters 3 and 4.

2.6.2 STARTING A RESTORATION PROGRAM: CRITERIA FOR SELECTING A SITE

Intact *Poutenia sandwicensis* stand at North Pualii Gulch, Honouliuli Preserve

Restoring a mesic forest area can be extremely gratifying. If a fairly intact native forest is selected for restoration, the response to management activities is usually quite remarkable in a rather short-time period. Once legal protection for the land is secured and knowledgeable personnel are chosen to plan the project, the all important process of determining the project location can begin. A number of criteria for selecting a site are listed below. The most important criterion is the level of intactness.

Site Selection Criteria

1) Intactness or native integrity
2) Long-term viability
3) Accessibility for management
4) Legal protection/feasibility
5) Available funding
6) Available human resources
7) Contiguity with adjacent native areas.
8) Irreplaceability/rarity
9) Number of rare plant and animal populations
10) Protection from fire
11) Cultural importance
12) Long-term maintenance requirements
13) Protection from feral ungulates or invasive weeds
14) Learning/Research opportunities

Finding an area may be simply a factor of opportunity. A landowner or agency is interested in restoring an area and the necessary human and financial resources are brought to bear on the problems at hand. Conservation planning on a landscape scale takes a more systematic approach. Maps of native communities are obtained and assistance from knowledgeable personnel (e.g. State forestry or National Park Service employees) is sought out. Important biological areas are identified and legal protection is sought as the first step to ensure mesic forested areas remain forested. More thorough inventory surveys are done by botanists and zoologists for areas slated for restoration in order to inform the planning process. Goals and objectives for an area are drawn up using the best available knowledge. Importantly, one should avoid making hasty management decisions that may actually be counterproductive to one's efforts (Porteous 1993).

2.7 COMMON MISTAKES IN PLANNING FOREST RESTORATION WORK

- **Restoration site too heavily degraded:** Project personnel may sometimes be overambitious in their expectations of what man and nature can accomplish and choose a site that has low viability in the long-term even with a high level of maintenance. Choosing a high quality site to begin with is the wisest use of scarce monetary resources.
- **Overemphasis on rare and endangered species population establishment:** If a forest garden is the goal, then that process should be made explicit from the outset of 'restoration' efforts. Planting an overabundance of rare species that do not match their natural patterns of distribution is not restoration (Jacobi pers. com.).

- **No long-term commitment to a site**: All too often, interest, funding, and activity are concentrated in only the first year or two at a particular site.
- **Failure to create and implement a monitoring plan that informs management efforts**: All action and no reflection can lead to a waste of precious conservation dollars and staff time, and potentially threatens the very resources that are to be protected (Salzer and Salafsky 2003).
- **Failure to plan for catastrophes**: Fire pre-suppression and fire prevention efforts are just two examples of anticipating the worst case scenario. Years of effort and habitat recovery can be undone by fires, but adequate planning (fire break roads, fuel load reduction, rapid and aggressive response plans) can help to quickly isolate and suppress fires.

Kunia Fire, Honouliuli Preserve 2004

2.8 RARE PLANT AND ANIMAL MANAGEMENT IN RESTORED AREAS

It is beyond the scope of this book to address the myriad of considerations when managing rare native biota. Readers are instead referred to the references in the following section marked by asterisks for more comprehensive treatments of this important topic.

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3.0 ANIMAL CONTROL

Fencing and community hunting at Honouliuli Preserve, Oahu

Because of the absence of large native grazing animals (ungulates) in the Hawaiian islands, native forests evolved for millions of years without any need to develop chemical or thorny defenses against browsing animals such as goats, sheep or cattle. However, the arrival of the Polynesians around 500 A.D. and the Europeans in the late 1700s also marked the arrival of a host of animals including ungulates, rats, cats, and mongooses to our otherwise isolated islands. Even as late as the early 1960's the Territorial government attempted to make Hawaii the 'game capital of the Pacific' as a tourist draw by introducing new species of game animals to Hawaii (Tomich 1986).

Today, non-native feral animals are one of the worst threats to native species and ecosystems in Hawaii. The devastating effects of ungulates and rodents are well documented and apparent in every native terrestrial ecosystem on every main island in the archipelago (Stone 1984).

Goat erosion evident on the left side of the left hand photo. Mosquito laden pig wallow in the right photo.

Impacts of alien animal pests on native ecosystems and humans include:

- **Destruction of native plants and their seed crop, preventing natural regeneration and altering forest microclimates** (Spatz and Mueller-Dombois 1975; Jacobi 1976, Baker 1979; 1981; Katahira 1980;Yoshinaga 1980; Higashino and Stone 1982; Diong 1982; Ralph and Maxwell 1984; Aplet, Anderson, and Stone 1991; Katahira, Finnegan, and Stone 1993);

- **Soil disturbance at a landscape scale, promoting erosion and surface water pollution because of increased sedimentation** (McEldowney 1930; Warner 1959-1969);
- **Loss of forest and ground cover resulting in lower groundwater recharge rates and diminished stream flows.** The entire island of Kahoolawe and the once wet forested slopes of West Molokai are testament to the punishment inflicted by unchecked feral goat populations and subsequent lowering of the water table;
- **Sedimentation of coral reefs, higher frequencies of algal blooms, and decreased shoreline property values.** West Molokai is again an example of the effects on marine resources of uncontrolled feral animal populations;
- **Contamination of surface waters due to water borne diseases** (*Leptospira* sp., *Giardia, Cryptosporidia, Staphylococcus aureus*) (Warner 1959-1969, Giffin 1978);
- **Contamination of soil and game meat with the following diseases transmittable to humans: pseudorabies, brucellosis, trigynosis, leptospirosis, anthrax, typhus, and campylobacteriosis** (Giffin 1978);
- **Create breeding grounds for disease bearing mosquitos** (Baker 1979);
- **Spread plant diseases and pathogens** (Baker 1979);
- **Permanent loss of forest, shrublands, bogs, and other uniquely Hawaiian habitats;**
- **Facilitation of invasive species into native forests, shrublands, and bogs through browsing and trampling of native species, dispersal of alien plant seeds, and soil disturbance favoring weeds** (Spatz and Mueller-Dombois 1975; Jacobi 1976, 1981; Yoshinaga 1980;Higashino and Stone 1982; Diong 1982; Aplet, Anderson, and Stone 1991); and
- **Destruction of native animals, nesting sites including eggs and chicks, and food sources for native wildlife** (Mountainspring 1987).

In order to minimize or prevent these impacts, ungulate control is often the first step in any forest restoration program and is vital to ensure long-term success. In fenced areas, forest recovery is often dramatic once animals are completely removed. This chapter will briefly describe some of the major animal threats to Hawaiian island ecosystems and what management control techniques are currently used in the field. The emphasis in this chapter is on the control of existing, widely established animal threats. Techniques for the early detection and prevention of additional vertebrate threats such as coqui frogs, parrots, and large chameleons are beyond the scope of this manual.

It should be remembered that the native forests of today were saved by the Territorial foresters in the early and mid-twentieth century. Their systematic and sustained fencing and hunting efforts remain a model of aggressive ungulate control. For example, from 1910-1958 the Hawaii Territorial Board of Agriculture and Forestry undertook an intensive and ruthless campaign to eradicate pigs on all islands by (Diong 1982). We would be wise to emulate their efforts if future generations are to also benefit from the watershed resources that we presently enjoy and take for granted.

Territorial Foresters at work in 1912 saving the forests we see today.

3.1 VERTEBRATE PESTS: UNGULATE CONTROL STRATEGIES AND METHODS FOR FERAL MAMMALS

The vertebrate pests generally found in Hawaii's forests are feral mammals which include cattle, goats, sheep, deer, pigs, rats, mice, and cats. Parkes (1991) lists six management strategies for vertebrate pests:

1) **Eradication:** Usually not feasible except for off-shore islands and local areas.
2) **One-off/permanent control:** Still requiring long-term maintenance, fencing or exclusion netting is an example of this strategy.
3) **Sustained control:** Suitable for game management areas where the goal is to maintain habitat requirements for continued hunting opportunities
4) **Sporadic or occasional control**: Unfortunately, this is a common practice which can result in a significant waste of monetary resources. Animals are removed with no clear goal other than to kill pests (Braysher 1993).
5) **Commercial or recreational hunting**: Ineffective at reducing animal populations for meaningful habitat recovery.
6) **No control**

Control methods for these animals include:

- Fencing
- Shooting (ground or aerial hunting)
- Hunting with dogs and knives or bows
- Trapping with cages
- Neck snaring
- Non-lethal leg snaring (a form of trapping)
- Baiting with poison (rodenticides) and
- Repellants (non-toxic chemicals to discourage browsing)

No toxicants (e.g. Compound 1080 [sodium monofluoroacetate]) are currently approved to control ungulates in Hawaii, although they are employed with success in New Zealand (Parkes 1983). While leg or foot traps for cats are not prohibited in Hawaii, they are not generally used by managers. Community pig hunters however often use non-lethal leg snares for pigs (power strap method).

The most common control methods currently used in Hawaii include fencing, shooting, trapping, neck snaring, and baiting with rodenticides. A discussion of the ethical and cultural issues associate with animal control can be found at the end of this chapter. Cost-effective feral animal control programs require a strategic, systematic, and integrated approach combining several control methods to eliminate unwanted populations and prevent re-invasion. C.P. Stone (1984) summarizes his recommendations for ungulate control programs:

Primary emphases in ungulate control should be:
1. The necessity for efforts lasting many years
2. Continual learning and feedback about success of control (monitoring).
3. Provision for sufficient resources to effect reduction.
4. The development of multiple methods to reduce animals.

Ungulate control, like weed control requires a thoughtful planning process and aggressive execution in the short and long-term. Defining the problem in terms of the damage being caused is the first step in effective management (Braysher 1993). Delaying fencing or removal programs only compounds ecosystem problems often resulting in costly weed control or restoration programs (Reeser and Harry 2005). Intact forests can only bleed so much before systemic failure begins.


Pig damage in a once pristine East Maui rainforest.

Fencing is the most successful and cheapest long-term solution to ungulate problems. Even after fences are complete, ungulate control outside of fenced areas is still required to keep pressure off the fences from animals attempting to dig, jump, ram, or squeeze their way back in. Fencing gives managers the opportunity to eradicate feral ungulates from their best native forested areas and keep them ungulate free for decades. In the face of hunter opposition to large-scale fencing, managers must remind themselves of their first and foremost role as stewards of the forest. Native dry forests in Hawaii are all but extinct and mesic forests will be next unless aggressive ungulate control measures are undertaken across large acreages for the next decade.



Fencing in a wet forest at left and dramatic native shrub recovery after fencing depicted in the photo at right.

Research and experience have shown that the most effective way to control feral ungulates over large landscapes is by using a strategic, systematic, and integrated approach which includes some combination of fencing, hunting, live-trapping, aerial shooting, and if possible snaring. The Texas Animal Damage Control service used neck snares, cage or pen traps, hunting with dogs, and aerial hunting with helicopters to eliminate feral pigs. From 1983-1992, they reported that snaring accounted for 55% of the pigs removed. Aerial hunting accounted for 17%. Trapping accounted for 14%, and hunting with dogs accounted for 6.3% (Littauer 1993). For another example, a case study of the pig eradication efforts employed on Santa Cruz Island is described at the end of the section on feral pig control.

Community support for such intensive and long-term ungulate control programs is vital to deter vandalism of fences and acceptance of conservation goals as social goods. Managing people and community opinions is in many respects a far more difficult enterprise than managing ungulates.

Importantly, weed control and fire pre-suppression should also be planned in conjunction with animal control efforts since the removal of ungulates is often accompanied by a large increase in alien plant growth in areas not completely dominated by native vegetation.

An unpublished draft of a paper edited by Don Reeser and Bryan Harry outlines the following core elements of a successful ungulate control program (Reese and Harry 2005). One could argue that a sixth element, community outreach and support is also essential. Portions of this paper are summarized, duplicated and adapted below. The lessons learned assume a closed system (i.e. fenced area).

Ungulate Control Strategies: Lessons learned

1) **Populations of ungulates must be isolated into discrete management units:** Fences and sometimes natural barriers such as cliffs, the ocean, or lava flows, are used to form management units to contain feral animals. The size of the management units will vary according to the ability of managers to eradicate animals within exclosures and the type of animal being controlled. Typically, pig exclosures are within the 100-1000 acre range given the difficulty of removing all pigs and maintaining fencelines in high pig density areas.

2) **A strategic, systematic, and integrated approach is needed:** Efficiency and effectiveness result from a strategic, systematic, integrated approach to removing ungulates. A consistent, phased strategy is usually needed involving multiple methods of animal removal. This sequenced and methodical strategy should begin with methods that quicky remove the majority of the animals (e.g. aerial shooting and/or intensive trapping), followed by systematic ground based control methods and monitoring that cover every inch of a fenced unit.

3) **Animals must be removed in greater numbers than their annual reproduction. Keep the pressure on until every ungulate is eradicated to avoid wasting time and money:** In order to reduce pig populations, more than 70% of their local population must be removed each year. Uncontrolled, a pig population can double in numbers every four months until the population reaches carrying capacity (Barrett and Stone 1993). For goat, sheep, and deer populations, more than a third of the local population needs to be removed for population declines (Jenkins, Nugent, and Maguire 1994). This scale of animal removal requires a huge and highly aggressive effort. Before fence units are even finished, managers should consider increased ungulate control efforts to avoid the problem of concentrating animals in smaller areas.

   Even a 25% reduction in animal control removal efforts can significantly increase the overall costs and time required for complete eradication from a fenced area. For example, at The Nature Conservancy's Kona Hema Preserve, it took three years to remove 420 pigs from a 1,800 acre fenced unit. The approximate cost of pig eradication was $67/acre or $40,000 annually, for a 3 year total of $120,000 (not including fencing). Using a VORTEX population model, a diminishment of effort to 75% (costing $30,000/yr) would have taken 10 years for complete eradication and would have cost $300,000, more than doubling the cost per acre. Any effort less than 60% of the current effort would have resulted in unsuccessful eradication. (L. Nelson pers. comm.).

4) **Fenceline inspection and maintenance is a never ending process:** Years of ecosystem recovery and management costs can be quickly negated if fences are allowed to fall into disrepair and only annual incremental increases in animals are removed. Regular fenceline inspections are needed as well as inspections after heavy storm or wind events. During the course of fence construction, additional material should be strategically placed in anticipation of fenceline failures in the future. This allows for the quick repair of damaged fencelines in remote areas. Placing permanent snare sets or live traps in an ungulate free fence area is a 'last line of defense' tactic to control any animals that penetrate fencelines.

5) **Monitoring for any increases in feral animal populations and ingress is also a never ending process:** Vigilance monitoring to detect animal ingress must be done on a regular and systematic basis. Coupled with animal removal is a monitoring program to best utilize data from animals killed in order to determine the success of ungulate control operations. Monitoring allows managers to carefully track the numbers of animals removed and their demographic data (sex, age, reproductive status) in order to evaluate the effectiveness of ungulate control

programs and refine management strategies. Given the difficulty of eradicating animals from any sizable area, it is unconscionable to neglect monitoring and allow populations to rebound to former levels. A tiny goat population if left unchecked can recover to 90% of its former levels in only four years (Reese and Harry 2005).

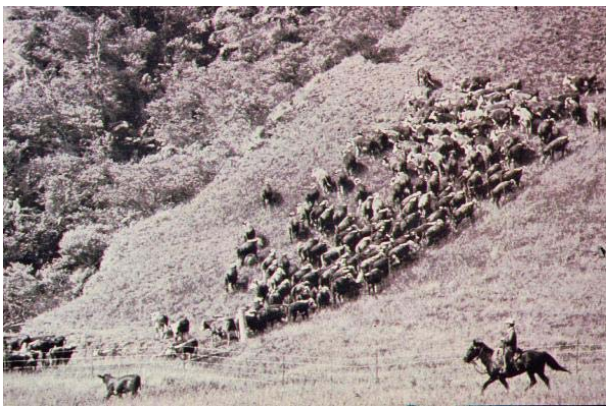
Monitoring programs to detect 'sign' or browsing usually involves regular helicopter transect inspections, ground transect analysis, and sometimes snare transects for pigs in remote areas. Judas goat searches are very effective in monitoring goat-free areas. Judas pig searches are being effectively used on Santa Cruz Island in California (see case study at the end of this chapter). Belt transects are initially good for orientation and detecting gross changes in ungulate activity levels. However, as animal population levels fall to low levels (e.g. <1 pig/km^2), systematic scouting is more effective at detecting animal presence or absence (Anderson and Stone 1993).

Detection of animal presence during helicopter transect inspections is difficult in remote, closed canopy forests. One untried method for detecting pigs is to drop bait (e.g. fermented corn/molasses mash or synthetic pheromones) from the helicopter in blaze orange colored bags that easily break apart containing fluorescent dye along with the bait. Locations of the dropped bait along transects are plotted with a GPS. A follow-up, aerial monitoring trip would detect if any of the bags were broken into or moved by pigs in the area. Any bags dropped from the helicopter would of course need to be fairly heavy to prevent them from being sucked toward the tail rotor. A similar approach could be tried in conjunction with ground based monitoring transects when workers are unable to effectively scout because of difficult terrain, but still need to determine levels of pig activity in an area.

Forward Looking Infrared Radar (FLIR) detection methods remain problematic unless the terrain is similar to flat open pasture and ungulate densities are fairly high to avoid problems of false positives.

5) Plan how to remove the last ungulates from an area before control efforts begin. Ungulates become quickly educated to control methods**.** Smart ungulates are difficult to catch and thus very costly to remove. If the goal is eradication, plan from the beginning how to eliminate failure (N. Macdonald pers. comm.). If at all possible, keep hunting pressure off the target animals to keep them ignorant of control methods until systematic and aggressive removal programs begin that ensure the last remaining animals can be removed. When removal programs begin, ensure a 100% control rate in any animal encounter.

3.1.1 CATTLE



- **Description:** Domestic cattle (*Bos taurus*) were introduced to the islands by the Europeans in 1793. Feral cattle are still found in forest areas on most of the major Hawaiian islands wherever ranch fencing is inadequate. Cattle, due to their sheer size and weight, have high demands for space and fodder. Cattle are also used in Hawaii to reduce fire fuel loads near wildland/urban interface areas and where other vegetative control methods are not as cost-effective.
- **Damage caused**: Cattle graze and browse native vegetation, compact soil, trample undergrowth, and spread weeds (e.g. gorse) through their feces or on their bodies, degrading forested areas to grassland pasture. Several grasses and legumes purposely introduced for cattle forage have also become noxious weeds. Riparian (stream) areas are particularly susceptible to damage caused by cattle.
- **Control methods:** Conventional 4 foot ranch fencing is usually sufficient. However, because cattle can damage fences by rubbing and leaning, a solar powered, electrified top "hot wire" is recommended where feasible. Placing braces on the outside of fences can prevent damage to fence corners. One-way gates are also helpful. General fencing protocols as well as a table of fencing specifications are further described in Appendix 2A.

  Feral cattle are also controlled by herding with helicopters or dogs, baiting and trapping with cattle pens and water, and aerial shooting. Preventing cattle from entering forested areas in the first place is the cheapest and preferred method. Good fences make good neighbors and managers should work with ranchers to retrieve livestock and contain them within pastures. A number of federal farm assistance programs are available to financially assist ranchers with protecting natural resources within and around their ranches.

3.1.2 GOATS

- **Description:** The goat (*Capra hircus*) was introduced to the Hawaiian Islands in 1792. Populations currently exist on nearly all the main Hawaiian islands. They are extremely agile and can jump or climb sloping trunks to reach trees and leaves over 6 feet high. They are also able to forage and thrive in extremely rugged terrain.
- **Damage caused:** Goats voraciously eat nearly every kind of vegetation and can thrive in a variety of environmental conditions from coastal areas to wet forests. They strip bark, trample undergrowth, compact soil, spread weeds, and cause significant erosion. The entire island of Kahoolawe and tens of thousands of acres of formerly forested areas of Molokai are just two examples of the biological disasters caused by large, unmanaged goat populations.
- **Control methods:** Fencing is the best (and cheapest) long-term control method. However, because of the goat's high jumping ability, it is recommended that electric fencing be used where feasible as well as a minimum 4 foot height of graduated mesh. Also, the social nature of goats highly motivates them to push under or through fences at gaps in order to join the rest of the herd. To prevent this, ground skirt fencing or running the bottom wire and barb wire flush with the ground is needed. Goats also get their horns caught in the fence mesh and routine fence checks are needed to repair damage and remove trapped goats.

  Because conventional hog wire fencing of cliff areas is extremely difficult at best, managers may need to deploy 'slinky' type fences. This type of light weight fencing is consists of coiled stainless steel wire similar to military concertina wire, but without the razors or barbs. It is used to block access in steep country or in high corrosion areas and several height sizes can be purchased. 52 inch high livestock panels with graduated mesh are also convenient to use along narrow and rugged ridgelines as they are easily cut to fit the terrain and do not require labor intensive corner bracing. Conventional fencing protocols as well as a table of fencing specifications are described in Appendix 2A.

  Ground hunting using high-powered rifles, high quality scopes and range finders is another common control method for goats. Common rifle calibers are .270 and .308 given the need for a flat trajectory over long distances. .223 semi-automatic rifles can be sufficient at shorter distances. Dusk and dawn are usually the most productive hunting periods as goats move into open areas for feeding or

display. Eliminating the dominant billy goat in a herd first, causes disarray in the remainder of the herd. Additional herd members will often remain in the open given the lack of a leader to lead them into cover.

Tagging and collaring a Judas animal

As herds become smaller through control and harder to find, the ‘judas goat’ technique can be used. A preferably white coated goat is captured and attached with an orange colored radio collar and/or GPS device and its ear tagged with a yellow or orange card. It will then be released to rejoin the herd on its own. The ‘Judas goat’ and the herd can then be located using radio telemetry or GPS and hunting can resume. Upon recapture, the waypoints from the GPS device from the goat can be downloaded to determine where the goat was wandering over time. Multiple small herds can be eliminated using the same collared goat. Goats ideally should be released into the same area that they were captured to maximize their survival over time. Several goats of both sexes and varying ages may need to be collared to ensure that time and money are not spent on a particular goat that happens to prefer a solitary life. However, young male goats were found to make the best Judas goats (N. Macdonald pers. comm.). The Judas goats also may not necessarily herd up with other goats, but the Judas goats can at least be used to find the general area of recent goat activity. A more sophisticated radio collar has a pulse monitor. When goats encounter other goats their pulse rate increases from about 45-60 beats per minute. This area can then be identified and control teams moved into place.


Deploying Judas animals and radio telemetry collars in use at Santa Cruz Island, California. Note the multi-frequency, specially modified antenna in use on the helicopter used for tracking.

GPS and radio telemetry systems are generally fairly expensive for the better models with GPS systems including hardware costing around $5000 and a Telonics VHF radio collar costing about $2800 not including very pricey replacement batteries that must be factory ordered.

It should be remembered that in most cases, ground hunting alone will not significantly reduce goat numbers. From approximately 1920 to 1970, 70,000 goats were removed from Hawaii Volcanoes National Park with no noticeable effect. It was only when fence units were erected that goat eradication was successful in a period of less than ten years (Loope et. al. 1988).

In order to clear fenced units of goats, a phased reduction program is usually employed (Reeser and Harry 2005). Specifically recruited and trained volunteer hunters can be used for the initial knockdown phase in non-remote areas. For the next phase, Judas goats are released and professional hunters remove most of the remaining population, aided by Judas goats. For the mop up phase, professional shooters from helicopters remove remnant individuals along cliffs. Judas goats are left to help professional hunters monitor and shoot any strays or new entries. Lastly, fences are routinely inspected and repaired to prevent ingress.

While sensitive to the concerns of the hunting and local resident communities, one major problem with using volunteer hunters in the first phase of control efforts is that ungulates become quickly educated to control methods and the emphasis on animal retrieval considerably slows control efforts. Consequently, eradication of ungulates from those management units becomes that much more costly and difficult for staff or professional hunters in the next phase of control.

In Makua Valley on Oahu a similar phased approach was used. Fencing was completed. Volunteer hunters and snares were then used, followed by aerial hunting and more snaring. The Judas goat method was tried on a limited basis but logistical problems rendered the goats released ineffective at finding the remaining goats in the valley.

Aerial hunting using autoloading 12 gauge shotguns or semi-automatic rifles (.223 Mini-Ruger) is also very effective for removing larger numbers of goats in a

short time. However, aerial hunting requires special training and certification as well as a very skilled pilot. Currently, Hawaii State law prohibits aerial shooting unless the shooter is state employee and is certified as a seated aerial gunner even on private lands. For shotguns, a preferred ammunition is a 3 inch magnum copper plated buffered #4 buckshot. This load provides good penetration and knock-down capability, which is desirable for humane kills (Littauer 1993). Semi-automatic rifles are modified by adding match barrels and match triggers to increase effectiveness. A red dot scope allowing the shooter the use of both eyes is also commonly used in aerial hunting operations. The disadvantages of aerial hunting are the risks inherent in any helicopter operation, poor weather which limits operations, and thick cover making hunting difficult. $800 per hour helicopter costs can also be prohibitive. Goats also quickly learn to become skittish at the sound of helicopters if aerial hunting is conducted too frequently, making detection difficult.

Bow hunting is also employed in game management units but is not a preferred method for resource managers given its limited effectiveness over time. Hunting and hunting related issues will be discussed in Section 3.2.

Snaring can also be a highly effective control method and is used in remote areas or areas with limited access due to terrain. However, because of the political issues associated with snaring, it is often used as a last resort. A discussion of the ethical issues associated with animal control is found at the end of this chapter.

3.1.3 MOUFLON SHEEP

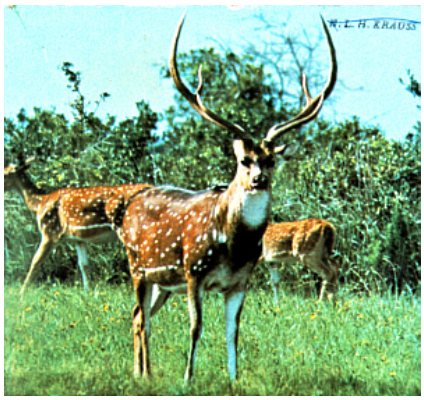
- **Description:** Introduced in the 1960s to the island of Hawaii for hunting, mouflon sheep have since thrived along the slopes of Mauna Kea. They are also present on Lanai.
- **Damage caused:** Sheep graze native vegetation, trample undergrowth, spread weeds, and cause erosion. Mamane/naio forests on Mauna Kea have been particularly hard hit by mouflon sheep.
- **Control methods:** Graduated hogwire mesh fencing at a minimum of 6’ is recommended. ‘Slinky’ type fencing may also be needed for cliff areas. Ground hunting with rifles is the most common technique for sporadic sheep control. Specifically recruited and trained volunteer hunters can be used for the initial knockdown phase in non-remote areas (Reeser and Harry 2005). Bolt action .270

and .308 caliber rifles are commonly used, but semi-automatic .223 rifles can be sufficient. The effectiveness of public hunting is limited. On the slopes of Mauna Kea on State land, volunteer hunting and staff assisted hunts failed to keep mouflon sheep populations at low levels after aerial shooting brought numbers to around 100 animals (Giffin in Environment Hawaii 1999).

Highly motivated volunteers given enough time can nevertheless be effective at sheep removal. On Santa Cruz Island from 1982-1992, largely volunteer hunting groups removed 36,000 sheep, completely eradicating sheep from the 96 square mile island.

Professional ground hunting teams with dogs combined with an aerial hunting team is particularly effective (Reeser and Harry 2005). The dogs and ground personnel will flush a sheep out into the open where the aerial hunting team can dispatch the sheep. Also, personnel in the helicopter can act as 'eyes in the sky' notifying ground personnel of animals in their area that may be blocked from view by brush or terrain.

3.1.4 AXIS DEER/MULE DEER



Axis deer

Mule deer

- **Description:** The first deer (*Axis axis*) were introduced to Hawaii in 1868. The majority of deer are on Lanai, but substantial and growing populations are also on Maui and Molokai. Mule deer are on Kauai. Because they are nervous, cautious animals, deer prefer the protection of the forest margins, however they thrive in a broad range of other habitats as well, including coastal kiawe thickets on Molokai.
- **Damage caused:** Deer graze native vegetation, trample undergrowth, spread weeds, and cause erosion. Deer populations will grow exponentially if left unchecked and food resources are adequate. Large deer removal efforts in the face of widespread deer diseases are currently underway in parts of the U.S. because deer populations were allowed to grow up to and beyond carrying capacity.
- **Control methods:** Deer fencing is highly effective if built properly. Deer are able to jump over or through fences when scared or will repeatedly jump into a well constructed high tensile fence and damage it to the point of fence failure. Covering the fence with a fabric has also been recommended to signal to deer that an impenetrable barrier is in front of them, although this is probably infeasible for miles of fenceline. Generally a minimum of 6 foot 6 inch high, graduated mesh

wire fence is recommended for deer with significant reinforcement by spacing posts at closer intervals. Since deer can still jump a six foot fence if they have enough running room or something to leap off from, 7 foot high fencing is better. However, given the difficulty of building tall fences in rugged terrain, some managers have opted to build shorter fences with the hope that deer will not jump over the fences unless pressured or faced with severe food or water shortages. An electrified top wire can also be used where feasible. General fencing protocols as well as a table of fencing specifications are further described in Appendix A.

Ground hunting with high-powered rifles at dusk and dawn is the most common technique for deer. Bolt action .270 and .308 caliber rifles are commonly used. Volunteer hunters can be used for the initial knockdown phase in non-remote areas followed by staff hunts to remove deer when volunteer interest wanes. If possible, hunting pressure should not begin until a plan for complete removal is set in place to keep deer naïve to hunting methods. Additionally, waiting until the mating seasons is underway also aids removal efforts as deer become more social and remain in groups for longer periods of time. Because deer are nocturnal and stunned by bright lights, night hunting using spotlights is employed, but prohibited in public hunting areas due to safety concerns. When 'night spotting' is used, lower caliber rifles are recommended for safety reasons (e.g. .22 magnum).

Timed feeders can also be used to attract deer into a designated feeding where they can be hunted with rifles, bow or snared. Cracked or whole corn is a suitable bait as the corn is sterile and can be cheaply obtained and stored.

A timed feeder with cracked corn can essentially re-domesticate feral animals and allow for effective removal efforts.

Snaring can also be a highly effective control method and is used in remote areas or areas with limited access due to terrain. However, because of the political issues associated with snaring, it is often used as a last resort. Hunting and ethical issues related to animal control will be discussed in at the end of the chapter in Section 3.2.

3.1.5 PIGS

- **Description:** Hawaii's pigs (*Sus scrofa*) are a feral hybridization of both a domestic Polynesian pig (brought to the islands in the 1600s) and a European introduction (brought by Captain James Cook in 1778). They are a major threat to Hawaii's native plants and animals and may be the greatest current modifiers of Hawaii's native forests given their large and widespread populations across the main Hawaiian islands.

- **Damage caused:** Due to uprooting, pigs can quickly destroy 80 percent of the plant ground cover in areas where they are found. Pigs also commonly uproot native tree ferns to eat the starchy interior and dig up the soil for wallows. These destructive activities create cavities in which water can collect, creating breeding grounds for mosquitoes (*Culex quinquefasciatus* and *Aedes japonicus*). Mosquitoes can then infect native birds with diseases such avian malaria (*Plasmodium relictum*) and bird pox (*Avipoxvirus*), to which they have little or no natural immunity. Pigs also eat large amounts of plant matter, trample undergrowth, and spread weeds on their hooves and through their feces.

The progression from pristine to heavily degraded can sadly be all too quick.

- Feral pigs also can harbor a number of diseases transmittable to humans including: brucellosis, trigynosis, leptospirosis, anthrax, typhus, and campylobacteriosis.

- **Control methods:** Fencing such as conventional 4 foot hogwire or hog panels adequately excludes feral pigs once they are completely eradicated from the site.

Semi-rigid, 36” or 52” high hog panels with graduated mesh are becoming more commonplace for fencing because of their flexibility (but higher strength), the reduced need for clearing large fence corridors, and the faster construction time as time consuming corner braces are not needed. Panels are also easily cut to needed sizes and bottom configurations and are especially useful along rugged ridgelines. The disadvantage of panels is their higher cost and heavier weight. A 16 foot long, 52 inch high panel currently costs about $40 or $2.50/foot whereas hogwire is about $1.27/foot. Because pigs dig, a ground fence skirt is often necessary in soft soils or along steeper slopes with uneven terrain. Given the acidity of forest soils, ground skirting and barb wire often deteriorate quickly when flush against the ground. Bezinal wire fencing or barb wire can now be ordered with a plastic coating over the galvanizing prolonging the lifetime of the wire considerably.

Plastic coated barb wire and plastic coated high tensile hog wire

The lowermost fence wires can also be set below ground to deter digging. Barb wire is ineffective once pigs begin tunneling or the earth beneath bottom wire or barb wire is eroded more than 4” away.

52” hog panels and ground skirt

48” hogwire and diagonal corner brace

Electric fencing where feasible (e.g. pasture areas) may also be effective. Placing a ‘standoff wire’ 4 inches toward the pig side of the fence and 10 inches off the ground may increase effectiveness. Existing hog wire fences can be easily retrofitted with a single electric hotwire to keep pressure off the main fence with clip on ‘outriggers’. Electric wires are commonly powered by relatively inexpensive solar panels. The main fence is also grounded to increase effectiveness (Littauer 1993).

A ‘slinky’ fence is also finding use in extremely steep areas to prevent pig ingress. This type of fencing essentially consists of coiled stainless steel wire similar to military concertina wire but without the razors. Fencing guidelines are detailed in Appendix A.

Ground shooting or hunting with hunting dogs and knives are also commonly practiced controls. Pig hunting with dogs is a very popular local tradition, for recreation and subsistence. Due to the local interest, volunteer hunting programs are commonly employed by resource managers, although their effectiveness is often limited. Several studies have shown that public or volunteer hunting is not effective in controlling feral pigs in remote areas (Anderson and Stone 1993; Barrett and Stone 1983; Molokai Hunting Test Working Group 1998). Experienced dogs are the key to successful hunts. Usually, dog and knife hunters will use a range of dog breeds for different purposes. Short or long-range ‘trackers’ pick up the pig scent, chase down the pig and begin barking to signal that a pig is cornered. ‘Grabbers’ such as pit bulls hold the pig until the hunter dispatches the pig. Dogs are also sometimes fitted with radio collars to assist tracking them, particularly in poor weather, or deeply dissected terrain. Training dogs takes time and effort, particularly if they are used around livestock. With a fairly minimal degree of aversion training, dogs can be quickly trained to only hunt one particular ungulate species and avoid livestock or other non-target ungulates. Also, because dogs are commonly injured while hunting, veterinary bills can be expensive. Hunting issues are discussed further in Section 3.2.

Dogs of varying age and ability returning from a hunt and a ‘sentinal’ neck snare in use as a last ditch control method in a pig free fenced area.

Neck snares have proven to be a highly effective albeit controversial control option. In remote areas in Hawaii, snaring can be the most cost-effective method for controlling pigs (Anderson and Stone 1993). In the upper elevation mountain areas of East Maui, the use of snares in unfenced areas lowered pig activity levels from about 70 percent to less than 2 percent. The snare is made from a loop of steel cable attached to a secure object and placed in a spot where the loop catches the animal as it passes through the area. A sliding lock closes the loop but does not open easily. A heavy swivel is commonly used at the end of the cable to minimize the risk of breakage when the captured animal twists around. Aircraft quality galvanized steel cable 3/32 or 1/8 inches in diameter is preferred. Large pigs can still break high quality snares even when set properly. In addition to animal welfare concerns, any livestock or hunting dogs are also at risk of being caught in snares. Setting snares is also far less time consuming than hunting with dogs. If used at all, snares should only be used by professional resource managers and be checked as frequently as possible to avoid prolonged animal suffering if a non-lethal catch occurs. Also, checks should be done much more frequently during the initial period of control when catch rates will likely be higher. Anderson and Stone (1993) recommend that new sets be established rather than moving snares to new locations as pigs would often return to the same area even after a considerable amount of time passes. Baiting snare areas with fruit, bread, seed corn, macadamia nuts, or carrion also increases their effectiveness. However, some managers do caution against checking snare sets too frequently as the smell of humans may deter pigs from entering the area. Snaring remains a highly controversial tool for controlling feral ungulates (in part because of its effectiveness) and as such many resource managers minimize its use when other options are cost-effective in the long-term (e.g. fencing) or are more politically attractive.

Box or circle traps made from hog panels or hog wire can also be used to effectively control pigs, although the baiting and checking of traps is highly labor intensive as traps need to be checked regularly to be used humanely and effectively. Commonly used bait includes bread, fruits, macadamia nuts, and seed corn. Bait is commonly spread around and in the trap for several weeks with the door wired open to draw pigs to the area and accustomed to the trap. The trap can then be set with bait left inside. In Texas, carrion has also been used effectively as bait for both traps and neck snares. Multiple pigs can be caught in one trap if an appropriate trap size and a one-way swing door is used. A simple cushion made of rolled fence wire or other material is placed at the bottom of the door to assist pigs upon encountering the swing door. Traps are commonly made from hog panels or doubled hog wire mesh. The Nature Conservancy's 4000 acre Honomalino management unit in south Kona was fenced and cleared of pigs over five years largely through trapping. It took 3 years to clear the 1800 acre Kapua unit also in South Kona also using trapping as the primary means of pig removal. Staff hunting using dogs also supplemented trapping efforts. The primary disadvantage of traps is their size and weight. They are bulky and difficult to transport. Traps are also vulnerable to theft when placed near public roads. Pigs may also become trap shy or avoid traps when ample food supplies are available elsewhere. It took

nearly a year for pigs in the Kamakou Preserve on Molokai to begin feeding on the macadamia nuts used as bait.


Box trap using panels and a one way door at left. At right, a simple corral trap made from hogwire.

- Bow hunting combined with the use of timed feeding stations has also been an effective method of removing pigs from farms adjacent to forest areas. Gunshots or barking dogs will scare a herd of pigs away from an area. However, an arrow is relatively silent and ideally, a number of pigs can be removed in one trip as they continue to approach the feeding area at dawn or dusk. Bait commonly consists of whole or cracked corn. A corn mash bait can also be made to draw pigs into a designated feeding area instead of a timed feeder. The bait consists of a mixture of fermented corn and molasses. Attractants consisting of female hog pheromones are also sometimes used by bow hunters, and can be surprisingly effective at drawing boars into specific areas. One method involves placing scent at various points along a hunting loop trail in an area of known pig activity. Later in the day, the bow hunter returns to that same loop trail to see if any boars have been drawn into the area by a presumed sow in heat. Synthetic pheromones are commercially available locally or online or natural pheromones can be obtained from harvested sows in estrus.
- Poisoning is not used in Hawaii as no toxicants are approved for use. It is worth noting that a comparison study between Hawaii Volcanoes National Park (HAVO and a national park in New Zealand (where feral pigs are also a problem), showed that the New Zealand method of poisoning pigs was 34 times cheaper and much more effective than the integrated Hawaii strategy of hunting, trapping, snaring and fencing. Pigs were reduced at both parks, but poisoning in the New Zealand park cost $\$35/km^2$ whereas at HAVO, $\$1180/km^2$ was expended (Hone and Stone 1989).
- Judas Pigs: The Santa Cruz Island Pig Eradication case study is described below. Judas pigs are being used extensively and effectively in this eradication project nearing completion.

Case Study #1: Honouliuli Preserve, Oahu

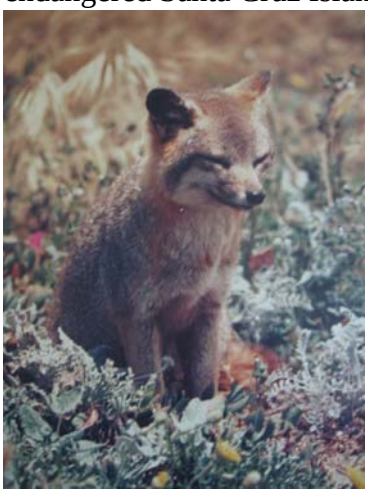
An example of a moderately successful integrated ungulate control program is at Honouliuli Preserve on Oahu, currently managed by The Nature Conservancy. The entire preserve is divided into three hunting units, two units for dogs and knife hunting, and one unit for bow hunting and/or box trapping only due to rancher concerns below that area of the preserve. Fencing is the primary pig control strategy for the most important biological

areas and weekly community hunting is used to relieve pressure on existing fences. Timed feeders are also used by bow hunters and resource management staff to draw pigs down and away from feeding in more intact and unfenced native forest areas. As a last resort, snaring was also used for a one year period in more remote unfenced areas when community hunting proved ineffective at preventing damage to unfenced rare plant and animal species. Trapping is also used by volunteer hunters who regularly check box traps. Informational briefings are also made to the Pig Hunters Association of Oahu to inform them of fencing proposals, snaring areas, and to recruit community volunteer hunters. In a six month period, 24 pigs were removed from a 3600 acre dry-mesic forest area. 12 of those 24 pigs were caught by volunteer dog and knife or bow hunters. All fenced units have remained pig free for over three years and even some unfenced areas have shown good recovery of native ground cover. The density of pigs is usually fairly low at Honouliuli in general due to the lack of an adequate food and water supply to support higher pig populations.

Case Study #2: Pig Eradication from Santa Cruz Island, California

Situated off of Ventura California, Santa Cruz Island is 60,000 acres or 96 square miles in size and is currently managed by both The Nature Conservancy and the National Park Service. The goal of conservation efforts on Santa Cruz Island is the recovery of a unique native ecosystem as well as the recovery of numerous rare and endangered plants and animals, most notably the Santa Cruz Island fox. From 1982-1992 36,000 sheep were removed from this largest of the Channel Islands and the pig eradication effort began in 2004 following a lengthy public information campaign, and Environmental Impact Statement and public review process. However, before pig eradication efforts began, 27. 5 miles of hogwire fences were constructed, dividing the island into 5 discrete management units in order to facilitate pig removal efforts. The terrain as depicted in the photo above, is often highly dissected and covered by a mosaic of open understory and thick chaparral. The pig eradication effort is expected to take two to three years and an estimated 80% of the total pig population has already been removed as of March 2006. A $4 million dollar, two year fixed price contract was awarded to Prohunt New Zealand following a competitive bidding process. Prohunt is a professional hunting company based in New Zealand that specializes in contracted animal wildlife control. In addition to their own staff, Prohunt brought their own helicopter (shown above), pilot, and hunting dogs to Santa Cruz Island. All hunting dogs went through extensive quarantine

procedures as well as aversion training to ensure the protection of the critically endangered Santa Cruz Island fox.




About only 250 of the endemic Santa Cruz Island foxes remain, and intensive captive breeding efforts are also underway. Dog kennels, intensive quarantine procedures, and aversion training ensure the safety of the wild foxes. Photo at left courtesy of The Nature Conservancy.

ProHunt operates at a level of efficiency and effectiveness that reflects a goal of getting the job done as quickly as possible and earning a profit. This private contract-based model of pig eradication at a large scale has its benefits and efficiencies. Prohunt has fewer limitations and obstacles than many government agency staff (e.g. helicopters protocols, working hours, control strategies and methods). The drawbacks to private contracting can include a negative public perception and in some cases cost.

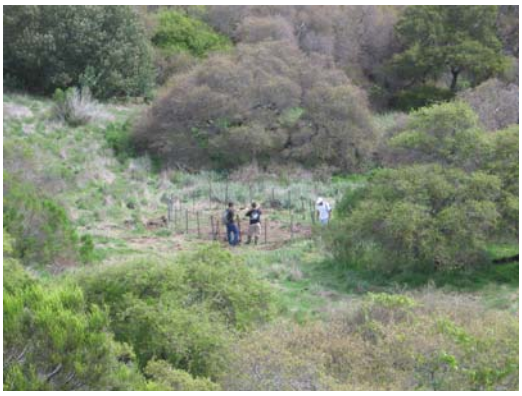
ProHunt's efficiency and effectiveness result from a strategic, systematic, integrated approach to removing pigs as well as highly skilled staff. They are very methodical in their approach to animal control and use a consistent, sequenced strategy. Their approach to each of the fenced units is as follows. Fenced units are generally cleared one at a time, although trapping may begin in an adjacent unit while hunting with Judas pigs and mop up scouting finishes in another unit.

1. Pre-baiting corral traps
2. Live trapping/Aerial shooting
3. Ground hunting with dogs assisted by their helicopter
4. Ground/aerial hunting with Judas pigs, and
5. Scouting and monitoring.

As of March 2006, 4734 pigs total had been removed by Prohunt with a total estimated population of about 6000 pigs before the start of control efforts.

Efficacy of Control Methods as of March 2006 on Santa Cruz Island

Method	**Percent of total pigs removed**	**Number of pigs removed**
Trapping	16%	741
Aerial shooting	79%	3751
Ground based hunting using dogs	4%	193
Miscellaneous	1%	49



1. Pre-baiting corral traps: Traps are used for the initial knockdown of pig populations in fenced units to avoid educating pigs about the threat of dogs. Using doubled hogwire rolls, simple corral traps were deployed in areas of high pig activity in the larger fenced units. Trap material is easily deployed by helicopter. Baiting using sterile cracked corn is also done by helicopter usually on the weekends when the helicopter is not needed to support the ground hunting teams. Food availability on Santa Cruz Island is generally limited so the pigs quickly learn to associate the sound of the helicopter with the arrival of food. Traps doors are secured open with food for several weeks until the pigs become well accustomed to feeding in the traps. Traps are placed near some cover but with open areas around the trap to assist with aerial shooting.

2. Live trapping/Aerial shooting: Pigs caught in the traps are aerially shot and removed from the traps by helicopter. Any pigs that may escape from the traps will often still come back to the traps the next day or so given their strong association with the traps and a ready food supply and because they are contained by the larger fences. As the number of pigs caught in the traps begins to decline, more systematic aerial shooting covering a larger area begins, although traps remain in place and are kept baited to keep attracting pigs to the trap area. Helicopter routes are also tracked using GPS to ensure systematic coverage. Aerial shooting is done with .223 Mini-Ruger Ranch rifle modified with a match barrel, match trigger, and red dot scope. All ammunition is non-lead based (using bismuth) to avoid secondary poisoning of bald eagles that are beginning to re-colonize the island.

3. Ground hunting with dogs assisted by their helicopter: As the pigs removed by aerial shooting begins to decline, systematic ground hunting with dogs begins. Hunting teams and their dogs are dropped off at the head of gulches and methodically work downwards to the gulch bottom. Ground hunters are in constant communication with the helicopter which serves as an ‘eye in the sky.’ The helicopter can readily direct ground shooters to pigs, move hunters and dogs back to the top of adjacent gulches, and deploy additional dogs as dogs tire. Dogs are carried in specially built ‘pods’ attached to the sides of the helicopter. The helicopter remains with the ground teams primarily to support them as needed. Hunters work in teams using only one or two dogs per subgulch and are in close communication with each other. Dogs are highly trained and will only bark up a pig and not attempt to bite it. Ground hunting teams carry GPS tracking units to record their routes and radio collars are placed on the hunting dogs to assist hunting and retrieve any lost dogs. Ground hunts usually end around mid-morning as the dogs tire and

efficiency begins to drop off. Nearly every inch of each management unit is covered by ground teams typically in two sweeps with each sweep lasting several weeks depending on the size and terrain of the management unit. GIS processing is done at the end of each day to guide hunting efforts the following day.



Tagging, inducing estrus, radio and GPS collaring, and deploying Judas pigs.

4. Ground/aerial hunting with Judas pigs: In conjunction with ground hunts, Judas pigs are extensively used for the mop-up phase of control efforts in mostly cleared fenced units. Up to 12 Judas pigs are used in one unit, they are randomly placed but pulled from that particular area. Both boars and sows are used, with some sows placed into estrus via commercially available hormones to assist with congregating males near Judas sows in heat. Pigs are captured using the helicopter and pig cage. Animals are tagged, sexed, and collared with both a GPS unit to track their routes upon re-capture and a VHF radio collar. The radio collar allows the helicopter or ground teams to track their movements upon release. The specially built cage for transporting pigs has a trap door on the bottom of the cage that can be remotely released by the helicopter pilot. This eliminates the need to have ground personnel assist in releasing Judas pigs.

Forward looking infrared radar (FLIR) technology was experimentally used to gauge pig densities but could not be extensively used for control efforts for several reasons including rugged terrain and cover making detection difficult, a number of false positives once the terrain began heating up with the sunrise, and the fact that pigs would simply move out of the area after flyovers.

Extensive transect monitoring will likely proceed once Prohunt's eradication efforts are complete to ensure complete eradication from the island.

Prohunt base camp Central Valley, Santa Cruz Island

3.2 HUNTING AND HUNTING RELATED ISSUES

Hunting can be a very effective method of animal control, and is a popular sport and tradition among Hawaii locals. For this reason, many islands have found some political success with volunteer hunting programs. Resource management agencies like the National Park Service and National Wildlife Refuge System however, have found much greater success at meeting long-term resource management goals using professional hunting programs, particularly in remote areas. Volunteer hunts, which bring together conservationists and community hunters provide can on occasion provide a cost-effective means to minimize the threat of feral ungulates on native plants and ecosystems. Currently on Molokai, large goat herds are also being controlled by community hunters who are flown by helicopter into areas otherwise inaccessible to them. At Honouliuli Preserve on Oahu, volunteer hunters help to keep pig pressure off fenced areas through their hunting efforts. In more urban and rural farm areas, mostly volunteer hunters and trappers perform a highly valuable service to farms, golf courses and graveyards by removing feral pigs from adjacent areas.

However, these programs also face a number of difficulties. A few of them are listed below:

- Community based hunting programs are often ineffective at achieving natural resource management goals simply because not enough animals are removed over time. Animal reproduction rates nearly always outpace volunteer hunter catch rates.
- Participation fluctuates as animal populations fluctuate. For example, hunter participation drops as pig populations drop, which in turn results in pig populations increasing again.
- Persistent public hunting pressure quickly educates ungulates making subsequent hunts or control work increasingly difficult.
- Hunters often do not or cannot hunt in remote areas without road access, therefore road and facilities maintenance is necessary. Further, remote areas sustain high levels of ungulate damage as animals are pushed by more intensive hunting activity in lower elevations.
- Flying hunters and dogs via helicopter into remote areas is extremely expensive and often logistically complex. For example, harvesting animals for their meat is a considerable additional expense in terms of the time and money required to bring coolers back from remote areas with helicopter vendor rates now around $800-$1000/hour. Further, field handling of carcasses and removal from remote sites does not meet USDA requirements for meat handling and processing for public consumption.

Transporting hunting dogs to remote sites by helicopter is logistically difficult and expensive.

- Hunters may be motivated (or allowed) to hunt only the largest 'trophy' animals, leaving females and younger, smaller animals to maintain and increase populations over time.
- Hunters may be hesitant to hunt unfamiliar or remote areas for fear of losing their dogs or intruding upon other hunter's hunting area.
- Permitting hunting in biologically important areas risks both damage to rare native vegetation and animals and the potential of alien introductions.
- Value differences between hunters and natural resource managers create tensions which are sometimes difficult to overcome. Vandalism of fences is an unfortunate result.
- Snaring programs and hunting with dogs need to be in entirely separate areas in most cases.
- Liability, trespassing, accidental forest fires, theft, injury to livestock and pets, and vandalism are common concerns are among private landowners, resource managers, ranchers, and farmers with regard to hunters.
- Hunter access is often highly restricted due to the above landowner concerns.
- Other user conflicts may restrict hunting such as recreational hiking or horseback riding in forest areas.

Overcoming these numerous difficulties is still possible and often politically highly desirable if communities are to be truly engaged in the protection of their own native resources. The approach of each resource manager to hunting will necessarily differ with respect to their own management goals and the concerns of stakeholder and community interests. It should be remembered however, that feral animals are replaceable, whereas endangered native plants, animals and communities are not.

Summary of Community Concerns

Wasted Meat: One common community concern of an ungulate control program is the wasting of meat from animals killed during the course of control work. It is worth noting however that far fewer animals are killed over time in fenced areas, once fencing is complete and animals eradicated from those units (Reeser and Harry 2005). Also, the total cost of salvaging meat from carcasses is oftentimes far greater than simply going to the store and buying equal amounts of prime cuts. For example, if one factors in vehicle fuel costs, ammunition costs, hunting license costs, dog food and veterinary costs, and

time spent hunting, ‘subsistence’ hunting may become a money losing, not money saving effort. From the management perspective, many managers prefer that animals be left to recycle the nutrients back into the forest rather than taking inordinate amounts of staff field time and considerable expense to dress, store and transport meat. Live trapping as mentioned previously can be effective and is good for public relations, but again, the labor costs of checking traps is considerable. Providing community hunters the first opportunity to ‘hunt out’ fenced areas before using other control methods is commonly done by managers in an effort to engage the local community in the protection of their own native resources as well as alleviate concerns about the wasting of meat.

A pilot program to establish small-scale, cooperative pig, sheep, or goat farms could be tried if community hunters are interested in cost-effectively providing ‘meat on the table’ for their families. Numerous rural development and farm assistance programs are available to financially assist individuals and groups with such an effort.

Loss of Access: Loss of access to favored hunting grounds because of fencing or resource management activities is another common hunter concern despite the availability of tens of thousands of acres in State designated Game Management Areas and Hunting Units within State Forested areas. Countless acts of vandalism to fences and gates continue to occur annually, resulting in repair costs in the tens of thousands of dollars. Initiating a community outreach program to detail why fencing is necessary for an area and the overall resource management goals is one proactive approach to improving community relations with the hunter community. A federal grant program through the U.S. Fish and Wildlife Service to improve hunter access to remote areas is also being tried in numerous areas throughout the state. An innovative ranger program to train students from the Waianae community on Oahu on basic resource management methods is also underway. The intent is to educate younger hunters on the goals of the conservation community as well as to provide hands-on job training in an effort to bypass the strife between hunters and conservationists.

Denial of Traditional Practices: Denial of access for hunting is also seen as a denial of traditional cultural hunting ‘rights’ and practices. As pig, goat, and deer hunting has been practiced for several generations in Hawaii it can rightly be regarded as a strong cultural tradition across Hawaii’s local ethnicities and not just among Hawaiians. Much debate is centered on this issue of whether hunting is a ‘right’ or privilege. Resolving the dynamic values and traditions of a very diverse hunting community with the values of conservationists is a difficult but necessary endeavor if the goal of fully fenced game areas and fenced important native areas is to be reached.

Since the time when early Polynesians brought the pig to Hawaii, the pig has played not only an important dietary role, but also an important role in Hawaiian legends, ceremonies, and spiritualism. (Jenkins et al. 1994). Indeed, “pigs were highly prized as gifts to gods and to humans.” (Mitchell 1992). With the recent resurgence in interest and practice of traditional Hawaiian protocols, the pig clearly has significant cultural importance for ceremonial practices, and the perceived indignities-like snaring or the wasting of meat is offensive to practitioners (Jenkins et al. 1994).

Contrastingly, some Hawaiians see the pig as very damaging. They believe these non-native animals pose threats to unique and culturally important native ecosytems, justifying strong control actions (Puanani Anderson-Wong, pers. comm.).

Humane/Ethical Issues: Humane concerns are also responsible for much of the controversy surrounding unattended neck snaring, unattended trapping, and hunting with dogs. Humane groups oppose neck snaring in particular as it can be one of the most inhumane methods of killing due to the length of time a captured animals can suffer in the snare, particularly if the animal is not snared by its neck as intended (Jenkins et al. 1994). Hunting with grabbing dogs also causes great suffering to pigs and to the dogs themselves as dogs are commonly injured by pigs during hunts.

From the humane perspective, fertility control, live-trapping and prompt relocation, and driving animals out of preserves are the most acceptable control methods because they are non-lethal. Of the lethal control methods, shooting by professional hunters appears least inhumane because of the low wounding rate and quick death (Jenkins et al. 1994). In their year 2000 report, the American Veterinary Medical Association's Panel on Euthanasia recommended a gunshot to the head as the most practical means of killing wildlife and free-ranging animals when euthanasia is not possible from the animal or human safety standpoint (AVMA 2000). They do caution this practice by stating that challenging conditions in the field in no way reduces or minimizes the ethical obligation of the responsible user to reduce an animal's pain and distress to the greatest extent possible during the taking of an animal's life.

3.3 RODENTS

- **Description:** Rats (*Rattus exulans*) were first introduced by the Polynesians in the 1600s, and then again by the Europeans 200 years later, in two forms: the black rat (*R. rattus*) and the Norway rat (*R. norvegicus*). House mice (*Mus musculus*) and mongooses are also a European introduction. These rodents are found in all native habitats from sea level to over 3000m in elevation, although mongooses generally prefer lower, drier elevations. Because of its size, arboreal behavior and nocturnal habits, the black rat is often considered one of the greatest threats to native forest birds.

Photo by Jack Jeffrey

- **Damage caused:** Rats have a large impact on the native ecosystem as omnivorous predators. They are agile tree climbers and feed on insects, snails, eggs, young and adult birds, and a wide range of fruits, seeds, and other plant material. Rodents are also a hazard to human health, as they are able to transmit leptospirosis and murine typhus.

- **Control method:** Hand applied poison baits and snap traps are the most common and effective control method against rodents.

Typical bait staion and snap trap placement. In areas where pigs are present, bait stations need to be secured above ground and out of reach of ungulates. Good snap placement in rat 'dens' or rat pathways increase effectiveness of snapping efforts.

- Applicators should be aware of the specific restrictions that exist for the State of Hawaii, including the use of tamper resistant boxes and a current license as a certified restricted use pesticide applicator to apply Diphacinone® rodenticide in conservation areas. Incidentally, much more toxic rodenticides such as Warfarin® which require only a single feeding for a lethal dose are available for home and commercial use without restriction. Appendix 3B details the regulatory requirements as well as describing methods for improving the effectiveness of bait stations and snap traps in the field. Be aware, however, that some brands of bait blocks may contain viable weed seeds that if germinated, may be a threat to native species.

  Efforts are currently underway to secure approval for the use of aerial broadcasting as a method of applying rodenticide in ungulate free exclosures following successful aerial efforts in New Zealand and British Columbia, Canada, and successful hand broadcasted baiting efforts in the Northwestern Hawaiian Islands and at Hawaii Volcanoes National Park.

- Small mammal fencing is another option, though it is much more costly and less commonly used. At Karori Wildlife Sanctuary in New Zealand, fences are made of a very fine mesh, excluding all land animal pests. A demonstration project was also done on the island of Hawaii by the Xcluder™ Pest Proof Fencing Company. A mesh wall is a more appropriate term for this type of fencing given its impregnability.

Excluder fence demonstration project on the Big Island done to assess effectiveness on uneven lava substrate.

3.4 CATS

- **Description**: Feral cats (*Felis catus*) were probably introduced by Europeans in the late 1700s. They are rampant in populated areas and also inhabit all forest types in the Hawaiian islands. Feral cats can have an unusually large home range.

- **Damage caused:** Cats famously prey on birds, eggs and rodents, but large insects may also makeup a significant portion of a feral cat's diet. In a study of diets and home ranges of feral cats, bird remains were discovered in 68 percent of cat scats collected in a montane wet forest of Hawaii (Smucker et al. 2000). Feral cats can also be a threat to human health as they can transmit disease (toxoplasmosis) placing pregnant women and immune suppressed individuals particularly at risk.

- **Control methods**

Box trapping: Box or cage traps are commonly used to trap cats in urban areas and can be effective in forest settings. However, most cats are wary of confinement and will also avoid the cage if their footing is unstable upon entry. Cage traps need adequate shelter, food, water, and regular checking if they are to be used humanely. Taped cat cries are also used where feasible to draw feral cats into a trap.

Leg traps: although not commonly used in Hawaii, they may prove effective where cats regularly use a trail in a narrow area. Again, regular checking is required.

No toxicants are currently approved for use in Hawaii and it is illegal to use products such as liquid Tylenol for feral cat control.

3.5 INVERTEBRATE PESTS

Slug found consuming critically endangered *Cyanea pinnatifida* fruit, Honouliuli Preserve.

The most destructive invertebrates in mesic forests are arguably ants, slugs, cannibal snails, black twig borer beetles and wasps. In urban and agricultural areas, these invertebrate pests are most commonly controlled with poison bait. For example, aerial baiting to control ants is a common practice in pineapple fields. However, many poison

baits used in agricultural areas are not labeled for use in conservation areas. Control methods are not discussed in detail in this manual for this reason. The severity and scope of impact of alien invertebrates on forest animals and plants is quite clear in many circumstances. If left unchecked, *Vespula pennsylvanica* wasps can deplete insects from hundreds of acres of forest by forming wasp colonies in the millions; severely disrupting food webs for native birds. Slugs can prevent recruitment of rare and common native forest species by consuming nearly all seedlings, leaving alien species like guava to proliferate and native canopy species to eventually disappear (S. Joe pers. com.). Black twig borer beetles use a wide variety of native semi-hardwood tree species as hosts (e.g. koa, hame, kopiko) and along with their associated pathogenic ambrosia fungus, are thought to be responsible for the near extinction of a number of endangered tree species. Promising research is currently underway to develop toxic attractants to control black twig borers in forested areas and coffee farms. Future drafts of this book may address invertebrate control methods in more detail. The Hawaii Ecosystems at Risk (HEAR) website www.hear.org details some of the most current research and invertebrate control efforts in Hawaii. Frank Howarth's article on the 'Impacts of Alien Land Arthropods and Mollusks on Native Plants and Animals in Hawaii' remains one of the most concise summaries of the problems of Hawaii's established invertebrate pests and is also now available online also the HEAR website. A full citation for this articles as well as another related article by Gagne and Christensen is given below and marked with asterisks.

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APPENDIX 3A: FENCING PROTOCOL

SUMMARY: Fence construction can be broken down into several steps usually performed in this order:

A. Fenceline scouting/scoping
B. Fence corridor clearing and fence material delivery to work site
C. Setting the line, pounding posts and constructing corner braces,
D. Stretching fence mesh and clipping barb and mesh wire
E. Setting deadman anchors, stretching and securing ground skirts, installing any electrified wires.
F. Installing any crossing styles, gates, one-way pig doors, dog ramps, or stream barriers.

Since one roll of hog wire is 330 feet or 100 meters in length, all the steps can be repeated over 100 meter stretches so that the fence is fully constructed 100 meters at a time.

Techniques used in the construction of a fence are dependent on terrain, cover, management goals, and the skills of the construction crew. One protocol can never satisfy all working conditions but the following general guideline should meet most field conditions.

1. FENCELINE SCOPING AND PLANNING
    1. The goals of the ungulate control program will dictate the type, size and location of ungulate fences. Funding should dictate the size, but not the type of fence used. For example, using pig fencing without ground skirting in high density pig areas is simply unwise and ultimately ineffective. Similarly, planning for future ungulate invasions may be more expensive in the short-term but cheaper in the long-term. For example, building a 7 foot high deer fence is more costly up front, but far cheaper in the long run than attempting to retrofit an existing 4 foot pig fence several years later.
        a. Usually the fence route will run along natural topographical features, property lines, vegetation communities, ridgelines or use natural barriers like cliffs.
        b. Straight runs as much as the topography allows is optimal for ease of construction.
        c. Minimizing impacts to native vegetation, streams, erosion prone slopes and important biological resources like rare plants, nesting trees, snail habitat requires thoughtful consideration during initial fenceline planning and scoping.
        d. Weed invasion along fence corridors should also be taken into consideration and managed as needed.
        e. Fence corridors can also have positive benefits such as providing a fire line or a fuel break in the event of a fire and access routes into remote areas.

f. Be aware of sources of fence failure such as large dead trees, landslide areas, flashfloods, ungulate densities, and vandalism when planning fence routes.
g. Strategic fencing using cliff lines and vertical drops is often fraught with the difficulty of scouting the cliffline both in the air and on the ground to ensure its impregnability. When in doubt, construct a complete fence route. Ungulates are often surprising in their determination and climbing abilities.
h. During initial flagging of the fence route, alternative fence routes should also be scouted to ensure the optimal placement of the fenceline. Poor planning results in miscalculated material needs and logistical difficulties of moving very heavy fencing materials in steep terrain.
i. Determining straight lines in thick, overhead brush for proposed fencelines is difficult at best. Standard surveying equipment such as a compass, GPS, pvc poles, laser levels, and range finders make this task easier. A sharp machete is also invaluable.
j. Taking the time to double check fence measurements, placement of drop zones, and material calculations will save you from costly mistakes.

2. FENCELINE CLEARING AND MATERIAL DELIVERY
    a. If not using hog panels, clear a corridor slightly wider than the height of the fence to allow ease of rolling out fence mesh.
    b. When possible, avoid cutting down large native trees, and detour around rare species.
    c. Cut down hazard limbs and dead trees before they fall on the completed fence. Felled limbs can also be later used for waterbars during construction.
    d. Brush in a straight line along fencing route.
    e. Fence braces need additional brushing for ease of installation.
    f. Large shrubs and trees need to be cleared and cut as flush to the ground or even slightly below ground level as possible. Stumps are not only trip hazards, they will also hang up fence mesh when material is being unrolled.
    g. If not using fence skirting, the ground should also be leveled as much as possible to allow the bottom wire and barb wire to ideally be no more than 2 inches off the ground. Taking the time to level the ground at the onset is often much easier than having to re-pound posts lower or using deadman anchors to bring the bottom wire closer to the ground.
    h. Since fence rolls are 330 ft (100m) in length, usually fence material drop zones are spaced 100m apart. Placing material at the top of small hills makes unrolling much easier. Dropping material on narrow, knife edge ridges requires a method of immediately securing the load to a tree or post to avoid having the load roll downhill. Pallets can also be placed under fence rolls to avoid this mishap.

3. SETTING THE LINE, CONSTRUCTING BRACES AND POUNDING POSTS
    a. Often it is easier to roll out the fence mesh before setting the bottom line and pounding any posts. Place the mesh on the side of the fence corridor to get it out of the way of post pounding.
    b. Tie a string between two guide posts that are separated as far apart as the terrain will allow. On uneven terrain set string in shorter intervals as allowed.
    c. If fenceline bends, make the bend have several shorter straight sections with the string running from corner to corner. Reset posts as needed to eliminate as many bends and corners as possible. Ideally, the fenceline will also run next to the unbrushed area so that once the fence is upright, the rest of the corridor can be used as a foot or vehicle path for maintenance.
    d. Once the final fenceline is determined, barbwire can also be rolled out and stretched to serve as a bottom guide for the alignment of posts instead of the string.
    e. If working in steep terrain or in loose soils, it may be easier to roll out any fence skirting and temporarily secure it to aid in footing. Constructing simple ladders is also of great benefit in steep sections.
    f. Brace all corners and crossing styles with additional posts and wire. The nubs of corner posts need to face away from the direction of the tension. Fence mesh may need to be placed on the proper side of a post before the brace is constructed.
    g. A variety of corner braces can be used depending on the terrain and necessity. Internal or external braces, horizontal or diagonal, a single bisecting angle or two diagonal braces may be needed. In some cases, even pounding additional posts flush with each other can serve as a brace when terrain disallows any of the above options.
    h. Pound posts about 10 feet apart on the far edge of the brushed corridor so that the hog wire can be rolled out in the clear area if not done so already. Posts may need to be spaced closer in steeper areas or where animal pressure will be especially significant for additional strength. If the fence mesh cannot be stretched, closer post spacing is needed. Pound posts in approximately 2.5 feet, leaving the lowermost nub no more than two inches above ground level. Posts should be pounded in perpendicular to the slope for proper clipping of posts to the horizontal fence mesh wires. Taller posts are needed in softer soils where they can be pounded in deeper. A rock drill and cement is often needed in rockier terrain
    i. In areas where the terrain dips and posts are prone to popping up once the tension is on, posts can be anchored by pounded in a second post at a 30-45 degree angle to the upright post. The second (or even third) angled post is secured to the upright post with o-clamps or smooth wire at ground level where the posts intersect. The effect is an in-line brace and is often much easier to construct than a deadman anchor.
    j. Orient posts with nubs facing toward the outside of the exclosure.

k. Periodically re-sight along the pounded posts to ensure their straight alignment and push posts into place as needed. Pull up any posts grossly out of alignment and re-pound. A crooked line of posts will make stretching the fenceline exceedingly difficult as the vertical wires of the mesh will constantly hang up on nubs once any kind of tension is applied.
l. Posts may twist in the ground because of roots, etc., a pipe wrench can be used later to straighten. If a post twists badly, reposition and pound again.

4. STRETCHING AND CLIPPING BARB WIRE
    a. Level ground as needed, being careful to not dig too deep when removing stumps. A hazelhoe is very useful for leveling and benching.
    b. Roll out barb wire.
    c. On uneven ground, don't tighten too much; stepping on the wire in low spots can give you an idea of tension.
    d. On flat and even ground barbwire tension can be tighter, but because the wire is twisted it has a lower breaking strength than smooth wire.
    e. Clip off the barb below the first nub above the ground on each post. Allow space for hog wire to be clipped off at the same nub.
    f. On uneven terrain, have people step down on the barb in holes or depressions while tightening.
    g. Barb wire is unnecessary if fence skirting is used.

5. STRETCHING HOG WIRE
    a. Roll out the hog wire in the brushed corridor.
    b. Stand up sections of the fence with the smaller squares along the ground.
    c. On uneven ground, stretch shorter sections as terrain allows using the "come along", rope, and 2x4 "sandwich" device.
    d. Hog wire can be stretched around one or two corners at the most depending on the angle of the corner. 90 degree corners are very difficult to stretch wire around.
    e. When standing the fence up, the fence can be hung loosely on the posts. Unhook the fence from the posts before stretching and be aware of roots and snags which may catch the fence as it is tightened.
    f. Use the bottom part of the fence as an apron on hill crest situations.
    g. At dips in the terrain, have persons stand on the fence to get an idea of the final tension needed.
    h. Use only sturdy trees or multiple tie off points to secure the come a long. Posts can also be used for tie off points when trees are unavailable. Posts should be pounded in at a 30 degree angle to minimize bending in the direction of the tension.
    i. Initially clip in or staple hog wire starting from the point furthest from the come along to preserve maximum tension. Use vertical wires near posts strategically to catch the fence from slacking backwards when tension is released. Wooden posts at corners or other strategic intervals are handy as the hog wire can be stapled to the post preserving fence tension.

6. Clipping Off Fence Mesh
    a. Five or six clips are placed on each post. More clips are needed for taller fences.
    b. Clip bottom wire below the first nub above the ground (the same place as the barb) and the next wire.
    c. Skip one wire, clip off.
    d. Skip two wires, clip off.
    e. Clip top wire.
    f. This is a guideline. Clip as necessary.
    g. Pinch clips closed at critical points, such as corners and step-overs.
    h. Aluminum tie wire can be used in place of clips when securing mesh to corner posts which have nubs facing away from the tension. Tie wire is also handy when the bottom wire is flush against rocky ground preventing wrapping of the clip wire around the mesh wire.

7. Setting Deadman Anchors or Duckbill Anchors
    a. On uneven ground, one 3 foot anchor goes between each post. Set anchor at the low point between the T-posts.
    b. Pound all anchors on unbrushed side of the fence.
    c. Pound anchors at an angle so as not to be pulled out by the tension in the fence.
    d. Pound the anchor in until 3 nubs remain above ground.
    e. Use two clips below the first nub above the ground. One clip on the barb. One clip on the bottom hog wire.
    f. Duckbill anchors can be used in place of deadman anchors to bring the bottom wire closer to the ground.

8. Constructing Fence Skirting
    a. Roll out the 3 ft. fence skirting with the small mesh holes next to the small mesh holes of the upright fence.
    b. Overlap the upright fence mesh and secure the fence skirt to the second or third horizontal wire of the upright mesh using galvanized hogrings or aluminum tire wire.
    c. Secure the fence skirt to the ground by pounding in deadman anchors, duckbill anchors, or nailing it to available roots. Large ohia logs and other long-lasting wood trees can also weight down the fence skirt if the terrain is too rocky. It should be noted that large pigs can be surprisingly strong and have been known to move boulders and logs in their efforts to dig under fencelines. Long sections of skirting can also be ‘stitched’ into the ground by using smooth wire woven in and out of the fence skirting and clipping the smooth wire to anchors at regular intervals. Pounding in the anchors will tension the smooth wire and secure the skirting tightly to the ground.

9. FINISHING STEPS: RE-POUNDING, STYLES, GATES AND OTHER CONSIDERATIONS

a. All posts and anchors can be pounded in an inch more to set the bottom wires tight to the ground if not already. If holes remain along the bottom of the fence, pieces of hog wire can be used as an apron.
b. Crossing styles can be easily constructed using posts and 'o' ring clamps to secure horizontal pieces to vertical posts. Nubs on horizontal pieces should face upward for maximum foot traction.
c. Gates are quite useful for high traffic areas, but should be built to open in only one direction (outwards from the enclosure) and be self-closing using springs or spring hinges.
d. Dog ramps and one way pig doors can also be built into the fenceline where desirable.
e. Stream crossings are particularly challenging, particularly given the flashiness of Hawaiian streams. Two strategies used by fence builders to fence a stream are mentioned here.
f. In intermittent and low flow streams, a hinged apron can be built in the stream bed. The apron is weighted with rocks or logs to prevent ingress in dry periods. During heavy flows, the apron lifts and is held by the hinge. The apron is again weighted down after the flow recedes.
g. In perennial, high flow streams, and in more remote areas with seasonal stream flow, a variation of the hinge technique is used using a heavy rubber mat instead of a fence apron. The rubber mat lifts during high flows and hopefully sits tight enough across the stream during low flow periods to prevent ungulates from moving upstream. Barb wire can also be stapled to the rubber mat as additional deterrence.
h. Fence 'wings' using panels or fence mesh can also be constructed at vertical cliff areas to prevent animals from moving around the end points of fencelines at cliff edges. The 'wing' simply extends the fenceline into open space preventing animal movement.

<u>TOOLS AND SUPPLIES:</u>

Barbwire spool roller
Post pounders
Barb stretcher
Come-along
Small sledge hammers
Fence tool – wire cutter, plier, etc.
Hog ring pliers
Tool bag
Gloves
Flagging
Ropes – as safety lines, if needed

Pulaski/Fire ax
Hazelhoe

Hand and longhandled picks
Chain saw
Gas powered auger
Weed eater
Gas powered rock drill
Machete
Construction string
10 penny nails or hex wrench for clips
Hip chain

FENCE MATERIALS NEEDED:

- Galvanized Anchors – Anchors should be spaded. Plan to use 40 anchors per roll of hog wire.
- Galvanized Barb Wire – One roll is 300 yards. Plan to use one roll of barb to 3 rolls of hog wire.
- Galvanized T-Posts – Plan to use 30 to 40 posts per roll of hog wire, various heights.
- Galvanized Unspaded posts-For horizontal braces and crossing styles
- Wooden posts-Treated and pointed at one end, various heights.
- Galvanized T-Post Clips – Plan to use 225 clips per roll of hog wire.
- Aluminum tie wire – Useful for securing hogwire to corner posts when conventional clips are too small.
- Galvanized Fence Wire – One roll is 330 feet (100 m). Measure fence line and plan accordingly. Extra material can also be used for fence repairs in the future.
- Galvanized Fence Panels-Width and height vary and can be cut to size. Usually panels are 16 ft. in length and 36-52 inches in height. Anticipate areas of overlap.
- Galvanized Smooth wire: 12 gauge usually most useful.
- Galvanized Duckbill anchors and setting post.
- Galvanized Fence staples.
- Various hardware for securing braces (caps, post brackets, nuts, bolts, and washers).
- Gates, gate posts, and hardware.

Fencing Specifications Table:

Target species	**Mininum Fence height**	**Graduated meshing**	**Fence skirting recommended**	**Electric top wire recommended**
Cattle	48”	No	No	Yes (as feasible)
Goats	48” (52” better) Slinky fence useful	Yes (no gaps at ground)	Yes (24”-36” as needed)	Yes (as feasible). Additional hot wires may be needed to control billys
Sheep	60”	Yes	No	Yes (as feasible)
Deer	78 (84” better) Slinky fence useful	Yes	No	Yes (as feasible)
Pigs	42” (48” better) Slinky fence	Yes (no gaps at ground)	Yes (24”-36”) as needed in soft soils	No

APPENDIX 3B: RODENTICIDE BAITING GUIDELINES

Under FIFRA Section 24c, the use of rodenticide in conservation areas is permitted in the State of Hawaii if SPECIAL LOCAL NEED (SLN) labeling is obtained. As with any pesticide, users must follow the product's instructions for use as well as the SLN label's restrictions. The SLN permit details:

1. WHAT PESTICIDE PRODUCT MAY BE USED: Pesticides that may be used are RAMIK Mini Bars®, JT Eaton Bait Blocks with Molasses / Peanut Butter Flavor®, or JT Eaton Bait Blocks with Fish Flavorizer®. Diphacinone is the active ingredient. Diphacinone is an anti-coagulant originally developed for use in humans to alleviate blood clotting. During animal testing it was found to be highly effective as an anti-coagulant in rodents.

2. WHO CAN APPLY WHICH PESTICIDE PRODUCT:At the time of this manual's publication, Eaton's Bait Blocks were re-classified as a Restricted Use Pesticide due to secondary poisoning concerns in the continental U.S. Restricted Use Pesticides require applicators (or their immediate supervisors) to have a current certification in restricted use pesticides obtainable from the State of Hawaii Dept. of Agriculture.

3. WHAT ADDITIONAL CROP OR SITES THE PESTICIDE MAY BE USED TO TREAT: These sites include forests, offshore islands and other non-crop outdoor areas.

4. WHAT RESTRICTIONS APPLY TO TREATING THE CROP OR SITE:
    a) Bait stations must be tamper-resistant. (Note: Experts have found that some models of bait stations are not tamper-resistant.)
    b) Bait stations should be secured on the ground in ungulate free fenced areas or in trees at least three feet above the ground where ungulates are still present.
    c) You must have SLN labeling on hand during application.

5. HOW SHOULD THE STATIONS BE PLACED:
    a) A grid setup is generally recommended to ensure adequate protection of resources conserved. Stations are to be spaced in 75-150 ft intervals. This number is based on extensive radio-collar work in Hawaiian rainforests (these figures can be adapted for dry forests, if substantial data is provided and approved).
    b) Place stations near rodent pathways and dens (e.g. rock overhangs, tree cavities, small caves etc.). Do not place bait stations out in the open or within 15 feet of any body of water or stream.
    c) If placing bait stations in areas that are not pig free (i.e. unfenced areas), bait boxes must be tied a minimum of 3 feet off the ground in an area inaccessible to feral pigs.
    d) Placing stations too close to protected resources can also invite rodent predation. For example, stations should not be placed at the base of

nesting trees for endangered birds, but rather an appropriate distance away (e.g. 50ft.).

e) Rodents may take a while to find a bait station, particularly if stations are tied in trees away from natural rodent dens. Adding smears of peanut butter to the inside lid of the box upon initial deployment may aid rodents in finding the stations. Also placing 'rodent ramps' using available tree limbs can also assist rodents in getting up to the bait stations in trees.

6. WHAT DOSAGE OR DILUTION TO USE:
    a) 4-16 oz. of bait per station. As indicated on the label, no more than a pound (16 oz.) should be in the station at any one time. Less bait may be needed at each station over time following the initial knockdown of target populations.

7. WHEN THE PESTICIDE SHOULD BE APPLIED:
    a) To be determined by the species to be protected. Some agencies bait year round at six week intervals (after the initial knockdown period) to protect snail populations. Other agencies bait only seasonally during rare plant flowering/fruiting periods or bird nesting seasons.
    b) Bait should also generally be replaced after periods of sustained heavy rainfall as it will likely be spoiled.

8. WHAT SPECIAL EQUIPMENT IS NEEDED:

    a) Inserting a chicken wire mesh in the bait station to raise the bait off the bottom of the box can prevent the decomposition of bait in wet conditions. Also using the wire rod as intended by the manufacturer to suspend the bait or placing the bait in a plastic bag will also extend bait longevity. Drilling drainage holes in the corner of bait boxes will also keep bait fresher for longer periods.
    b) Snap traps are also recommended in conjunction with baiting for initial knockdown of rat and mice populations as well as for presence/absence monitoring. Bait avoidance does happen.

9. OTHER SPECIAL REQUIREMENTS:
    a) Bait stations must be labeled with name and phone number of responsible agency.
    b) Treated areas must have warning signs. Signage shall follow the wording as designated on the SLN label.
    c) Check area periodically and collect and dispose of any dead animals found.
    d) Spoiled or uneaten bait and dead animals collected may be buried on-site. However, burial on site shall be at a depth such that it will not result in exposure to non-target animals.
    e) All users must consult the U.S. Fish and Wildlife Service, in writing, of each new location two weeks prior to deployment.

f) Secondary poisonings shall be reported to the Dept. of Agriculture as indicated on the SLN label.

BAITING CHECKLIST

1. Obtain Restricted Use Pesticide Applicator's certification.
2. Notify the U.S. Fish and Wildlife Service at least 30 days before baiting to obtain other approvals as needed.
3. Determine the species to be protected based on resource management goals and objectives for the area.
4. Determine the target species to be controlled (rats, mice, mongoose).
5. Determine which type of bait will be used (e.g. Eaton's 2 oz. blocks peanut butter/molasses flavorizer for rats or Fish flavorizer for mongoose)
6. Determine the type of station to be used. If making your own, submit a description and preferably a sketch. (Note: stations must be inspected and approved) before deployment if using a non-standard model.
7. Determine the potential non-targets in the area. Is it the project area fenced? Is there public access and potential for tampering?
8. Post warning signs (wording different from the language required on the SLN label needs approval).
9. Determine the spacing and location of stations. Mark and map station locations and resources to be protected.
10. Determine the frequency to check / recheck stations. Monitor bait take and adjust the frequency of checking and amount of bait deployed accordingly.
11. Record the amount of bait used per calendar year: EPA requires a report of how much pesticide is being used under each 24c label.

4.0 WEED CONTROL

4.1 INTRODUCTION

Invasive alien plants introduced since the late 1700s have destroyed the native integrity and viability of large portions of Hawaiian mesic forests. These noxious plant species or invasive weeds have had devastating and in many cases irreversible effects in nearly every Hawaiian terrestrial ecosystem (Smith 1984).

Alien plant species in natural areas:

- Serve as food sources for other forest pests such as feral pigs and goats.
- Displace native plants as they colonize disturbed sites (e.g. pig diggings, burned areas, landslides).
- Suppress native forest regeneration mainly through competition for space, light, water and nutrients and sometimes by allelopathic properties.
- Alter light regimes, hydrological cycles, nutrient cycles, landslide and fire frequencies.
- Alter nesting habitats and food resources for native birds.
- Serve as hosts for insect pests and plant diseases.
- Can form monotypic stands susceptible to landslides or heavy surface runoff due to a lack of groundcover vegetation.
- Often cannot be used as host plants by endemic native invertebrates that have evolved to prey on specific native plant species.
- Can be highly toxic or injurious to livestock and humans.

Since even fully intact and remote native forest stands are vulnerable to invasion from noxious weeds such as the Australian tree fern, an integrated animal control, weed management, and revegetation/regeneration program is needed for any successful forest restoration effort. In particular, given the highly fragmented and often alien dominated condition of mesic forests in Hawaii, highly intensive and long-term weed control strategies and tactics are needed to ensure the recovery and viability of those remaining native mesic forest remnants. Much attention and money is often given to the newly established 'Genghis Khan' weeds of Hawaii such as *Miconia calvescens*. However in mesic forests, noxious weeds such as Christmas berry, strawberry guava and molasses grass are already very well-

established. Although the underlying native ecological processes in these invaded mesic stands are in many cases irreversibly altered, with time, money and considerable effort the native structure and ecological functions of mesic forest areas can still be restored.

4.2 WEED CONTROL STRATEGY

This chapter largely focuses on the strategies and tactics to control well-established weed populations. Usually a variety of 'tools' in a manager's tool bag of strategies are needed to effectively combat target weed species. In Hawaii, this usually involves a strategy of:

1) Identifying resource management goals and objectives given the threats and natural resources at stake. This includes setting short-term benchmark goals that contribute to long-range goals and objectives. Winning smaller battles generates the necessary momentum for victory in extended campaigns.
2) Surveying and mapping distributions of selected target weed species
3) Developing an integrated weed management plan for an area
4) Conducting trial and/or full blown control programs using herbicides or other weed control methods to:
a) Control satellite and core populations of targeted weed species
b) Prevent further introductions, new infestations
c) Stop ecosystem disturbance (i.e. ungulate control) and
d) Allow native species to reestablish themselves
5) Monitoring results of control efforts through implementation of a monitoring plan and good record keeping
6) Adapting management strategies accordingly

Much time, money and labor have been wasted in weed control by those who did not carefully identify what goals and objectives they hoped to achieve, in which specific areas, in what time frame, using which control and monitoring methods, and in what priority of action. Priorities for control should be on preventing new infestations, and controlling infestations that are the fastest growing, most disruptive, and affect the most highly valued area(s) of the site (Wittenberg and Cock 2001).

With feral ungulate control as the first phase of restoration, these weed control efforts are often the second phase of restoration efforts, setting the stage for the third phase, the natural regeneration (or if need be planting) of mesic forest components.

4.2.1 PREVENTING WEED ESTABLISHMENT

Four fundamental goals in weed control are to:

(1) Eliminate weed seed sources: Removal of nearby seed sources can significantly reduce weed problems as most seeds fall near parent plants. Removal of large, mature weed trees

which contribute the bulk of seeds to adjacent areas is critical to short term gains and long-term success. Wind, birds, and feral animals do contribute to long distance dispersal, but are largely out of a manager's control. Also, educating and assisting neighboring landowners to eliminate weed sources on their properties is vital to prevent re-invasion (Porteous 1993).

(2) Eliminate potential sites for establishment of weeds. Weeds by their nature are effective colonizers of disturbed sites and open areas. Bare areas vulnerable to weed colonization need to be planted with native species or a temporary cover species in order to exclude more aggressive weeds and eventually achieve forest canopy closure. Regular site monitoring and follow-up management of restoration sites and adjacent areas is necessary for long-term success (Porteous 1993).

(3) Detect and control incipient, habitat modifying weed species. Short of preventing invasion, detecting highly aggressive weed populations early on for control efforts is far more cost-effective than attempting to control and revegetate established stands of weed trees, shrubs or groundcovers. Not all weeds are aggressive and threatening to mesic forests (e.g. orchids). Managers will need to assess which weeds pose the greatest risks to the resources they are managing and act accordingly. Again, a number of invasive weed species are considered invasive because they can establish themselves in even undisturbed intact forest areas (e.g. strawberry guava, Christmas berry, koster's curse, inkberry, Australian tree fern). Vigilance monitoring to detect those incipient invasions is needed on a systematic and regularly scheduled basis to avoid costly large scale weed control efforts in the future.

(4) Prevent invasions by proper quarantine, inspection, and decontamination protocols. For purposes of brevity, this chapter will not review procedures to prevent weed invasions through quarantine, inspection, and decontamination of plant material, field gear and vehicles. However, the same vigilance directed toward detecting incipient invasive infestations should also be directed toward quarantine and sanitation efforts. Numerous examples exist of recreational users or workers in natural areas spreading weeds into new areas because their field gear was not properly decontaminated. In short, think like a weed when analyzing how and where weeds gain entry into natural areas. Trailheads, staging areas, camp sites, helicopter landing zones are all notorious points of entry for weeds.

4.2.2 PREVENTING WEED RE-ESTABLISHMENT AFTER SITE TREATMENT

Former molasses grass slope planted with *Bidens* sp.

Disturbed open spaces are ideal for weed establishment because 'nature abhors a vacuum' as the saying goes. Therefore prompt and consistent follow-up treatment is critical. The re-establishment of weeds can be prevented by:

1) Outplanting or direct seeding fast growing native plants (e.g. *Bidens* sp.) to shade the soil and prevent weeds from germinating. Nursery production schedules need to be coordinated with site treatment operations for this method to be successful.

2) Eliminating the existing weed seed bank by letting the weed seeds germinate in the area for a few weeks, months, or even years and then selectively spot spraying the area over time before revegetating or as regeneration occurs. Re-treating an area before weed species go to seed again is especially important when scheduling site maintenance operations.

3) Using pre-emergent herbicides to prevent broadleaf weeds or grasses from germinating until revegetation or native regeneration can occur. At very small scales, weed block cloth with or without impregnation with herbicides may also be an attractive option. At medium and large scales, aerial broadcasting soil applied pre-emergent and post-emergent herbicides is an approach used by commercial forestry operations in the United States to eliminate weeds before tree planting.

4) Planting a fast growing, non-native (but sterile) cover crop (e.g. rye) until native revegetation occurs. Ideally, native plant species should be used, but a substitute may be needed if stock is not readily available. Farmers commonly employ the cover crop method when taking fields out of production.

5) Proper decontamination of field gear to ensure weed seeds are not brought back into treated areas by field personnel.

It is important to note that:

- Areas that have been heavily infested with weeds will contain weed seeds that are viable for many years. Heavily infested sites must be monitored and treated repeatedly for several years as reinfestation is likely to occur.

- Overclearing, or clearing an area greater than can be dealt with in any one year, should be avoided. Clearings provide another opportunity for the establishment of the weeds removed, as well as any other quick-growing weed species, thus compounding the problem. Some managers have recommended removing no more than 10% of the canopy in one year as a general rule of thumb.

- Large amounts of dead biomass in concentrated areas are also a potential fuel load problem for fire prone areas.

- Ideally, restoration sites will be located primarily in fairly intact native forest areas. In this case, restoration consists of essentially augmenting and assisting native areas and all that is needed is follow-up spot spraying after the incipient weed infestations are removed.

- Not all weeds are bad and need to be eliminated immediately. The benefits of shade and organic matter provided by weeds should not be overlooked. These benefits should be utilized as appropriate for grass suppression, soil fertility, and wildlife habitat.

- In many mesic areas, native birds (e.g. elepaio) have adapted to using introduced species such as strawberry guava as their primary, preferred habitat. Elimination of guava stands would severely impact the elepaio's habitat. A phased weed reduction program coupled with a native canopy and understory planting program is a more appropriate strategy for important wildlife areas.

- Herbicide use should be minimized as much as possible when equal or better control methods are available given the largely unknown effects of herbicides on soil microorganisms and other potential secondary impacts.

4.3 METHODS OF CONTROL

Methods of weed control include:

- Manual or mechanical control (by hand or by using power tools or heavy machinery)
- Chemical control using herbicides
- Controlled grazing
- Controlled burns
- Mulching
- Quarantine and sanitation to prevent weed spread
- Limiting access to prevent unnecessary disturbance from trail clearing, vehicle impacts, camping sites etc.
- Feral animal control to prevent weed dispersal and soil disturbance

- Biological control (using biological agents such as fungi or insects to control targeted weeds)

When selecting a method of control, factors to consider include the:

- ecology or life history strategies of the target weed
- level of infestation
- available resources of labor, time, money
- efficacy of the control method selected
- applicator experience levels
- availability of water for herbicide
- level of risk posed by the weeds of concern to the resources at stake
- accessibility of the site
- weather conditions at a site both diurnally and seasonally
- risks to non-target organisms such as livestock, rare snails, birds, or stream animals

This chapter will focus on the most common weed control methods currently used in Hawaii, namely manual, mechanical, and chemical control. It should be noted that sufficient quarantine and inspection programs are the first (and most cost-effective) line of defense. Stopping noxious plants before they get to Hawaii or another island is critical to preventing further invasions and is an issue that must be continually addressed at county, state and national levels. Also, despite the drawbacks of research costs over time, many experts believe that biocontrols are a legitimate weed control option when all else has failed. A brief discussion on issues related to biocontrol will follow.

4.3.1 MANUAL OR MECHANICAL CONTROL

Hand or weed wrench pulling is an effective method if infestations are relatively low, weeds are easy to pull up, and soil disturbance is acceptable. Soil disturbance commonly causes more seeds to germinate. If depletion of the weed seed bank is desired, soil disturbance may also be desired. Manual weed pulling should be avoided in more fragile soils such as areas with covers of moss and lichen or in areas prone to wind or water erosion. It is important to wait until weeds reach a 'pullable' height to avoid the energy of pulling smaller weeds that may die on their own or break at the base of the stem and allow for re-sprouting. Once the weed is removed, shake the soil from the roots and hang it to die on nearby plant if it is capable of re-rooting itself. Place leaf litter or mulch if available over the bare site to discourage further weed establishment and prevent erosion. Plants should be pulled from the base and often several short tugs are needed to break roots away from surrounding soil. A weed wrench is a useful leverage tool for tap rooted weed trees and shrubs that minimizes soil disturbance and the need for herbicides. The manual removal of weeds ideally should completely remove root systems as a number of weed species readily re-sprout if any portion of the tap root remains in the soil.



Hand and power tools such as hand saws, loppers, machetes and chainsaws are commonly used for more mature, established weeds. For example, Manuka or Australian tea tree will die if cut at the base.

Ring barking or girdling is probably ineffective at killing most weed tree species in Hawaii. This involves removing a complete band of bark from the trunk of a tree. Most trees will simply resprout below the girdle or close the wound over time. The effectiveness of this method may be limited to preventing weed trees from having enough energy to flower and seed. It might also find use in well head protection zones where herbicide use is prohibited.

In certain situations, string trimmers, brush cutters, chainsaws, or other gas powered devices are more efficient in initially topping weed growth and preparing the area for herbicide treatments. For example at Honouliuli Preserve, to control six foot high patches of Clidemia hirta or lantana, staff use light chainsaws and loppers to initially top the weeds to just above ground level. When the lantana or clidemia vigorously resprouts, herbicides (glyphosate or triclopyr ester) are used to control the topped mature plants as well as any new seedlings. It is important to not spray too early or too late when using this 'slash and spray' method. Spraying too early when the leaves are just emerging will not allow the herbicide to translocate downward as plant sugars are primarily moving upward. Spraying too late when the weeds have re-established their energy reserves and seedlings are inaccessible is also inefficient. Plants should be sprayed when new leaf growth is fully mature and energy reserves in the plant remain low.

For more accessible restoration sites, the use of heavy machinery equipment can greatly facilitate wholesale clearing of an infested area or selective treatments by attaching power sprayers to ATVs or tractors. The impacts of heavy equipment will need to be weighed against the labor saving benefits.

4.3.2 CHEMICAL CONTROL, SELECTION, AND APPLICATION GUIDELINES

Chemical control, using herbicides, is often very effective and necessary for weed infestations at various scales. Herbicides, however, must be carefully selected so that they best meet the goals of efficacy, economy, and environmental protection. It should be noted that most herbicides are not highly toxic. For example, glyphosate is considered in a category of being almost non-toxic with household chemicals such as bleach, aspirin, and table salt receiving a higher (moderately toxic) rating level (P. Motooka et al. 2002)

As with all pesticides, users should carefully read and follow product label directions and use the recommended application rates. Also, users should have a plan for herbicide storage, transport, mixing, clean up, and disposing of unused or contaminated material before herbicides are used. (M. Tu et. al. 2001). Particularly important label information includes:

- the required personal protective equipment (known as PPE),
- the environmental hazards,
- the stated uses of the herbicide, application rates, and
- site descriptions of where the product can be safely applied.

It is also the responsibility of herbicide applicators to understand the persistence and mobility of herbicides in the environment in which they are used. Using an extreme example, at the superfund site in Kunia on Oahu, some 200 gallons of a pesticide used for pineapple operations were accidentally spilled. Three decades and millions of dollars in cleanup costs later, the surface and groundwater in the area of the spill is still polluted because the pesticide is extremely persistent and very mobile. In other words, the pesticide has a very long life span and does not readily breakdown or degrade unless exposed to several costly stages of treatment. The standard measure of persistence is the 'half-life' of the herbicide, the time it takes to detoxify half of the herbicide in the environment. It is also still active as a toxin because of its mobility in the soil. It does not adhere (adsorb) to soil particles very well and thus remains able to move further downwards in the earth to reach and contaminate surface and groundwater supplies. In general, non-persistent and immobile herbicides are environmentally safer to use given their lower risk of contaminating drinking water supplies. Temperature, soil composition, and rainfall patterns also affect the degradation and mobility of herbicides in ecosystems (P. Motooka et al. 2002).

Information from two excellent P. Motooka et al. (2002 and 2003) publications is provided in **Box 4A** as well as in **Table 4D**: Common Mesic Forest Weeds and Control Methods. A full citation is given at the end of this chapter for these highly useful publications. Another highly useful and comprehensive weed control handbook is available on-line: Weed Control Methods Handbook: Tools and Techniques for Use In Natural Areas, authored by M. Tu, C. Hurd, & J.M. Randall, 2001. A full citation and internet link is provided at the end of this chapter.

Box 4A: Herbicide Selection and Use

There are a number of important factors that must be considered when selecting an herbicide:

(1) The herbicide formulation must be effective on the target weed, without significantly harming surrounding non-target species.

(2) Removing one weed species (e.g. targeting grass using a grass specific herbicide) may result in its replacement by another broadleaf weed species instead.

(3) When considering cost, the lower-cost herbicide should be used if the herbicides are of equal efficacy. However, the cost per acre, and not the cost per gallon, should be considered.

(4) Herbicide resistance is also another factor in selection. Because over-reliance on a single herbicide formulation may result in resistance over time, rotation of herbicides, as well as overall control methods, may be necessary for long-term weed control.

(5) Herbicide applicators should be adequately trained and equipped for the type of herbicide selected and the application method used.

(6) Surface and groundwater contamination should be prevented by avoiding the use of persistent, soil-mobile herbicides in areas of high rainfall.

As a general standard, make sure herbicides are applied under the following conditions:

- When energy reserves in the weeds are low (e.g. in the spring when leaves are flushing) so they are more susceptible to herbicides as the chemical is more efficiently translocated throughout the plant,
- When there are some fully expanded "soft" leaves which allow better penetration of the foliar herbicide because the cuticle is thin in this stage of growth,
- When the weeds are young, smaller and not woody, thus requiring less herbicide and fewer treatments,
- When it is not raining or windy (or predicted to be in the next few hours), so that herbicide is not washed away after application, spread to non-target species or into nearby streams or ponds.

After herbicides are applied, leave plants in the ground until the roots have died off. Do not re-apply herbicide too soon after initial treatment; wait until the plants begin actively growing again to minimize labor and costs.

4.3.2.1 HERBICIDE APPLICATION TECHNIQUES

For smaller tracts of land, weeds are most commonly treated by foliar spray application, frill treatment, cut-stump method, basal line treatments, or by injection. These latter methods are detailed and illustrated below. For large tracts of land, especially with rough terrain, aerial applications can be more cost efficient. Aerial based methods are briefly described following the 'land-based' methods.

In all situations, be sure to read and closely follow all herbicide label instructions, wear appropriate protective gear, and take all other necessary safety precautions.

Herbicides should be applied according to the recommended rates. Take the necessary time to research application rates if not specifically listed on the product label for the target species.

Common Mistakes:

1) Overdosing: A common mistake is to over apply an herbicide by using too high a concentration and/or too high a volume in an effort to really knock out the target plant. For example, an inexperienced user may want to soak down a target weed with a higher concentration than recommended. The result is a waste of material, unnecessary release of

herbicide into the soil, and ironically poor weed control (Motooka et al. 2002). Systemic herbicides work best when they are fully translocated or moved throughout the plant from young leaf tips to the lowest and furthest roots. For that to occur, the vascular system of the plant must remain intact for some period. Too high a concentration of herbicide can shut down one type of vascular tissue, the phloem too soon (Motooka et al. 2002). The result can be quick defoliation for woody trees but eventual re-sprouting from root suckers at the base of trees or from outlying surface root systems. This was observed at Honouliuli Preserve in one trial plot using a 50% concentration of triclopyr ester product in crop oil applied basally to Christmas berry trees by frill cuts 15 inches in basal diameter. Quick canopy dieoff occurred but twelve months later numerous root suckers were noted. Tens of root suckers now required treatment instead of just the few original mature trees.

2) One time treatments: Another common mistake is to expect the target weeds to be eliminated in one treatment once and for all. Plan instead for a sustained campaign of weed combat consisting of a number of treatments and methods for different stages of plant maturity. For example, large mature trees may need to be treated and re-treated with cut stump, basal or frill applications. Saplings and seedlings may need to be treated with a low-volume foliar spray over time. Sanitation measures may need to be implemented to ensure re-invasion does not occur.

3) Drift killing non-target plants at unacceptable levels: This commonly occurs when attempting to spray herbicide on plants above shoulder level, waiting too long to conduct follow-up treatments, using high pressure equipment, or when conducting aerial spraying operations. Applicators unfamiliar with target species and desired native species may also be responsible for careless herbicide use. One of the first principles of restoration 'do no harm' means that the intended effects of weed control should have net benefits to the restoration site. At one restoration site, hundreds of naturally recruiting koa seedlings were killed in the process of spraying tens of passion vine re-sprouts. This is a situation that could have been avoided by more prompt follow-up of weed growth and by using a lower spray volume.

4) Conducting spray operations without checking weather conditions: Farm workers have been poisoned in the past because wind changes were not anticipated and workers were placed downwind of spray operations. Similarly, applicators in forest settings need to be constantly aware of wind direction and the location of their co-workers, keeping the wind at one's back to minimize contact with spray. Conducting foliar spray operations in high wind situations and when rain is imminent is a waste of labor and an unnecessary release of herbicide into the environment. For some species at higher elevations, herbicide uptake is also very poor during colder, winter months (e.g. ginger).

5) Not using the right herbicide, dosage, and method of application for the task at hand: Volumes of information for determining proper herbicide use can be found on the Internet. Attempts to cut corners and save money can also result in poor weed control. For example, at one restoration area, triclopyr ester was used without the carrier crop oil on large guava trees. Defoliation occurred, but all trees ultimately recovered.

6) Failing to keep good records and analyzing the data: Good record keeping and timely analysis of the data is essential to improving the effectiveness and efficiency of weed control operations. At a minimum, managers should be recording rates of herbicide use, methods used, date and location of area treated, weather conditions, name of applicators, time required for application, and levels of infestations before and after treatment for targeted species.

7) Applying herbicide when the plants are under stress: Drought, extreme heat, frost, fire, and disease are conditions which inhibit herbicide uptake mainly because plants are not transpiring.

4.3.2.2 FOLIAR SPRAY APPLICATION

Molasses grass control, note the lack of long sleeves and Tyvek suit around the waist. A common mistake when applying herbicides is to ignore PPE requirements.

Foliar spraying is the easiest and often the most economical method of applying herbicides. Using this technique, herbicide is sprayed from either a back pack sprayer or other pressure sprayer power equipment. Recent innovations have made possible very-low-volume and ultra-low-volume applications that greatly reduce labor and material costs. References to this 'drizzle method' are cited at the end of this chapter. Some important considerations when using foliar sprays:

1) Avoid drift or overspray to non-target species by being mindful of wind direction, spray volume, droplet size, herbicide volatility, nozzle direction, and applicator fatigue. Also, spraying weeds when they are small and closer to ground level eliminates the need to point the nozzle upward and cause spray drift. Foaming agents can also be added to minimize drift. Particularly valuable non-target plants can be protected with bags or open bottom containers. Attaching a funnel to the nozzle head can also ensure that spray remains directed downward.

2) Marker dye is also very helpful when treating individual plants to prevent double spraying and wasted material.

3) Good coverage of the target plant is essential. Spraying on only one side of the plant will cause injury to that side only. Good canopy coverage can be achieved when using a backpack sprayer by spraying weeds when they are small, walking around the target plant, and using the nozzle and wand to reach distant or covered areas.

4) Climbing vines present problems of drift to desired trees and shrubs underneath. Cut vines at the base or waist height first and then spray when the foliage re-sprouts.

5) Use surfactants (surface-active agents) to aid herbicide performance as recommended by product labels for a particular weed. For example, molasses grass has numerous sticky hairs and in order for herbicides to penetrate the hairs and increase the area of contact by the herbicide to the actual leaf blade surface a surfactant is used. Otherwise, the herbicide would mostly remain as droplets on the hairs of the leaves.

6) Grass specific herbicides such as Fusilade DX® are very useful when the grass is growing amongst native dicot species. However at higher concentrations of herbicide, native sedges will also be affected.

7) Spray volume rates (spray volume per acre) should be kept as low as possible while still maintaining adequate coverage to ensure maximum cost and product efficiency. Proper calibration of equipment is needed.

8) Shoulder pad and waist belt attachments for back pack sprayers are relatively cheap ($30) and well worth the money to avoid applicator fatigue. A list of suppliers is provided at the end of this chapter.

9) At Honouliuli Preserve, back pack pump sprayers designed for fire suppression are used for herbicide operations on cliffs and on rappel. The pump sprayers are far less cumbersome and do not have a venting hole which is a source of leakage. Smaller pump sprays are also used for spot work around rare plant populations.

Molasses grass control to protect endangered *Tetramolopium lepidotum lepidotum* plants.

4.3.2.3 BASAL FRILLING OR NOTCHING TREATMENT

While labor intensive, basal frilling, notching or the 'hack and squirt' method is a very effective method for many large, woody, tree species. Frills or notches are mechanically made to the bark of plant in order to apply the herbicide directly into the sapwood or conductive tissues of the plant. If the plant has active, functioning leaves, the herbicide is then translocated throughout the plant and the plant dies usually over a period of three to twelve months depending on the size of the tree.

With a sharp chisel or axe:

1. First, clear debris, basal suckers, and small branches away from the base of the tree first to give a clear working area for frilling with axes.
2. Make deep, 45 degree cuts into the sapwood at regular intervals around the base of the tree. Cuts must be deep enough to penetrate the vascular tissue underneath the outer bark, but should not extend too far into the non-vascular pith. Forty five degree angle cuts are used to hold the herbicide in, make greater surface contact with the sapwood, and prevent the herbicide from running off onto the soil or other non-target plants.
3. Avoid using slashing machete cuts as this often causes the herbicide to run out of the cuts and usually only a small portion of the slash cut actually penetrates into the sapwood (Motooka et al. 2002).
4. Notches should be made as close as possible to the ground to avoid suckering at the root crown.

5. Be careful not to ring-bark (completely girdle) the plant as this will reduce the uptake of herbicide and the overall effectiveness of this method. Cut frills about 2-4 inches apart (Motooka et al. 2002).
6. Some harder to kill species (e.g. Octopus tree (*Schefflera actinophylla*) require frill cuts completely around the base of the tree. Even a five inch intact area intact and untreated area can sustain a sizable tree with water and nutrients. Herbicides move very well vertically up and down the tree's vascular tissues but move very poorly horizontally, hence the need to notch around the base (Motooka et al. 2002).
7. If a portion of the tree base is unreachable by axe, a small handsaw can also be used to cut into the sapwood. Handsaws are particularly useful for injuring the inside area of the crotch of trees that branch close to the ground when there is little room to swing an axe. A chisel is also useful for this purpose. For some eucalyptus tree species, frill cuts are still effective higher on the trunk. Chainsaws can also be used to expose the cambium on larger trees. Sawdust should be blown out of the cut before herbicide is applied.
8. For multi-stemmed plants, notch below the lowest branch or treat each stem individually.
9. Immediately apply herbicide using a paintbrush, squeeze bottle, or hand-held spray bottle to the frill cut area, making sure the herbicide is applied completely around the base of the tree. Be cautious of backsplash when spraying or squeezing herbicides close to one's face.
10. The amount of herbicide applied varies with the tree or brush species but the general recommended rate is 1 ml per notch (Motooka et al. 2002).

4.3.2.4 CUT-STUMP METHOD

This method is useful for small to medium-sized woody weeds, usually in areas where there is a need to clear standing vegetation. It is often the most effective method of killing woody vegetation (Motooka et al. 2002).

1) Using handsaws or chainsaws, cut the base of the plant as close to the ground as possible. Stumps close to the ground are less likely to cause 'pongee stick' puncture injuries and are less of an eyesore. Straight, flat, horizontal cuts are needed to ensure that the herbicide rests on the cut area while being absorbed.
2) Remove sawdust or debris to present a clean surface before applying herbicide.
3) Apply herbicide immediately to the sapwood of the stump. For smaller plants, use a small squeeze or spray bottle. For larger dicot plants, apply the herbicide around the outer rim of the cut only as the pith of the tree or shrub is non-vascular tissue.

It is essential that the herbicide be applied immediately to the cut because the sap in the sapwood will recede into the stump, drawing down the herbicide with it into the region of the root crown where shoots originate. Waiting even a few minutes allows air into the sapwood and blocks the entry of the herbicide.

Note: this method may not work in high rainfall periods because the sap will quickly ooze out of the stump and keep the herbicide from entering the sapwood.

4.3.2.5 BASAL BARK APPLICATIONS

Basal applications are commonly used for smaller trees or for trees or shrubs with numerous stems. Triclopyr ester herbicide at 20% concentration of product or more is mixed with crop oil and applied to the base or basal area of trees and shrubs. Trees with thin bark or juvenile bark are susceptible to this method. Strawberry guava, gorse, cat's claw, miconia, and albizia trees are killed by basal bark treatments. Large trees with thick, corky barks (such as paperbark, or java plum) cannot be killed by simple basal bark applications.

1) Basal streak applications: Apply herbicide-oil solution as horizontal or vertical streaks around the trunks of trees from ground level to 18-24 inches. At least two streaks on opposite sides of the tree are needed. For example, for strawberry guava trees less than 3 inches in diameter, 24 inch long vertical streaks of 20% triclopyr ester product in crop oil can be applied about 3 inches apart around the trunk. A spray bottle or back pack sprayer with an adjustable nozzle can be used.

2) Basal bark applications: Apply a collar or band of liquid herbicide completely around the base of the target weed or shrub. The width and height of the band will vary with the diameter and sensitivity of the target species, but complete encirclement of the tree is necessary. For example, very low volume treatments of strawberry guava are still very effective. Generally, only a one inch band of triclopyr ester product at 20% concentration in crop oil for 3-5 inch diameter strawberry guava tree is sufficient to kill the tree over a period of 12 months. Avoid runoff of herbicide onto the soil by using controlled amounts and low output equipment. A squeeze bottle can be used for very low volume basal applications. A backpack sprayer can also be used to spray higher along the stems and for hard to reach areas.

4.3.2.6 INJECTION

Tree injection is useful for large shrubs and large trees when felling and removal is difficult or damaging to surrounding vegetation. Injection can also be a faster method of treating large trees instead of basal frilling. Tree injection is also useful for some species that are hard to kill by the frill cut method. Slow changes in canopy light levels are also often far more preferable in order to minimize the opportunity for more aggressive weed species to colonize new, large light gaps. Best results are achieved when plants are actively growing.

1) Drill holes sloping downward into the sapwood at regular intervals around the tree, using a cordless drill, brace and bit, or chainsaw driven auger.
2) Place the correct dose of herbicide into each hole, immediately as it is drilled.
3) If necessary, wait until the liquid subsides then apply the remainder. Follow the manufacturer's recommendations for the correct dosage.

E-Z Ject spring action 'guns' are another method of injection. They deliver pre-measured glyphosate in .22 caliber brass shells. For large, soft bark trees such as White Moho (*Heliocarpus popoyanensis*), the E-Z Ject guns are useful. However, the brass shells remaining in the trunks of trees could pose a hazard to individuals attempting to chainsaw stumps in the future.

4.3.2.6 PRE- AND POST-EMERGENT SOIL APPLIED HERBICIDES

Several pre- and post emergent herbicides are registered for use in Hawaii. A more thorough discussion of the application and effects of these soil applied herbicides is given in the Herbicidal Weed Control Methods for Pastures and Natural Areas of Hawaii publication. A full citation is given at the end of this chapter. These herbicides are applied to the soil and taken up by the roots of the target plants. The products come in granular or pelleted form or as a wettable powder or liquid concentrate. More field trials in forest settings are needed to confirm their effectiveness against the most common mesic forest weed species as well as any secondary effects. The active ingredient and product names are as follows:

Dicamba (Veteran® 10-G [BASF])
Hexazinone (Velpar® and Pronone Power Pellets® [Dupont])
Tebuthiuron (Spike® 20P [Dow Agrosciences])

Dicamba as a granular formulation has not been very effective against Hawaii's woody plants. It is however an excellent foliar herbicide for guava and other species.

Hexazinone is a persistent, mobile, non-selective herbicide that is of low animal toxicity. It is more suitable for smaller hot-spot applications rather than large-scale broadcast applications given its non-selectivity. Used sparingly, it would also pose no threat to groundwater contamination particularly if used in drier areas.

Tebuthiuron is formulated as a broadleaf herbicide that is of low animal toxicity but unlike Hexazinone, is of poor mobility in soils. This makes it a far more environmentally safe herbicide to use. It has been effective against Christmas berry, guava, and lantana although larger plants are probably more tolerant. As with all granular herbicides, applying the proper amounts is important given their high cost and herbicide concentrations per pellet.

Liquid pre-emergents or post-emergent soil applied herbicides are commonly applied in the United States using a spot gun which is also called a gunjet or meter jet spray gun. Measured amounts of herbicide are applied to the soil at the drip line or root area of target weeds with each trigger pull. Hand broadcast applications of granular formulations are done using calibrated fertilizer spreaders.

Field trial results for soil applied herbicides can be found on the internet for various species through the Hawaii Ecosystem at Risk website: www.hear.org. Reference information for P. Motooka's summarized results of herbicide trials is given at the end of this chapter.

4.3.2.7 AERIAL HERBICIDE OPERATIONS

Aerial operations using helicopters are becoming more commonplace in Hawaii for difficult to access areas or for medium to large scale infestations. Boom attachments to helicopters have been in use for forestry and farming operations in the United States for decades. In Hawaii, individual Miconia plants and marijuana patches are controlled using the 'spray

ball' method. In New Zealand variations of the same idea are being used. Herbicide filled containers are slung or carried under the helicopter and herbicide is released via spray roses and electric pumps. A modified 44 gallon drum with an electric pump is one variation that has proven to be very reliable after several years of operation. Another variation uses a pressurized drum instead to release low-volumes of material.

Granular or pelleted soil based herbicides are also aerially applied in the United States using hoppers normally used for applying fertilizers. The hopper is slung under the helicopter and calibrated to release designated amounts per acre.

Other operations involve simply removing the boom attachment from the spray tank and replacing it with a short piece of hose attached to the skid on the pilot's side. A standard adjustable nozzle is used and set to fan or jet spray depending on the operation. A similar setup is also used for spotgun operations. The spotgun is attached to the skid and operated by a hydraulic ram. A remotely operated pivoting nozzle hung below the helicopter is a variation of this spot spraying method.

Placing a rear seated 'gunner' in the helicopter for spot spraying has also been tried in New Zealand. A spotgun is used and the applicator must wait until the helicopter is directly over the target to avoid rotor wash and drift problems. More trials are needed to determine effectiveness of this method for control of small scale infestations.

A 'human sling' method has also been developed and approved by the New Zealand civil aviation agency. Simply a variation of a common rescue method, a person is slung underneath the helicopter to work inaccessible cliff areas.

4.3.3 BIOCONTROL AND ISSUES RELATED TO BIOCONTROL

Hawaii has one of the oldest and most extensive biological programs in the world. Since the early 1900s, over 70 species and one disease organism have been introduced to the islands to combat 21 species of weeds. Of the 70 species, only 11 have successfully eliminated the host weed to the extent that it is no longer a major ecosystem threat. Most of these successes have been in the study of agricultural weeds because their value as a commercial crop attracted substantial funding, and also because their cultivation presented a low risk of threat to non-target, native plants. However, by 1983, a number of weeds found in native ecosystems were enough of a concern to launch a biological control program specifically focused on weeds in Hawaiian forests. With millions of research dollars invested since that time, many resource managers believe that biocontrol may be, in some of the most severe cases, one of the only remaining options for ultimate restoration.

Potential biocontrol projects are selected based on numerous factors including severity of the infestation of the target species, potential for control, value of the species being protected, and risk to non-target species. Some species are more likely biocontrol candidates than others. Miconia, for example, is a good candidate for biocontrol research because all of its relatives in Hawaii are also weeds.

Many experts believe that in some severe cases, biological control should be given serious consideration. Biological control, however, has several drawbacks: 1) it is expensive; 2) implementation may take 10 years or more; 3) chances of success are about 50%; 4) a potential ecological hazard exists when introducing a foreign organism into an ecosystem; 5) it may be difficult to justify, economically, and ecologically; and 6) conflicts of interest can arise between individuals or groups with different views about whether a plant is a problem or not. For these reasons, biological control should be only a part, rather than the overall solution, of the control program for any weed species. Additionally, often several 'tools' or biological organisms are needed to fully control just one species of plant or invertebrate pest with different organisms attacking different life stages of the target species.

4.4 REFERENCES

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Suppliers of Herbicide Equipment:

American Sales and Service
Ben Meadows
Forestry Suppliers
Northern Equipment
Wylie Manufacturing Co.

In Hawaii:

Verdicon/UAP Co.
Gaspro Co.
Most larger garden supply or hardware stores as well as landscaping equipment supply or repair businesses.

Herbicide Suppliers in Hawaii:

BEI Co. (Brewer Environmental Industries)

Verdicon/UAP Co.
City Mill
Home Depot

TABLE 4 A: COMMON MESIC FOREST WEEDS

The following plant list contains some of the most widespread and threatening weeds to mesic forest areas. Table 4 D lists control methods for the most commonly encountered and/or most threatening weeds of mesic forests. For other species, information is readily available on the internet or as a publication. In particular, two sources of information are particularly helpful for determining control methods:

Motooka, P., L. Castro, D. Nelson, G. Nagai, and L. Ching. 2003. Weeds of Hawaii's Pastures and Natural Areas: An Identification and Management Guide. University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources.

And the Hawaii Ecosystem at Risk website: www.hear.org (which also contains control information taken from the P. Motooka et al. publication)

Note that in most cases, repeated treatments will be necessary within a year and over subsequent years for complete control.

Top weed species for mesic forests in Hawaii
* = worst weeds given ability to form dense, monotypic cover in short time periods

Species	Common name	Habit (tree/shrub/grass)
*Angiopteris evecta	*mule's foot fern	fern
*Blechnum appendiculatum	*rasp fern	fern
Christella dentata x parasitica	downy wood fern	fern
*Sphaeropteris cooperi	*Australian tree fern	fern
*Andropogon virginicus	*broomsedge	grass
Bambusa vulgaris	feathery bamboo	grass
*Cortaderia jubata	*jubata grass	grass
*Melinus minutiflora	*molasses grass	grass
Oplismenus hirtellus	basket grass	grass
*Panicum maximum	*guinea grass	grass
Paspalum conjugatum	hilo grass	grass
*Pennisetum clandestinum	*kikuyu grass	grass
Phyllostachys nigra	black bamboo	grass
*Setaria palmifolia	*palm grass	grass
Schizachyrium condensatum	no common name	grass
Arthrostema ciliatum	arthrostema	shrub

Asystasia gangetica	chinese violet	shrub
Bidens pilosa	begger tick, spanish needle	shrub
Buddleia asiatica	butterfly bush	shrub
*Buddleia madagascariensis	*smoke bush	shrub
Triumfetta rhomboidea	bur bush	shrub
Triumfetta semitriloba	sacramento bur	shrub
*Clidemia hirta	*koster's curser	shrub
*Lantana camara	*lantana	shrub
*Leptospermum scoparium	*manuka/tea tree	shrub
Leucaena leucocephalla	koa haole	shrub
*Melastoma candidum	melastoma	shrub
Oxyspora paniculata	oxyspora	shrub
Physalis peruviana	poha	shrub
Pluchea carolinensis	sour bush	shrub
*Rhodomyrtus tomentosa	*downy rose myrtle	shrub
*Ricinus communis	castor bean	shrub
Rivina humilis	coral berry	shrub
Rubus rosifolius	thimbleberry	shrub
Stachytarpheta dichotoma	joee, oi, blue rat tail	shrub
*Tibouchina herbacea	*cane tibouchina	shrub
*Tibouchina urvilleana	*glory bush	shrub
Acacia melanoxylon	blackwood acacia	tree
Acacia confusa	Formosan koa	tree
*Acacia mearnsii	*black wattle	tree
*Ardisia elliptica	*inkberry	tree
*Bocconia frutescens	*bocconia, tree poppy	tree
*Casuarina equisetifolia	ironwood	tree
Cinnamomum burmanii	padang cassia	tree
Citharexylum caudatum	fiddlewood	tree
*Coffea arabica	coffee tree	tree
Eucalyptus sp.	eucalyptus	tree
Ficus microcarpa	Chinese banyan	tree
*Fraxinus uhdei	tropical ash	tree
Grevillia banksii	kahili flower tree	tree
Grevillia robusta	silk oak	tree
*Heliocarpus popayanensis	*white moho	tree
Melia azedarach	chinaberry, pride of india	tree
Melaleuca quinquenervia	paper bark	tree
*Miconia calvescens	*miconia	tree
*Paraserianthes falcataria	molucca albizia	tree
*Montanoa hibiscifolia	Christmas daisy	tree
*Morella faya	faya tree	tree
*Pimenta dioica	all spice	tree
*Psidium cattlelianum	*strawberry guava	tree
*Psidium guajava	yellow guava	tree
*Schefflera actinophylla	*octopus tree	tree
*Schinus terebinthifolius	*Christmas berry	tree
*Spathodea campanulata	African orange tulip	tree

*Syzygium cumini	*java plum	tree
*Syzygium jambos	*rose apple	tree
*Toona ciliata	*Australian toona	tree
*Trema orientalis	gunpowder tree	tree
*Caesalpinia decapetala	*cat's claw	vine
*Coccinia grandis	*ivy gourd	vine
Glycine wightii	tinaroo glycine	vine
Merremia tuberosa	wood rose	vine
Paederia scandens	maile pilau	vine
*Passiflora suberosa	corky passion vine	vine
*Passifora molissima	*banana poka	vine
Passiflora edulis	passion fruit/lilikoi	vine
*Rubus argutus	*blackberry	vine
Ageratina adenophora	maui pamakani	herb
Ageratina riparia	hamakua pamakani	herb
*Erigeron karvinskianus	daisy fleabane	herb
*Hedychium coronarium	*white ginger	herb
*Hedychium flavescens	*yellow ginger	herb
*Hedychium gardenerianum	*kahili ginger	herb

Table 4 B: Product names for commonly used, unrestricted herbicides. Mention of a trademark, company, or proprietary name does not constitute an endorsement, guarantee, or warranty by the author.

Dicamba
Banvel®:amine salt,Clarity®;DGA salt,Veteren® 10 G (BASF)
Vanquish®, DGA Salt (Syngenta)

Fluazifop-p-butyl
Fusilade DX® or Fusilade II®
Note: Fusilade DX® is a selective, grass specific herbicide

Glyphosate
Roundup Original®, Roundup Pro®, Roundup Ultra®, Roundup Ultra Max®, Roundup Pro-Dry®, Rodea® for aquatic and wetland sites, (Monsanto)
Several other new products by Monsanto and other companies are also available. Roundup Pro-Dry® is particularly useful for carrying herbicide into remote areas when water is available at the treatment site.

Hexazinone
Velpar 90W®, 90% wettable powder (DuPont)
Velpar L®, 25% miscible liquid (DuPont)
Pronone Power Pellets®, large pellets for grid applications (Dupont)

Metsulfuron
Escort®, 60% dry flowable (DuPont)
Ally®, 60% dry flowable (DuPont)

Tebuthiuron
Spike® 20P (Dow AgroSciences)

Triclopyr (also recently approved for aquatic uses)
Garlon 3A®, amine salt (Dow AgroSciences)
Garlon 4®, ester (Dow AgroSciences)
Pathfinder II, ester, ready to use (Dow AgroSciences)
Redeem®, amine salt (Dow AgroSciences)
Remedy®, ester (Dow AgroSciences)

For aquatic uses, applicators should read refer to the label for directions and limitations on use.

Table 4C: Mix rates of Roundup Pro® and Fusilade DX® in milliliters and English standard (liquid) measurements for various sized containers.

Roundup Pro® Mix Rates (ml)					
	24 oz	**1 gal**	**3 gal**	**5 gal**	**25 gal**
1%	7	39	118	192	946
2%	14	79	237	384	1892
5%	35	192	567	946	4732
10%	70	385	1134	1893	9464
Turf Mark	2	10	30	50	150
Roundup Pro® Mix Rates (oz)					
		1 gal	**3 gal**	**5 gal**	**25 gal**
2%		2 2/3	8	13	2 qt
5%		6 1/2	19 1/3	1 qt	5 qt
10%		13	38 1/3	2 qt	2 ½ gal
Turf Mark	As needed	1/3	1	1 3/4	5

Fusilade DX® Mix Rates (ml)					
	24 oz	**1 gal**	**3 gal**	**5 gal**	**25 gal**
Fusilade DX®	4.2	22	67	110	550
Surfactant	2.8	15	45	110	375
Turf Mark	2	10	30	50	150

5.0 PROPAGATING NATIVE PLANTS: INTRODUCTION

Growing your own plants for a restoration project is a highly rewarding endeavor. The other method to obtain plant material is through contract growing; hiring a commercial nursery to produce the needed plant material. Most native plants are fairly easy to grow from seeds or cuttings as long as a number of basic propagation methods are followed. This chapter highlights the various facets of nursery operations for restoration purposes. Content for this chapter is largely based on: Native Forest Restoration: A Practical Guide for Landowners (Porteous 1993). It has been adapted for Hawaiian restoration nurseries where appropriate.

5.1 SOURCES OF NATIVE PLANTS

Plant propagules (seeds, seedlings, and cuttings) for outplantings should come from the same local area as the restoration site for the following reasons:

1) **To ensure the maintenance of local gene pools and the use of locally evolved ecotypes.** In other words use species, subspecies, and varieties appropriate to a specific restoration area in order to restore the genetic health of a local community of native species. As an example the coastal ilima (*Sida fallax*) variety is not used in mesic forest restoration at Honoululi Preserve because it is radically different in growth habit. Ilima at Honouliuli Preserve is presumably the same species, but unlike the coastal ilima which grows prostrate to the ground, in the preserve, ilima is a large shrub reaching heights in excess of 12 feet.
2) **To prevent the spread of plant diseases and insect pests.** The use of locally grown plant materials can help prevent the spread of highly destructive fungal, or viral pathogens, as well as insect pests on and between our islands. Koa (*Acacia koa*) wilt disease is spread by contaminated seeds. Ohia (*Metrosideros polymorpha*) rust is now spreading on Oahu and carried on leaves. A presumed papala kepau (*Pisonia umbellefira*) virus killed a number of large, mature trees on Oahu in a few short years. The number of new agricultural pathogens also grows every year. Restorationists should be part of the solution to forest loss, not part of

the problem by inadvertently transmitting plant diseases and insects from place to place.

5.1.1 COLLECTING WILD PLANTS

Plants for restoration are normally obtained by one of three methods: by seeds, cuttings, or seedlings. Collecting seeds and cuttings will be discussed in later sections of this chapter. One method of obtaining seedlings is to collect them directly from the wild. Several mesic tree species produce copious amounts of seedlings below the parent plant. Trails, roads, and fencelines slated for clearing are other areas where seedlings can be taken. If left alone, the majority of those seedlings would not survive due to self-thinning. These dense clusters of seedlings can be 'salvaged' and placed into pots for traditional container growing. Generally, the smaller the seedling is the better the success rate. Material should never be taken from protected areas such as National Parks or Natural Area Reserves.

- Seedlings about 1-5 cm generally have a good rate of transplanting success from the ground to a pot.
- When digging up the seedling it is helpful to make several angled cuts into the soil around the seedling. The goal is to take up as much of the soil surrounding the seedling's roots in order to avoid transplant shock, in other words, the root ball should be left intact as much as possible.
- Seedlings should then be graded into size classes and the seedlings carefully transplanted into prepared and fertilized pots as soon as possible.
- Seedlings should not be left out in the sun, but rather shaded and protected from the wind until the roots have re-established themselves.
- It may also be helpful to trim one-third of the leaves of broad leaf tree species to minimize water loss.
- Since seedlings taken from the wild tend to have weaker root systems, they may take longer to grow to appropriate outplanting sizes. Further, the failure rate for transplanted seedlings upon final outplanting is likely to be higher than nursery grown stock given their weaker root systems. Nonetheless, this method can be used to supplement nursery grown material and is particularly useful for growing trees that are difficult or very slow to germinate.

The following tree species have been successfully outplanted at Honouliuli Preserve using wild seedling stock. Seedlings were collected at 2-5 cm in height and outplanted as 12 inch dibble, ½ gallon, or gallon sized pots. Plant heights at the time of outplanting varied from 5 cm to 50 cm. The majority of the seedlings were grown in field nurseries adjacent to outplanting areas. Survival rates are currently about 70%.

Acacia koa
Psydrax odorata
Pisonia umbellifera
Pisonia brunoniana

Myrsine lanaiensis seedlings will also be attempted soon.

Two smaller, endangered fern species (*Diellia unisora* and *Diellia falcata*) were successfully transplanted by the TNC-Oahu Program from wild sites threatened by landslides. Growing native ferns from spores is difficult and can take years to reach outplanting sizes.

5.1.2 CONTRACT GROWING

Besides growing plants oneself, hiring a grower instead can be just as cost-efficient. Reliable commercial growers will produce a set quantity of plants of a designated size at a known cost. The value of using a contract grower is that they have the facilities and knowledge to produce high quality plant material at a low unit cost. The more plants grown under contract the cheaper each plant will be. Community groups, individuals, or schools with similar plant material needs could consolidate orders to get a better price. Some important considerations regarding contract growing:

- Seed or cutting material should still come from the same local area as the restoration site. Seeds can either be given to the grower or the grower can be told where seeds can be collected.
- Nursery plants need to be properly labeled (species, source populations)
- Seed material must be collected and given to the grower well in advance (oftentimes 9-12 months or longer).
- Plants need to be delivered free of insect pests and other pathogens (including soil mealy bugs and nematodes).
- Plants still need to be hardened off. Plants grown for restoration will be subjected to many environmental extremes (heat, drought, wind storms etc.). Life in the wild is a far cry from the lush, heavily fertilized environments at most ornamental or landscape nurseries.

5.2 CONSTRUCTING A NURSERY

Propagating native plants is a lengthy process, but an integral part of revegetation efforts. One of the first essential steps in this process is constructing a nursery. The main requirements for a small nursery are:

- A convenient location with access to clean water
- A work area for seed sowing and potting.
- A cool, shady, moist area to germinate seeds and grow plants once they have been potted.
- An open, but sheltered area where plants can be placed to harden off before being planted.
- A storage area for pots, media, fertilizer, tools, and insecticide.

The facilities required will naturally depend on the scale of the nursery operation. While smaller numbers of plants can be grown in a domestic garden, larger production efforts require some sort of shade house to germinate seeds and establish small plants once they have been potted.

The area chosen as a nursery area should be sunny, sheltered, flat, and have both easy access and a reliable water supply. The location should preferably have the same rainfall and elevation as one's restoration sites. Although less accessible, nurseries established in the field are an attractive alternative. Field nurseries will be discussed in a Section 5.3.

5.2.1 WORK AREAS


Important work areas to plan for include a garden shed and a workbench. A garden shed is ideal for storing materials such as soil, fertilizers, and plant containers. A flat workbench is useful for sowing seeds, outplanting seedlings, and re-potting plants into larger containers.

5.2.2 SHADE HOUSES

A shade house or shade frame is essential for the germination of seeds and getting plants established 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 can be small or very large. A shade house 15 x 15 ft or larger can easily be made from 'easy up' tent poles and shade cloth. 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. A darker shade house (70% shade) for germinating plants, and a shade house with 50% shade cloth for hardening plants are used by the TNC-Oahu Program. Some growers prefer to keep the ends of their shade houses open (non-enclosed) for maximum air circulation.

5.2.3 HARDENING OFF AREAS

After establishing themselves in their containers plants are then placed out in an area to "harden off." This important stage allows the plant to develop more woody tissue (lignification), deeper and more developed root systems, and thicker leaf cuticles in order to be more robust and ready to withstand the natural conditions of a forest. Higher light levels also help plants reach maturity and reproduction.

Weed control is necessary in the hardening off area and shade houses. This can be done by:

a) Using herbicides to kill existing weeds and then laying polythene sheeting and gravel. The polythene sheeting is laid over the site and a layer of gravel chips less than a half inch thick is spread on that to a depth of about 2 in.

b) Laying a weed control mat. Although more expensive than the above, this strong, woven polypropylene fabric allows water to seep through and air to escape, and is also stabilized against ultra-violet light. Water seepage prevents standing puddles of water (which often occur when sheet plastic films are used), minimizing bacteria, algae, and fungal problems. For best results, the ground should be leveled and covered with gravel before installation.

5.2.4 QUARANTINE AREAS

For larger scale nurseries, a quarantine area can be helpful in isolating pest problems. As new plants are brought in or conversely, being readied for outplanting, they can be placed in the quarantine area to ensure that further contamination does not occur. The quarantine area can be attached to an existing shadehouse as long as some kind of sufficient barrier exists to block the spread of insects and pathogens.

5.2.4 FIELD NURSERIES



Pisonia sp. seedlings on automatic drip tube irrigation

Field nurseries established at the margins of an existing forest remnant or adjacent to restoration sites can provide favorable conditions for the propagation of native plants. At Honouliuli Preserve and at Haleakala National Park, field nurseries produce large amounts of common and endangered plants with minimal upkeep. Automatic timer

irrigation systems 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. Seeds are also started on regular nursery benches. Media can be surrounding forest soil or standard nursery mixes brought in by foot or helicopter. Field nurseries have several benefits despite being less accessible:

- Plants are exposed to the same climate and insect environment as the restoration site where they will be used.
- Travel expenses of bringing plants in by foot or helicopter are greatly reduced if not eliminated.
- There is far less risk of bringing in new insect pests or pathogens to restoration areas.

5.4 PROPAGATION OF NATIVE PLANTS FROM SEEDS

Propagation from seed is the easiest and most commonly used method of propagating native trees and shrubs. It is also preferable to propagating from cuttings, as propagation by seed produces greater genetic diversity. Appendix 5A is an example of a plant production calendar used to ensure adequate nursery plant material is available for planting. For detailed and comprehensive instructions on the collection, handling, and storage of seeds from native Hawaiian plants, please see the excellent on line manual, *Seed Storage Practices for Native Hawaiian Plants* available at: www.hawaii.edu/scb/docs/science/seed/seedmanual.html or through the Hawaii Conservation Alliance website. It was produced by Alvin Yoshinaga of Lyon Arboretum and the University of Hawaii's Center for Conservation, Research and Training. The table of storage properties for specific native plant species continues to be updated. The following considerations are intended to provide a cursory highlight of some of the information contained in the above mentioned seed storage manual.

5.4.1 SEED COLLECTION AND TRANSPORT

Photo by Amy Tsuneyoshi

Seed collection times will vary even within local areas from year to year. From the time of flowering and on, plants intended to be collected from should be closely monitored. Creating a flowering and fruiting calendar for native species in your area is an invaluable

aid to seed collection. Also, make sure all necessary permits to collect that seed are obtained well in advance.

A common problem is the lack of sufficient quantities of seed for larger restoration efforts. Using planter boxes for growing seed stock or row crop farming are two strategies commonly used to generate large quantities of native plant seeds for restoration purposes.

Seeds must be mature and healthy when stored, otherwise their germination rate will be poor, their seedlings will have poor vigor, and their storage life will be short. Collect mature seeds from healthy plants. As with store bought produce, some seeds, if collected immature, can be ripened by storing the fruits in a cool, well-ventilated place. A ripe apple giving off ethylene gas can also be placed with the undeveloped fruits to assist in maturation.

Seed can be stripped or picked off lower branches of trees and shrubs, or collected off the ground. Where seed is prolific and the relevant permission is obtained, small branches can be pruned off for stripping at a later time. Where seed is out of reach, shade cloth sheets can be laid on the ground or suspended above the ground (to deter rodents) during seed fall. If seed is light and easily dispersed by the wind, it is best to collect seed capsules shortly before they open. Seed can also be raked up with forest litter.

In general, procedures for transport of seeds are similar to those for fresh produce. Seeds should not be exposed to high temperatures. Avoid leaving storage containers in the sun or inside closed vehicles. Seeds need to be packed loosely and be well ventilated. For example, if the seeds are kept in plastic bags, the bags should be open to allow air circulation.

5.4.2 SEED CLEANING

Before sowing or storing seed for sowing later, some seeds must be cleaned to remove material such as fleshy fruit and seed husks. The following most common seed cleaning techniques for a number of mesic native trees, shrubs, sedges, and grasses are listed below.

SOAKING: Briefly immersing seeds in water will help to initially sort out the viable and nonviable seeds. Good seeds will generally sink while the nonviable seeds, as well as debris, will float to the top and can be discarded. Species that have fleshy pulp surrounding the seeds should be soaked in clean, cool water from 2-24 hours depending on the species. This technique aids in softening the pulp, making the seeds easier to remove. Fungicide or diluted bleach solution (5 %) may be added to the water to keep seeds viable.

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 more readily strained through cheesecloth to remove excess water in preparation for drying.

DRYING: Once seeds are largely separated from the pulp, they can be dried in a low humidity area or by using silica. Avoid using heat to dry seeds. See the above mentioned seed storage manual for a discussion on drying seeds.

FRICTION: Rub the fruit together to break away husks and separate out the seeds. 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.

SAND: Sterile sand is added to fruit with sticky or very tiny seeds to help separate them and make sowing easier.

5.4.3 SEED TREATMENT

Special treatment of seeds can speed up germination in some species and/or improve the rate of germination in others. There are several main types of seed treatments:

- mechanical scarification
- acid scarification
- heat treatment and
- cold treatment (stratification).

5.4.4.1 MECHANICAL SCARIFICATION

Many seeds have a hard protective coat that prevents the entry of moisture essential for germination. These seeds can be treated by manually cutting the seed coat, soaking the seeds in hot water, or subjecting seeds to a flame, causing their seed coats to crack.

The hard outer seed coat can be broken manually by:

- Nicking the outer coat with a nail clipper (dog nail clippers work best for larger seeds).
- Scraping it with a file or on sandpaper.
- Placing the seeds with other course material such as cinder and shaking the mixture. A motorized rock tumbler might also work for larger seeds.

It is important to not remove the entire seed coat; rather the goal is to simply create a small breach in the seed coat barrier, just enough to allow water in. It is also important to preserve the integrity of the embryo. This can be done by making the cut on the side opposite the embryo. Before the entire batch of seeds is nicked, a few seeds may be cut open to determine the location of the embryo. Note that this technique is most practical for plants with small seed lots as the process is very time consuming.

5.4.4.2 HEAT SCARIFICATION

The easier and more common method of scarification uses hot water, and varies based on the degree of treatment necessary. Some techniques are listed below:

- Heat about 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. Remove boiling water from heat to cool slightly. Pour water over seeds and let sit anywhere from 30 seconds to several days before sowing.
- Briefly immerse the seeds in boiling water for various durations depending on the species, then transfer to cold water. Placing the seeds in a mesh bag makes these treatments easier to do. Experiments can determine the optimum immersion time, thirty seconds is a good time to start with.

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.

5.4.5 LABELING

All seeds need to be properly labeled and identified when stored or transported. Labels may include the following:

- Name of species
- Location seed was collected
- Environmental factors such as rainfall, temperature, range, and elevation
- Number and health of plants collected from
- Date
- Collector's name
- Seed lot number

- Any scarification, drying techniques before storage
- Seed cleaning method including any insecticidal or fungicidal treatments
- Recommended seed storage method

5.4.6 SEED STORAGE

Given the number of issues associated with the storage of native species, readers are referred again to the online manual "Seed Storage Practices for Native Hawaiian Plants" produced by Alvin Yoshinaga.

5.5 SOWING SEED

Seed germinating soil can also 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. Alternatively, mixtures of sand and peat in varying proportions can be used, as well as other materials such as vermiculite for more water retention. Fertilizers containing micronutrients (e.g Apex™ or Micromax™) should 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.

Mycorrhizal inoculated soil from naturally occurring native plant populations can significantly assist plant growth. A website containing instructions for making your own mycorrhizal inoculated soil is give at the end of this chapter.

Seeds should be treated (scarified, soaked, sterilized etc.) prior to sowing. 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.

5.6 SOWING IN CONTAINERS


Containers suitable for sowing seed include: plastic seed trays (available from horticultural suppliers and some nurseries), 1-2" pots, dibble tubes (shown above) and many household plastic containers. These containers should have good drainage, hold the germinating medium, and be easy to handle.

Fill the seed sowing container with soil mix, then smooth and press down the material. Keep seed distribution as even as possible. The use of 1" plug seed flats or dibble tubes are very helpful in keeping seeds separated and assisting with transplanting after initial growth Seed flats (shown above) are useful for seeds with very staggered germination times. Fine seeds should be firmly pressed down into the media to ensure good seed to soil contact. Other seeds are firmed down in a similar manner, then covered with media to their own depth and lightly pressed down. A common mistake is to bury seeds too deeply. Tiny seeds need only be scattered on the top of the soil and gently pressed into the media with a flat surface. Larger seeds should only 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, not direct sunlight to avoid drying out and excessive heat. The seed trays should never be allowed to dry out, but rather 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 cooler, higher 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 a somewhat expensive method. An alternative, cheaper method is to place plexi-glass over the flats and covering the plexi-sheets with newspaper. As soon as germination begins, the covers and newspaper should be removed.

5.7 CONTAINER SOWING USING COMPANION PLANTING TECHNIQUES

Companion planting, or growing plants together in the same container in the nursery, has proven successful for some native Hawaiian plants (Garnett 2003). In fact, certain combinations of species planted together have shown to be more successful when grown together than when grown separately. One such example is *Acacia koa*, when co-planted with *Bidens*.

To do this, sow koa seeds 4 in. deep into a "dibble tube" (SC-10 Super Cell; 1.5 in. diameter, 8 in deep; Stuewe& Sons Inc.), then either transplant a *Bidens* or direct sow their seeds on the substrate surface. As the shrub grows, it binds the container substrate, and after outplanting the koa seeds eventually sprout and establish. In addition, the fast growing *Bidens* provide a seed source on site within a year, which can be allowed to fall and sprout in place, be harvested and scattered on another site, or be harvested and returned to the nursery to propagate more plants (Garnett 2003).

5.8 TRANSPLANTING SEEDLINGS AND LARGER PLANTS

MATERIALS NEEDED FOR TRANSPLANTING:

- Clean pots (for seedlings, 1-2" pots; for bigger plants, one size bigger than pots which plants are already in)
- Moist media (mixture depends on plant)
- sterile cinder to place at the bottom of pots for drainage (optional)
- Plant tags & pencils
- Small digging tools
- Plant trays for organizing & carrying large numbers of small pots
- Liquid fertilizer or transplanting hormone (optional)

5.8.1 WHEN TO TRANSPLANT

For seedlings, transplant after the first 2-4 true leaves appear. For older plants, transplant before the plant outgrows the pot. This can be a subjective judgment, but generally if you check the bottom of the pot and can see roots in the drain holes, the plant is ready to transplant. Ideally, the plant should be transplanted just as roots are reaching the bottom of the pot to avoid root coiling.

5.8.2 MEDIA

Media will depend on the plant species, but generally a well drained media is highly recommended. If available, place washed larger rocks, clean gravel, or sterile cinder at the bottom of pots to prevent soil from leaking out the drain holes and to improve air circulation to the roots. Rocks at the bottom will however make pots heavier and more difficult to transport.

Prepare the soil mixture for your transplants by mixing and wetting the media until all parts are moistened. An equal ratio of perlite, cinder and sterile peat soil is a good general mix. Perlite (also called sponge rock is simply cinder exploded like popcorn by putting it under high pressure). Vermiculite and more peat can be added for plants that like wetter soils.

A balanced fertilizer with micronutrients should also be well mixed into the media. Even distribution of fertilizer is often difficult when mixing large batches of soil. A cement mixer is very helpful for larger batches of transplanting media. Otherwise, mix smaller batches of media (e.g. one wheelbarrow full).

5.8.3 TRANSPLANTING SEEDLINGS

Again, transplant when the first 2-4 true leaves appear. Pick a shaded area to work and have all supplies ready (pots, moist media, digging tools, plant tags etc).

With a small flat tool (Swiss army blade, tongue depressor, chopsticks etc), gently lift seedling out of the media by carefully digging underneath it. Avoiding damaging root hairs as much as possible. If need be lift seedling only by the leaves as the stem is very fragile.

Plant seedlings in 2 or 3 inch pots. Do not place seedlings in too large a pot as the root system is too small to take up that much water and the seedling will rot.

Avoid coiling roots at the bottom of pots. Place a small amount of moist soil at the bottom of pots, and hold seedlings in the middle of the pot. Again, for small seedlings, hold leaves, not the stem. Place soil around roots while holding the seedling up. Bury seedling up to original soil level with moist soil. Perlite can also be placed on top of the soil if damping off is a problem. Damping off is a fungus which attacks seedlings that are in media that remains too wet. Place seedlings back in the shade. Gently rinse any dirt off the leaves.

5.8.4 FERTILIZING SEEDLINGS

If fertilizer was not mixed into the media already at the time of transplating, after about 2-3 weeks after transplanting when roots have ‘reset’ themselves, small amounts of slow release fertilizer with micronutrients can be added as top dressing, but liquid fertilizer is usually best at this stage.

5.8.5 DEALING WITH SEEDLINGS ROOTED TOGETHER

Either gently pull seedlings apart if not too stuck or if seedlings are really rooted together simply pinch one stem to kill one of the seedlings. Pinching stems can also be done in the tray before transplanting to thin weak looking seedlings out.

5.8.6 TRANSPLANTING BIGGER PLANTS

Again, see if roots are beginning to appear by the drain holes. Have transplanting materials ready. Pick pots only one size larger than original pots. For example, plants in 4 in. pots can be transplanted to 1 gallon 6 in. pots. Transplanting into too large a pot (over potting) will not save time as the plant's roots cannot take up all the water in the pot and eventually the roots may rot. Partially drying out the soil in the plants to be transplanted often makes it easier to get the plant out in one mass of soil and roots.

Moisten transplanting media by soaking pots half filled with soil in a full sink or by wetting mixed media in a wheelbarrow. Place some cinder or gravel in the bottom for drainage.

To extract plants from the pots, gently squeeze the sides to loosen soil. Place hand on top of the soil with fingers around the stem. Turn pot over carefully, making sure the top of the plant does not break against any surface. If the plant does not slide out, gently spank the bottom of the pot to free it. Do not pull on the stem to take plants out as this breaks surface roots that do much of the water and nutrient uptake. A chopstick can also be inserted into the drain holes to push plants out from the bottom.

Keeping as much of the root ball intact, place in center of new pot and place soil around plant, reburying it at the original soil level. Burying it too deep will rot the stem. Burying it too shallow will expose surface roots over time.

Top dress with slow release fertilizer or liquid fertilizer to avoid transplant shock for delicate species (these tend to be ferns and other high water demanding herbaceous plants). Placing plants in the shade will also help alleviate transplant shock.

5.8.6.1 DEALING WITH COILED OR MATTED ROOTS

Unless you're transplanting bonsai plants, cutting roots is generally a bad idea as it often does more damage than good. Gently tugging apart roots is fine but remember that uptake of water and nutrients happens by diffusion across very fine root hairs, the ones most easily damaged by handling, resulting in plant "shock". Plants will eventually explore new soil areas given time.

5.8.6.2 DEALING WITH PLANTS STUCK IN THEIR POT OR POTS TOO BIG TO LIFT

Carefully use a sharp knife or scissors to cut the pot and/or break the pot apart to take the plant out. Avoid pulling hard on the stem as it damages the roots. Rolling pots under pressure may also help to free plants.

5.8.7 CONTAINER GROWING

Commercial potting mixes or a mix of ⅓ Sunshine # 4 peat soil, ⅓ cinder, and ⅓ perlite can be used. Slow release fertilizer should also be mixed into the potting mix.

Root trainers pots (a.k.a. book pots) are commonly used for tree and shrub species. They are sheet plastic containers in sets of four or more, hinged along the bottom. The sides are spread apart to lift out the plant for planting. The individual containers have vertical grooves to discourage spiral growth of the root system. The containers fit into a wire basket and are held off the ground, which air prunes roots as they emerge at the bottom of the container. Normally, seeds are directly sown into the root trainers and excess seedlings are pinched off.

Tree pots of various sizes or dibble tubes are commonly used for trees (tree pots are available from Stuewe & Sons Inc.). The vertical grooves similarly train roots down and the large drainage holes at the bottom assist in aeration. Tree pots need to fit into wire mesh racks or crates to keep them upright. Dibble tubes of various sizes are placed intro dibble tube racks. Dibble tubes are also very useful for growing large quantities of 'plugs' for grass species.

5.8.8 PROPAGATING PLANTS IN THE OPEN GROUND

Unlike plants grown in a container, plants grown in the open ground have no restriction on root growth, and when the plants are lifted out of the ground for transport to the planting site, the roots often have little or no soil around them.

Seedlings or cuttings can be transplanted into prepared beds, or alternatively, seed can be sown directly into the beds. Use a rake to cultivate the top 2 inches prior to seed sowing. The seeds can be sown in rows or broadcast over the whole bed. After sowing, moisten the seedbeds and place fifty percent shadecloth over the seedbeds to help retain moisture, increase humidity, and exclude rodents, birds, and cats (Porteous 1993).

Because of nematode problems throughout Hawaiian low-elevation agricultural and urban areas, propagating plants in the open ground is not suitable for restoration sites free of nemotodes. However, The Nature Conservancy-Oahu Program has had some success using planting beds underneath their field nursery tables in order to acquire additional seedling stock and maximize scarce water supplies.

Once the seedlings have germinated, they can be lifted out into containers or planted in restoration sites directly.

5.8.9 PROPAGATION OF NATIVE PLANTS FROM CUTTINGS

Many trees and shrubs can be raised from cuttings. In taking cuttings, note the following:

- Take cuttings from a range of plants to ensure greater genetic variation.
- Always take cuttings from healthy plants.
- Short side shoots should be used rather than rapidly growing terminal shoots.
- Always use a clean, sharp knife or clippers to avoid damage to stems.
- Keep cuttings cool and moist at all times during preparation.
- Keep detailed records of all aspects of the process and results.

5.8.9.1 SOFTWOOD CUTTINGS

Cuttings are a useful propagation method when large quantities of plant stem material is available. Species which naturally root at multiple nodes (e.g. vines) are especially useful. Cutting 'slips' are made by cutting apart material about 9-12 inches long. Cutting material should be treated similarly to cut flowers. As cutting slips are made, they should be placed into a bucket of water to minimize water loss and prevent an air bubble forming at the cut end which prevents water uptake. Lower leaves are stripped or cut off and upper leaves are commonly trimmed to a third of their original size to minimize water loss. Slips can be placed into rooting hormone as needed and placed into prepared flats or containers with at least a 1/3 to a half of the stem inserted into the media. For species with multiple stem nodes, insert at least two nodes below the surface of the media. Because cuttings have no root system, they should be placed in the shade and under an automated misting system to ensure rooting. Full rooting can be determined by gently tugging on stems. The more resistance is felt, the stronger the root system. Any cuttings which do not take (i.e. just rot and not root) need to be removed to prevent fungal contamination of remaining stock.

The root systems of plants generated from cuttings are generally not as healthy and extensive as plants grown from seed. Exceptions include certain vines and grasses grown from split culms. Of course, the longer plants are allowed to grow in containers, the larger their roots masses become.

5.9 NURSERY PEST MANAGEMENT

As with weeds, early detection and quick response is the best approach for effectively controlling nursery pests. A nursery should be inspected at least once a week to determine if new infestations occurred. See **Appendix 5C** for a Phytosanitation and Standards Guidelines adapted from the Makua Implementation Plan for detailed instructions on managing common nursery pests. **Appendix 5D** contains a table of the most commonly used pesticides in nursery operations.

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Appendix 5A: Production Calendar

FYO5-FY06 PRODUCTION SCHEDULE: COMMON NATIVES

			GROWING PERIOD										*PLANTING PERIOD*				
TREES:	**GOAL**	**POT SIZE**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**
ACAKOA	3000	DIBBLES															
PISBRU	1500	DIBBLES															
PISUMB	1000	DIBBLES															
PIPALB	1000	DIBBLES															
LABKAA	200	1/2 G															
UREGLA	50	1/2 G															
CHAOBO	200	1/2 G															
METPOL	200	1/2 G															
POUSAN	72	1 G															
TETOAH	72	1/2 G															
PITGLA	200	1/2 G															
MYRLAN	200	1/2 G															
MYOSAN	72	1/2 G															
PSYHAT	100	1/2 G															
PYSODO	72	1/2 G															

			GROWING PERIOD										*PLANTING PERIOD*				
SHRUBS:	**GOAL**	**POT SIZE**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**
DODVIS	400	BOOK POTS															
HEDTER	150	1/2 G															
DIASAN	400	BOOK POTS															
BIDTOR	400	BOOK POTS															
COPFOL	100	1/2 G															
SIDFAL	160	BOOK POTS															
COVER:	**GOAL**	**POT SIZE**															
PLUZEY	400	BOOK POTS															
CARWAH	400	BOOK POTS															

Appendix 5B: Propagation and Outplanting Information for Common Mesic Native Hawaiian Plants

SCIENTIFIC NAME	HAWN NAME	TYPE	SEED	POT SIZE	NURS PERIOD (mos.)	GERMIN / GROWTH RATE	PRIORITY/ FIELD NURSERY	COMMENTS
CANOPY								
Acacia koa	koa	C	O	1 gallon tall Dibble tubes 4 inch	9 5 5	fast/fast	high/YES	Sow seeds in book pots after hot water soak, re-sow non-germinatiors. Harden off to stimulate phyllodes. Responds well to fertilizer and/or mychorrhizal innoculated soil. More info available at ttp://pdcs.ctahr.hawaii.edu:591/hawnprop/
Charpentiera obovata	papala	C/U		1/2 gallon tall	9	moderate/fast	high/YES	Moderate, staggered, germination rates (up to 4 months) for older stored seed. Fresh seed germinates in 3-4 weeks after overnight soak. Rapid growth after 6 inches high. Recommend continued outplanting 1/2 gallon. Smaller plants susceptible to lethal predation from native borer bug: Mapsidius charpenterii.
Dodonaea viscosa	aalii	C/U		Book pots 4 inch	9	fast / fast	high/YES	Quick germination if hot water soaked. Sow directly in book pots given tap root. Pest resistant, but prone to powdery mildew, scales. Tolerates light shade to full sun. Spray with fungicide to reduce mildew, but only after they are established in 4 inch pot. Field stock is better for seed collecting. More info available at http://pdcs.ctahr.hawaii.edu:591/hawnprop/
Metrosideros polymorpha	ohia	C	O	1 gallon tall	12	slow/slow	high/YES	Slow germination (2 mos.). Sow directly in dibble tubes and pinch weaklings. Prone to aphids and root mealy bugs. Shade to full sun. Fertilizer will significantly increase growth rates. Recommend outplanting at 1 gallon tall boy for maximum survival. More info available at http://pdcs.ctahr.hawaii.edu:591/hawnprop/
Myrsine lanaiensis *M. lessertiana*	kolea	C	R	1 gallon tall	11	slow/slow	med/YES	Slow germination. Shade to full sun. Slow growing in nursery, faster once outplanted. Recommend outplanting at 1 gallon tall for maximum survival.
Pisonia brunoniana *P. umbellifera*	papala kepau	C		1/2 gallon Book pots	9 5	fast/fast	high/YES	Quick germination if seeds excised from "fruit" or ends snipped. Sow directly in dibble tubes or book pots. Seeds will rot if heavily watered. Shade to partial sun. Prone to aphids and root mealy bugs. Grows slowly in wild. Recommend outplanting at 1/2 gallon or book pots in very large numbers.
Pittosporum glabrum	hoawa	C		1/2 gallon short	16	slow/fast	med/YES	Research needed on breaking dormancy of seeds. Can be 12 months before germination and then all at once. Plants tolerate drying down of soil in pots, fairly pest resistant. Rapid growth once planted in ground.
Pouteria sandwicensis	alaa	C		1/2 gallon short	12	moderate/slow	low	Seeds prone to rotting if heavily watered. Slow growing seedlings, faster after 6 inches. Staggered germination, sow in large quantities for sufficient plant material.
Psychotia hathewayi	kopiko	C		1/2 gallon short	12	moderate/slow	med/YES	Germination in about 3-4 months, seedlings grow very slowly at first. Fairly pest resistant. Does not like heavy watering.
Psydrax odorata	alahee	C		1/2 gallon short	12	slow/slow	low	Easier to collect seedlings below garden trees than attempting to germinate from seed. Fairly pest resistant. Suitable more for dry-mesic forest areas
Sapindus oahuensis	lonomea	C		1 gallon tall	12	moderate/slow	low	Faster germination if you remove exocarp (see Koebele / Culliney book). Very sensitive to brown mites. Low priority given slow growth and sensitivity of nursery grown trees to water stress. Recommend outplanting at 1 gallon tall boy size. More info available at http://pdcs.ctahr.hawaii.edu:591/hawnprop/
Tetraplasandra oahuensis	ohe mauka	C		1/2 gallon short	12	moderate/slow	low	Viable seed will germinate in large numbers. Fairly pest resistent. Seeds may require dormancy period for germination characteristic of Araliaceae species.

O=orthodox, R=recalcitrant

Appendix 5B: Propagation and Outplanting Information for Common Mesic Native Hawaiian Plants

SCIENTIFIC NAME	HAWN NAME	TYPE	SEED	POT SIZE	NURS PERIOD (mos.)	GERMIN / GROWTH RATE	PRIORITY/ FIELD NURSERY	COMMENTS
UNDERSTORY								
Bidens torta	kookoolau	U	O	book pots 4 inch	6 6	fast/fast	high/YES	Rapid germination (1 mo.), growth, maturation (12 mos. for seed set), and tolerance for range of environmental conditions (light shade - sun) make kookoolau one of the best understory restoration species. Does not tolerate heavy shade. Recommend direct seeding in the field when large numbers of fruit are available as well as in book pots. Outplant at book pot or 4 inch size.
Chenopodium oahuense	aweoweo	U		Dibbles 4 inch	4	fast / fast	low	Sow directly in book pots or 4 inch pots. Low priority for current mesic / wet restoration sites (because it is a dry forest / shrubland species). Recommend direct sowing in full sun, erosion prone areas for quick cover.
Cyanea angustifolia	haha	U		1/2 gallon	12?	fast/slower	low	Quick germination, but slow growth at seedling stage. Sow directly in dibbles or book pots. Faster growth after outplanting. Experiment with adding native myco soil for speed. De-seed fruit in a solution of 1/150 bleach and water, which helps seeds sink to the bottom of the container (otherwise seeds may float on surface due to water tension and be difficult to separate from pulp. Both nursery stock or field stock is good for collecting seeds. Once common understory species, low priority for propagation given pest problems.
Hedyotis terminalis	manono	U	O	1/2 gallon short Book pot	12 9	moderate/fast	high/YES	Moderate germination (1 month) if fruits soaked in water overnight. Sow directly in dibble tubes and pinch weaklings. Prone to aphids and root mealy bugs. Tolerates shade to full sun. Does not like heavy watering. Recommend outplanting at 1/2 gallon short boy or book pots.
Urera glabra	opuhe	U		1/2 gallon short	12	moderate/slow	low	Dioecious plant, not all seeds viable. Specialty species used for host plant for ground snails. Experiment with cuttings for faster propagation.

Appendix 5B: Propagation and Outplanting Information for Common Mesic Native Hawaiian Plants

SCIENTIFIC NAME	HAWN NAME	TYPE	SEED	POT SIZE	NURS PERIOD (mos.)	GERMIN / GROWTH RATE	PRIORITY/ FIELD NURSERY	COMMENTS
GROUNDCOVERS								
Alyxia oliviformis	maile	G	R	1 gallon tall	15	slow/slow	low	Take creamy pulp off seed, wash, and dry for 2-3 days. Soak overnight and plant; germinate in usually less than 2 weeks, but are slow growers. Field stock better for seed collection. Long, infrequent, germination times (6 mos.) and slow growth make maile an ineffective restoration groundcover although a common understory plant in wet-mesic areas. Recommend direct seeding in the field when large numbers of fruit are available as well as in book pots. Outplant at book pot or 4 inch size. More info available at http://pdcs.ctahr.hawaii.edu:591/hawnprop/
Carex wahuensis	ncn	G		book pots 4 inch	6 6	moderate/fast	high	Sow seeds in book pots after hot water soak, re-sow non-germinatiors. Can take up to 8 months to germinate, but they usually come up all at once. Hearty and very functional for controlling erosion on slopes with its fibrous root system and its one of the few understory / fullsun ground covers. Produces more seeds planted in the ground vs. in pots.
Plumbago zeylanica	iliee	G		book pots 4 inch	5	moderate/fast	low	Easiest from cuttings, although plants should have fully developed root system before outplanting. Pest resistant. Suitable for cover in dry-mesic shaded to sunny areas. Plant in clusters in large quantities otherwise years before it dominates as aggressive groundcover.
Rumex albescens	huahuako	G		Dibbles Book pots	4	fast/fast	high/YES	Very fast growth re-sow over non-germinators in book pots or directly in short boys. Tolerates pots over long periods. Needs full root system before outplanting. Suitable for cliff areas and landslides. Direct sowing on site recommended.

O=orthodox, R=recalcitrant

Appendix 5C: Phytosanitation Standards and Guidelines

The objective of this document is to state the level of sanitation that will be required during ex-situ operations. Sanitation is a key factor in reintroduction/ augmentation by preventing the introduction of foreign organisms into the wild. All plants to be used in reintroduction/ augmentation projects in this plan will be rigorously checked for compliance with the requirements described in the narrative below:

REQUIREMENTS

1. Nursery Certification by Department of Agriculture (Plant Quarantine Branch)
The Department of Agriculture (DOA) developed this certification process for plant growers in Hawai‘i that want to export their goods out of state. The nursery certification encompasses various aspects of plant production ranging from general sanitation, to standards of nursery conditions, to pest control. Complying with the certification requirements will require the facilities and equipment to provide clean plants and the absence of nematodes in all plant pots. Examples of the minimal Department of Agriculture certification requirements as of 1999 are as follows. Plants or plant parts used must be:

1. Propagated from clean (nematode- and virus-free) seed or from cuttings taken at least 12 inches above the ground.
2. Planted in suitable material prepared or treated to assure freedom from burrowing nematodes.
3. Grown in sterilized pots, containers or beds.
4. Placed on sterilized benches or sterilized supports which are at least 18 inches above ground or floor level.
5. Protected from contamination until delivery.

2. Nursery/ Growing area

- The nursery ground must be free from weeds, live roots and other plant material. The floor shall be paved, or covered with coarse gravel to insure that no dirt areas are exposed. The walkways must be paved with concrete, black top or gravel.
- A six feet buffer zone around the growing area must be free from any vegetation.
- The plants must be grown in an enclosed area to prevent weed seeds from blowing into pots.
- Plants and aerial roots shall not be grown lower than 18 inches from the ground level to top of benches.
- Water hoses must be kept off the ground.
- No plants are to be placed over the propagative stock (hanging containers or secondary benches), nor under the benches to prevent contamination to plant material.

3. Media

- The grower must use media that is free from weeds, weed seeds, pathogens and pests.
- Media must be stored on a concrete slab in an enclosed area (e.g. in bins that are covered, or warehouse)

4. General Sanitation

- The grower must sterilize tools regularly.
- The grower must keep growing area, benches, and work surfaces free from threats (eg. Weeds, nematodes, pathogens…).
- The workers shall also maintain the same requirements of cleanliness.
- Benches and plant boxes, used pots, flats and implements must be washed free from soil.
- All dead, diseased or infected material in or around the pots should be appropriately disposed of on a daily basis.
- Dead, diseased or decaying plant material should be pruned off with sterilized tools (and re-sterilized between cuts) to prevent further contamination (e.g. flaming tools).
- Adequate spacing between plants is necessary in order to have good air circulation between and around the plants to prevent pest problems.
- Propagules must be free from threats (e.g. pathogens, nematodes etc.). Use appropriate methods to clean seeds (e.g. fungicides or dilute bleach solution).

5. Threat Control program

*PLEASE NOTE: 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, please contact the State of Hawaii, Department of Agriculture Pesticide Division for further information.

- It should be noted that if restricted pesticides are used, the applicator must be a certified pesticide applicator.
- The grower must have a monitoring and spraying program for each threat category.
- A copy of all the monitoring and spraying schedules, plant species treated, threat/pest treated, last time sprayed, and chemicals used should be kept in a log book.
- See the Threat Monitoring and Control appendix for more information on specific threats.
    - Look for signs and symptoms.
    - Identify the target pests (make sure it is a pest and not a beneficial insect).
    - Monitor for pests presence and their levels of abundance.
    - Know their life cycle.
    - Monitor on a weekly basis.
    - Contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

QUARANTINE FACILITY

In order for a facility to be used as a quarantine facility, it must meet the requirements stated in the sanitation guidelines above as well as the following requirements:

- The quarantine facility must have insect screening on all walls and roof of the greenhouse.
- A daily walk-through of the facility is required to inspect the quarantined plants for possible threat problems.
- Inspection of plant material will be done prior to outplanting by a qualified inspector.
- Length of time in quarantine: At least two weeks, three weeks if the plants show susceptibility particularly to disease (Note: at least 10 days is required to detect insects, 3 weeks to detect fungal diseases).

TRANSPORTATION

- Use a vehicle free from threats (e.g. arthropods, mollusks, pathogens etc.) to transport plants. The storage area of the vehicle shall be enclosed to protect the plants from wind damage and potential threat problems.

OUTPLANTING

- For outplanting guidelines, refer to HRPRG guidelines, and follow Alien Species Protocols.
- Clothes, gear, tools, and other planting equipment should be free from foreign substances.
- Use on site mulch if needed instead of bringing in to site.

Phytosanitation Checklist

- ☐ Nursery facility walkways covered with coarse gravel or paved with good drainage
- ☐ Plastic/Metal Benches at least 18" above ground
- ☐ No vegetation within six feet of growing area
- ☐ Growing area, walls and roof, must be enclosed
- ☐ Insect screening used over vents (if applicable)
- ☐ Adequate storage for media (concrete/paved floor and enclosed on all sides)
- ☐ Adequate mixing and pouring and storage areas for pesticides
- ☐ No plants over or under growing area
- ☐ Water hoses kept off ground
- ☐ Adequate facility for washing and disinfecting pots
- ☐ Regular inspections by greenhouse staff

Equipment

- ☐ Use of sterilized tools and benches, disinfected pots and trays (if reused), and DOA-approved media.
- ☐ Use of yellow and blue sticky traps to detect infestations early
- ☐ Clean transportation vehicle to pick up and drop plants at other sites
- ☐ Be prepared to detect and control pests, and have proper equipment and training available to conduct daily inspections (e.g. magnifying glass)
- ☐ Adequate chemical application equipment and Personal Protective Equipment

Chemical

- ☐ Compliance with State D.O.A. regulation regarding use of all pesticides
- ☐ Completion of State Restricted Use Pesticide Applicator Certification
- ☐ Prepared to apply broad and narrow spectrum fungicides, herbicides and insecticides for prevention and control
- ☐ Prepared to spray greenhouse disinfectant (Contact DOA for a list of approved chemicals)
- ☐ Must be prepared to provide a spray schedule and history

Cultural

- ☐ Benches cleaned when rotating crops at least every other month
- ☐ Appropriate watering schedule to prevent pests (i.e. not too wet)
- ☐ Watering/irrigation done to prevent splash-over into adjacent pots
- ☐ Dying/dead material removed daily
- ☐ Plants spaced on benches to allow for adequate air movement and drying
- ☐ Propagules inspected and cleaned before planting
- ☐ Workers wearing clean clothing and shoes

Threat Monitoring and Control

This reference is provided for the nursery grower to help identify threats, their signs and symptoms and suggested methods for their control. This is just a general summary of threats, for more information contact your local agriculture extension agent, university professor, or Department of Agriculture personnel.

1. Arthropod Monitoring and Control

- Look for signs and symptoms.
- Identify the target pests (make sure it is a pest and not a beneficial insect).
- Monitor for pests presence and their levels of abundance.
- Know their life cycle.
- Monitor on a weekly basis.
- Contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

a) **Ants**:

- DESCRIPTION: There are many types of ants that affect plants in the nursery as well as in the wild. If needed, collect a specimen and have it properly identified by someone from the Department of Agriculture, University of Hawaii Department of entomology, or any other qualified agency.
- SIGNS AND SYMPTOMS: Ants are usually found on plants that have scale, mealy bug or any other insect that produces honeydew. The ants farm these insects for the honeydew they produce. They can be seen crawling all over the plant and/or pot. "Tunnels" built by ants that are made out of potting media from the pot can be found on the stems protecting insects that produce honeydew.
- CONTROL: There are two distinct types of ants to control. One type is sugar loving and the other prefers an oil-based food. Bait for ants at first sign of presence. If population increases, find and destroy the nest.

b) **Aphids**:

- DESCRIPTION: There are many types of aphids that attack plants; however, all of them are soft-bodied and have piercing sucking mouthparts. Their bodies are pear-shaped and can range in colors from yellow to green to black. Aphids secrete a sweet, sticky substance, which is called honeydew. Ants farm aphids for a constant source of honeydew, which is the ant's source of food. The females bear live young. If needed,

collect a specimen and have it properly identified by someone from the Department of Agriculture, University of Hawaii Department of entomology, or any other qualified agency. Once they reproduce, they can have many generations a year.

- SIGNS AND SYMPTOMS: When aphids are present on the plant, pale yellow spots are visible on the foliage. Also, leaves may be curled, puckered or stunted. Presence of sticky honeydew is also a good indicator of aphids. Sooty mold may be visible growing on the honeydew. Check under leaves and at growing points for aphid infestation.
- CONTROL: Be aware that there are several beneficial insects that prey on aphids. If population numbers increase, spray insecticide as directed on the chemical label. Just a note: aphids are usually attracted to plants over-fertilized with nitrogen.

c) **Beetles**:

- DESCRIPTION: Beetles range in size, shape and color; however all have hard bodies and wings (Ball, 1990). They have chewing mouthparts.
- SIGNS AND SYMPTOMS: Check for chewed up plant parts such as leaves and flowers. If left unattended, the beetle can totally denude the plant.
- CONTROL: Manually pick beetles from the plant by hand. Remove leaf litter around the plant to eliminate suitable habitat.

d) **Black Twig Borer**:

- DESCRIPTION: Adult females are twice a big as the males at about 1/16 inch long and are shiny black in color. The males are reddish-brown in color and can't fly. The entire life cycle can take about a month to complete (Tenbrink, 1994). They have chewing mouthparts.
- SIGNS AND SYMPTOMS: Stems become weakened and breakage often occurs. Look for small round holes. The twig borers will create holes in the branches and create a living area. Die back of the plant is not caused by the borers feeding on the plant. Instead, it is caused by the physical infestation and the introduction of pathogens (Tenbrink, 1994).
- CONTROL: Remove and destroy infested parts. There may be some biological control insects, but more information is needed. Not too much is known about control methods.

e) **(True) Bugs**:

- DESCRIPTION: True bugs range in body shape, size and color. Typically, the body is shield shaped and about 1/6-1/2 in long (Ball, 1990). When smashed, they often exude a distinct odor. They have piercing-sucking mouthparts.
- SIGNS AND SYMPTOMS: The infested plant may have disfigured growth such as discolored spots, stunted growth, or wilted shoot tips (Ball, 1990).
- CONTROL: If infestation is low, hand pick the insects. Clean the area surrounding the plant of leaf litter to decrease suitable habitat.

f) **Cutworms**:

- DESCRIPTION: Cutworms are soft-bodied caterpillars that are dull gray or brown in color, and are 1 to 2 inches in length. They are nocturnal feeders that find refuge in the

soil or leaf litter during the day. As adults, they change into moths. The females lay the eggs in the soil, and they can produce an average of 5 generations a year. (Ball, 1990).

- SIGNS AND SYPTOMS: If seedlings are mowed down or chomped down near the soil line, that's a good indicator of cutworm damage. Some cutworms also attack the seedlings from below the soil line, damaging the roots and causing the plants to wilt. (Ball, 1990).
- CONTROL: Put up biological, chemical or physical barriers around the seedlings to deter the cutworms. There may be some beneficial biological control.

g) **Leafhoppers**:

- DESCRIPTION: Leafhoppers have wedge-shaped bodies that are 1/8-1/4in long. They have a hunched look to them since their folded wings are slightly protruding from their bodies. (Ball, 1990 and Kessing, 1993). They range in colors from green, brown or yellow. They are not very active, however, when disturbed, they can jump suddenly or move sideways with agility. They have piercing-sucking mouthparts and can spread virus (Ball, 1990).
- SIGNS AND SYMPTOMS: They feed on all part of the plant (except the roots). As they feed, toxins are released into the plant causing yellowing or discoloration. Leaves will turn yellow and fall off. Leafhoppers excrete honeydew, so ants and sooty mold may be present. (Ball, 1990)
- CONTROL: There may be some beneficial biological control (eg. Mymarid wasp) (Kessing, 1993). Keep area around plants clear of leaf litter and weeds.

h) **Mealy bugs**:

- DESCRIPTION: Mealy bugs have piercing-sucking mouthparts, and can attack either the foliage or the root system, depending on the species. They are mobile throughout their lifecycle. Depending of the species, males are relatively short-lived, living an average of 27 days, while the females can live around 115 days (Martin, 1992). Their bodies are covered with a white waxy substance that gives it a "mealy" look (Tenbrink, 1993).
- SIGNS AND SYMPTOMS: Leaves will look droopy and the areas they feed on will be yellow and discolored. They excrete honeydew, which can cover portions of the plant. Look for sooty mold, which grows on honeydew. If ants are present, that's a good indicator that mealy bugs are there. They can be vectors of pathogens.
- CONTROL: There may be some beneficial biological control (eg. Parasitic wasps). Mixing white oil with the chemical will aid in smothering the scale.

i) Scale:

- DESCRIPTION: Scales are related to mealy bugs and aphids, and have bodies that range from 1/12 inch to 1/5 inch (Ball, 1990). Most scales are only mobile during the first stage of their lifecycle. Usually, after their first instar, the female scales become immobile attaching themselves to the plant and form a protective coat. This protective coat can vary from cottony white masses to waxy shells. Males, if present, are not able to feed since they don't have mouthparts. The females either lay eggs or bear live

young under the protective scale (Mau, 1992). Several generations can be produced per year. (Ball, 1990)

- SIGNS AND SYMPTOMS: Areas where they are feeding on will turn yellow and may drop. They excrete honeydew can cover portions of the plant. Look for sooty mold, which grows on honeydew. If ants are present, that's a good indicator that scales are there. They can be vectors of pathogens.
- CONTROL: There may be some beneficial biological control (e.g. Parasitic wasps). Spraying the scale during their mobile stage is the most effective chemical practice. The dead scales are persistent on the plant, so check the scale population prior to spraying (it may just be dead scale shells). Just a note: Over use of nitrogen fertilizer can encourage growth of scale attracted to succulent new growth.

j) Spider mites:

- DESCRIPTION: Spider mites are extremely tiny. Adult females, which are larger than the males, are not any bigger than 1/20 inch (UCDANR, 1995). They have piercing-sucking mouthparts that they use to feed on the underside of leaves and flowers. As they feed, toxins are injected into the plant that result in distorted growth and discoloration of the plant. New generations can be produced as quickly as 2 weeks if the conditions are right (Ball, 1990).
- SIGNS AND SYMPTOMS: Check the underside of leaves and on flowers for webbing and tiny excrement pellets as this will indicate the presence of spider mites. Also, if the foliage begins to turn yellow and develop a dry, sandpapery texture, or become distorted in growth that is a good indicator of spider mites. To check whether the spider mites are still on the plant, use a handlens and examine the underside of leaves. Tap the branch tip or leaves while holding a white paper underneath to catch the spider mites. (Ball, 1990; UCDANR, 1995)
- CONTROL: There may be some beneficial biological control (eg. Parasitic mites and ladybird beetles). Spider mites thrive in hot, dry, dusty conditions. The warmer the conditions, the faster they reproduce. Make sure the plants have adequate water because when plants are water-stressed, they are more susceptible to spider mite damage. Be aware that some chemicals such as carbaryl and pyrethroids can actually increase spider mite production (UCDANR, 1995).

k) Thrips:

- DESCRIPTION: The adult thrips are winged and are less than 1/25 inch long. They are shiny and usually black or yellow in color. They can have around 8 generations per year. They have a rasping mouthpart. They thrive in dry environments so make sure the plants are adequately misted and watered. (Ball, 1990)
- SIGNS AND SYMPTOMS: Check the new growing tips or buds for thrips. If the leaves are curled, or if tiny, black excrement on the leaves is visible, that's good indicator that thrips are present. Also, if there is dried tissue on the leaves, or discoloration or disfiguration of the leaves or flowers, that can be another indication of thrips. (Ball, 1990 and UCDANR, 1996).
- CONTROL: There may be some beneficial biological control (eg. Predatory mites). Prune affected flowers and foliage, and dispose of properly. Use sticky traps to

monitor. Keep plants adequately watered, and do not let it become water-stressed. (Ball, 1990 and UCDANR, 1996).

l) Whitefly:

- DESCRIPTION: Whiteflies are white, tiny moth-like four-winged insects with piercing-sucking mouthparts. The immature whiteflies resemble aphids, however they are legless and not very mobile once they start feeding.(Ball, 1990 and Flint, 1995). They produce many generations per year, sometimes one generation in less than three weeks depending on the temperature. They thrive in warmer climates. (Flint, 1995)
- SIGNS AND SYMPTOMS: Check the underside of the leaves for whiteflies. If present, the leaves will prematurely turn yellow and then fall off. The plant growth will also be stunted. Whiteflies produce honeydew, so check for presence of sooty mold or ants.
- CONTROL: There may be some beneficial biological control (eg. Parasitic wasp). Use sticky traps to monitor the whitefly population on a weekly basis in conjunction with a weekly foliage inspection. (Flint, 1995). Horticultural soaps and other insecticides can be effective in controlling the population. "Try to time treatments when your monitoring results indicate that most of the population is in the first, second, or third instar stage." (Flint, 1995). When spraying, make sure there is good coverage of insecticides to the underside of the leaves.

2. Weed Monitoring and Control

- Any plant in the pot other than the designated plant is considered a weed.
- Monitor on a weekly basis.
- Install weed mat in and around the growing area.
- Have a buffer area around the growing area/nursery of at least 6 feet
- Enclose growing area to prevent weed seeds from blowing in to pots.
- Pull weeds from pots and growing area as they come up. Do not let them go to seed.
- If weed problem gets out of hand, apply herbicide.
- Contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

3. Nematode Monitoring and Control

- Look for signs and symptoms.
- Identify the target pests (make sure it is a nematode).
- Know their life cycle.
- Monitor on a weekly basis.
- Due to the fact that there are many different nematodes, contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

  - DESCRIPTION: Nematodes are tiny, microscopic, worm-like organisms that are usually translucent with a white hue, and have bodies that are covered by a tough cuticle. (Ball, 1990).
  - SIGNS AND SYMPTOMS: In general, plants affected by nematodes look unhealthy or stunted. It is difficult to identify nematode damage, but with root-knot nematodes can you see the actual damage, which are galls on the roots. Look for plants that look sickly

for no apparent reason. Chlorotic leaves or yellow patches on the plant, wilting, and stunting are the main symptoms to look out for. For a positive identification, a dissection of the root is necessary. If there is nematodes present, the roots will be reduced and have galls. (Holtsmann and McSorley, 1993 and Ferreira and Boley, 1991).

- CONTROL: There are a few cultural control steps that can be implemented to prevent the spread of nematodes. Have good sanitation practices like removing and destroying infected parts or plants from the growing area and disposing of them properly. Do not dispose of in the compost piles. There are some nematocides that are no longer recommended for control. It would be best to contact DOA, or a UH Agriculture specialist to check on the species of nematodes, and chemicals to use for controlling nematodes.
- MONITORING: To check for root knot nematode: take soil from suspected area and plant susceptible crop like cucumbers, after first true leaves appear, pull seedlings up and carefully wash soil off soil to see if nematode galls are on roots. Another test uses radishes. After 6 days check radish seedlings for galls.

4. Mollusk Monitoring and Control

- Look for signs and symptoms.
- Identify the target pests (make sure it is a pest and not a beneficial insect).
- Monitor for pests presence and their levels of abundance.
- Know their life cycle
- Monitor on a daily basis, usually early morning is best.
- Contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

a) Slug

- DESCRIPTION: Slugs are terrestrial mollusks that do not have shells. They have slimy bodies are usually 1 to 2 inches (some can even reach 8 inches) long and travels on a foot that leaves a trail of slime behind. The colors range from white, yellow to black. They have a rasping mouthpiece. The eggs are in translucent-white, individual sacs, which form a cluster, and is usually found in a dark, cool, moist areas or underground. Slugs can produce about 6 generations per year and they take about a year to mature. (Deputy and Murakami, 2000).
- SIGNS AND SYMPTOMS: Look for the slime trail, which is usually silver in color. Damage to the plant, such as large ragged holes in leaves, flowers, and stems, is done by the slug. They can quickly defoliate the plant if not controlled. Check the undersides of pots and in drainage hole of the pot to see if they are present. Slugs begin feeding at the bottom of plants and work their way up. (Ball, 1990)
- CONTROL: Keep area around plant and in pot clear of leaf litter. Manually dispose of any slugs in growing area. Set up traps to lure slugs and then dispose of them. Set up a physical or chemical barrier to deter slugs. Use baits to kill slugs. (Deputy and Murakami, 2000)

b) Snails

- DESCRIPTION: Snails are soft-bodied mollusks that are protected in a shell. They can range in color from cream, pink to gray. The markings on the shell vary from species to

species. They can be found in moist, dark areas, usually coming out at night to feed with their rasping mouthpiece. (Ball, 1990) They produce about 80 eggs at a time, and can lay eggs up to 6 times a year. The eggs are rounded and white in color, and can be found in the upper layer of the soil. The snails mature in two years. (Deputy and Murakami, 2000)

- SIGNS AND SYMPTOMS: Look for the slime trail, which is usually silver in color. Damage to the plant, such as large ragged holes in leaves, flowers, and stems, is done by the slug. They can quickly defoliate the plant if not controlled. Check the undersides of pots to see if they are present. (Ball, 1990)
- CONTROL: Keep area around plant and in pot clear of leaf litter. Manually dispose of any snails in growing area. Set up traps to lure snails and then dispose of them. Set up a physical or chemical barrier to deter snails. Use baits to kill snails. (Deputy and Murakami, 2000)

5. Pathogen Monitoring and Control

- Look for signs and symptoms.
- Identify the pathogen.
- Know their life cycle.
- Monitor on a daily basis.
- Contact your local agriculture extension agent or Department of Agriculture agent for proper identification, up-to-date chemicals and current control practices.

1. Bacterial disease

- SIGNS AND SYMPTOMS: Infected plants often have rotted leaves, stems branches, or tubers, which have a foul odor. When cutting into an infected area, a small amount of whitish or yellowish ooze will seep out. Other symptoms include wilted leaves or stems, or odd shaped galls on the stem or on the roots near the soil line. Symptoms can spread quite quickly by splashing water (such as irrigation or rain) or by infected soil. They can enter a plant either through wounds or through the stomata. (Ball, 1990)
- CONTROL: Besides chemical control methods, also remove all infected plants, and wash hands and sterilize tools after handling infected plants. Use good spacing between plants to encourage good air circulation. Clean up and remove diseased plant parts and dispose of them by placing in plastic bag or sealed container right away.

2. Fungal diseases

- SIGNS AND SYMPTOMS: Look for rust-colored or powdery-white looking spots on either side of leaves. These spots will eventually make the leaf chlorotic and will eventually kill the leaf tissue. Also, look out for water soaked spots, greasy looking areas, or black streaks or blotches on the leaves or stems. (Ball, 1990).
- CONTROL: Besides using fungicide control methods, remove affected areas and dispose of in a plastic bag or a sealed container. Be sure to wash hands and sterilize tools after handling infected plants. Use good spacing between plants to encourage good air circulation. (Ball, 1990)

3. Viral Diseases

- DESCRIPTION: "Viruses are basically parasites, multiplying inside their hosts or if no host is available, lying inactive but viable in dead plant material for up to 50 years while waiting for a new victim." (Ball, 1990. pg345)
- SIGNS AND SYMPTOMS: Be aware of plants that have poor overall growth (like stunted leaves, and flowers). There may be yellowish mottling patterns on the leaves, stems or blossoms that make the plant look sickly. (Ball, 1990)
- CONTROL: Viruses are spread by insects with piercing-sucking mouthparts such as aphids and leafhoppers. Garden tools and humans are other vectors of viruses. Do not take cuttings from infected plants as the cuttings will also have the virus. Remove and destroy (not in the compost pile) the infected plants, and wash hands and sterilize tools after use. (Ball, 1990)

6. Small Mammals and other pest monitoring and control

- Look for signs and symptoms.
- Identify the target pests.
- Monitor for pests presence and their levels of abundance.
- Know their life cycle
- Monitor on a daily basis.
- Contact your local agriculture extension agent or Department of Agriculture agent for up-to-date chemicals and current control practices.

a) Rats/Mice

- SIGNS AND SYMPTOMS: Look for seedlings and/or seeds dug up, uprooted and eaten. Droppings and tracks.
- CONTROL: traditional mousetrap and bait. Use good sanitation practices by cleaning up all possible food sources, using rodent-proof containers of metal or glass, and removing tall grass, weeds and shrubby growth.

b) Birds

- SIGNS AND SYMPTOMS: Young seedlings and/or buds may be nipped off. Look for droppings and feathers.
- CONTROL: Barriers and deterrents like metallic ribbon and owl figures.

c) Toads and Frogs

- SIGNS AND SYMPTOMS: Look for evidence of nestling in pots such as vegetation in pots that are smashed or pushed to the side of the pot. Toads and frogs are potential carrier of nematodes.
- CONTROL: Do not have standing water anywhere that would make it favorable to toads or frogs. Capture manually and dispose/release in favorable habitat far away from the growing area.

Appendix 5D

Pesticide Chart

Mention of a trademark, company, or proprietary name does not constitute an endorsement, guarantee, or warranty by the author.
Always check or test for plant sensitivity when using a new pesticide or at higher rates than listed.

FUNGICIDES/ALGAECIDES:

Product	Primary Active Ingredient(s):	Mode of Action	Class	Toxicity Category	Application rate	Interval	REI (restricted entry interval)	Notes:
Banrot	Thiophanate-methyl (25%) and Etridiozole(15%)	Systemic	Benzimidazoles and Thiazoles	III, IV	12g/3 gal 2 1/4tsp/3 gal	1/week for flats, wilting seedlings due to damping off as needed	12 hrs	Can combine w/ Zerotol, alternate w/ subdue (not good to mix with other pesticides/fertilizers unless adequately trailed)
Sulfur	Elemental sulfur	Contact?	Inorganics	IV	2 to 4 tablespoons/ gal	30 days	24 hrs	Good for mildew of mints, supposedly works on mites(need test trial) spray with water
Subdue	Mefenoxam: (R)-2-[(2,6-dimethylphenyl)-methoxyacetyl-amino]-Proponic acid methyl ester	Systemic	AC	III	7 drops/gallon	1/week for flats	Till spray is dry	Can combine with zerotol, alternate w/ Banrot Possibly phytotoxic -Dave P.
Zerotol (Algae/fungus)	Hydrogen dioxide	Oxidation (kills fungi, bacteria, algae and their spores on **contact**)			2 oz/ gallon (1:100) 6 oz/gallon for floors	1/week for flats 1/month for floors and benches	0 hrs (none)	3 applications on consecutive days for heavy infestation, can be combined w/ subdue maxx

INSECTICIDES:

Product	Target Pest:	Primary Active Ingredient(s):	Mode of Action	Class	Toxicity Category (toward humans)	Application rate	Interval	REI	Notes:
Amdro	Ants	Hydramethylnon		Miscellanous	III	Lightly sprinkle around nursery when ants present (see label)	As needed		Use on baseboards and around ant nests, more frequently needed during dry periods
Avid	Mites (red spider, brown, broadleaf)	Abamectin		Insect growth regulator	II	1.2 ml/gallon	As needed	12 hrs	2 applications 14 days for heavy infestation May cause phytotoxicity to mints during hot/dry periods… (use lower concentration)
Cinnamite	Mites (red spider, brown, broadleaf)	Cinnamaldehyde	Contact	Miscellaneous	II	25 mL/gal or (0.85 oz/gal)		4 hrs	Lobelioids, mints highly sensitive Don't apply to stressed plants, causes flower dieback
Concern	Various	Potassium salts of fatty acids				3.5 oz/gal	Spot treatment	0 hrs (none)	Lobilioids, mints sensitive
Dipel DF	Fungus gnats, caterpillars	Bacillus thuringiensis, subsp. kurstaki, strain HD-1		Microbial	II-III	½ - 1 tsp/gal	14 days (also depending on environ. factors, see label)	4 hrs	Larvae must eat dipel deposits to be affected For heavy infestations: 2

									applications 14 days apart
Enstar II	Various, good for green- house white flies	S-Kinoprene		Insect growth regulator		2 ml/gallon (see label)	1 time/per month (see label for curative treatment cycle)	12 hrs	Affects life cycle (no immediate kill) Combine with Maverik for best control
Gnatrol	Fungus gnats	Bacillus thuringiensis, subsp. israelensis, strain 65-52				1 oz/gallon	1 time every week (or as needed after heavy rains)		Stops feeding of larva stage only
Marathon	Green-house whiteflies, mealy bugs, aphids et. al	Imidacloprid	Systemic	Misc.	II	¼ teaspoon/ gallon pots 1/8 teaspoon for half gal. pots or 4" pots	Every 2 Months	12 hrs	Takes 2 weeks for full effect, water light to activate, ineffective in water logged soils, no deep watering for 3 waterings, keep soil dry-moist
Merit 2.5 G	Green-house whiteflies, mealy bugs, aphids et.al.	Imidacloprid	Systemic	Miscellaneous	II	2 cups/full yard cart (6 cu. ft)	Mix into media for rare plants when transplanting	12`hrs	Use only for rare plant known to be pest magnets
Merit 75 WP (wettable powder)	Green-house whiteflies, mealy bugs, aphids et.al.		Systemic		II	¼ tsp per 2.5 gal		12 hrs	3 weeks prior to outplanting, no deep watering for 3 waterings, keep soil dry-moist
Mavrik aquaflow	Really good for mites only, combine w/ Enstar II for whitefly infestations	Tau-fluvalinate	Contact			1.2 ml/gallon	1 time/month (see label for curative treatment cycle)	12 hrs	Non phytotoxic, combine w/ Enstar II for max. effectiveness
Orthenex	White-flies, mites,	Acephate	Systemic	Organo-phosphate	II				Mints seem to be sensitive

	aphids, various others.								(showed phyto-toxicity) Good to alternate with seven for whiteflies.
Sevin	Various: Greenhouse whiteflies, mealy bugs, aphids et. al.	Carbaryl	Contact and stomach poison	Carbamate	II-III	1-3 oz/gallon	1 time every 7-10 days for heavy infestations of	12 hrs	Lobeliods Platydesma, mints, sensitive to repeat spraying, Residue cooks in sun, wash off within a day or two during dry periods
Sulfur	Mites and other insects	Elementary sulfur				Max: 6 tsp/gallon Effective at 2 tsp/gallon	As needed		2 applications 10 days apart, good for controlling fungi too
Talstar F	Mites and other insects	**B**ifenthrin		Synthetic pyrethrins or pyrethroids	II		1 time/month rotate with other pesticides (Enstar/Mavrik)	12 hrs	2 applications 14 days apart for heavy infestation
Ultrafine	Aphids, mites, thrips	Paraffinic oil	Contact	Oil		2.5 tbs/gallon	As needed (consecutive sprays shouldn't exceed more than once every two weeks)	4 hrs	Mints, lobelioids highly sensitive to paraffinic oil

SNAILS/SLUGS:

Product	Target Pest:	Primary Active Ingredient(s):	Mode of Action	Class	Toxicity Category (toward humans)	Application rate	Interval	REI	Notes:
Deadline	Slugs, snails	Metaldehyde				See label, lightly hand disperse in garden and around outside of nursery or inside PVC pipe on benches	As needed		When pellets get wet, they get moldy (attacked by fungi).
Snail/slug bait (liquid)	Slugs, snails					A few drops around seed flats	As needed		

TOXICITY CATEGORY	SIGNAL WORDS REQUIRED ON LABEL BY EPA	ORAL LD_{50} (MG./KG.)	DERMAL LD_{50} (M.G./K.G.) 24-HR. EXPOSURE	ORAL DOSAGE TO KILL AN ADULT*
I. Highly Toxic	DANGER, POISON, Plus Skull & Crossbones symbol	0 to 50	0 to 200	A few drops to 1 tsp.
II. Moderately Toxic	WARNING	50 to 500	200 to 2,000	1 tsp. to 2 Tbsp.
III. Slightly Toxic	CAUTION	500 to 5,000	2,000 to 20,000	1 oz. to 1 pt. (1 lb.)
IV. Low Toxicity	CAUTION	>5,000	>20,000	1 pt. (1 lb.) or more

6.0 NATIVE REVEGETATION

Photopoints over two year period. From solid *Clidemia hirta* to an endangered species garden. Kaluaa Gulch, Honouliuli Preserve, Oahu

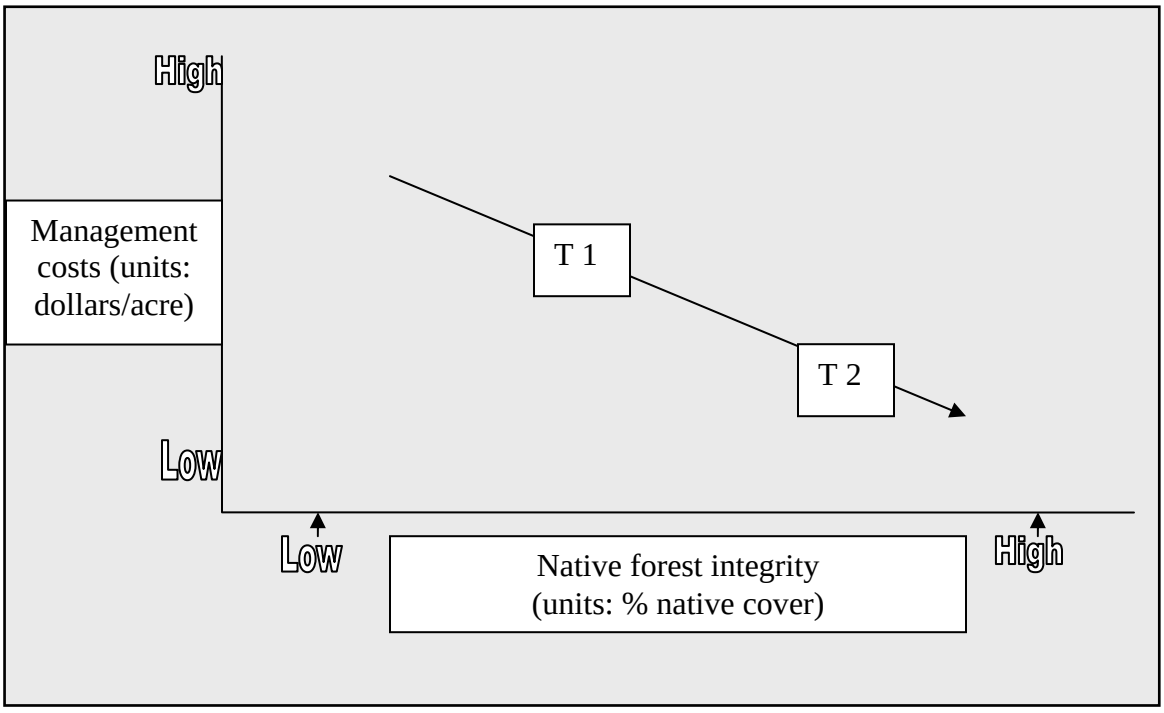
6.1 INTRODUCTION

As emphasized in the chapter on site planning, restoration sites should ideally require only minimal levels of effort to bring native areas back to being fully intact. This ideal is not so much additive restoration, but rather subtractive restoration. Ungulates and low level infestations of weeds are removed and the forest primarily heals itself. Protecting and restoring these relatively intact sites should be a priority. Subtractive restoration efforts are generally a wiser use of scarce monetary resources for reasons outlined in the restoration site planning chapter. Allowing the native forest to regenerate itself native is one method of revegetation.

However, additive restoration efforts are often necessary for mesic forest areas given their high level of decay. In many areas, only the native canopy remains with alien weeds such as Koster's curse (*Clidemia hirta*) dominating the understory. Given the right weed control and planting strategies, even lower quality sites can be restored to largely intact native forests over time.

For these high intensity management areas, planting is used following weed removal. This chapter highlights various revegetation strategies, and lays out numerous

considerations regarding more technical aspects of restoration such as planting site selection, site preparation, and planting techniques. The following graph illustrates the costs associated with restoration at various levels of management intensity.



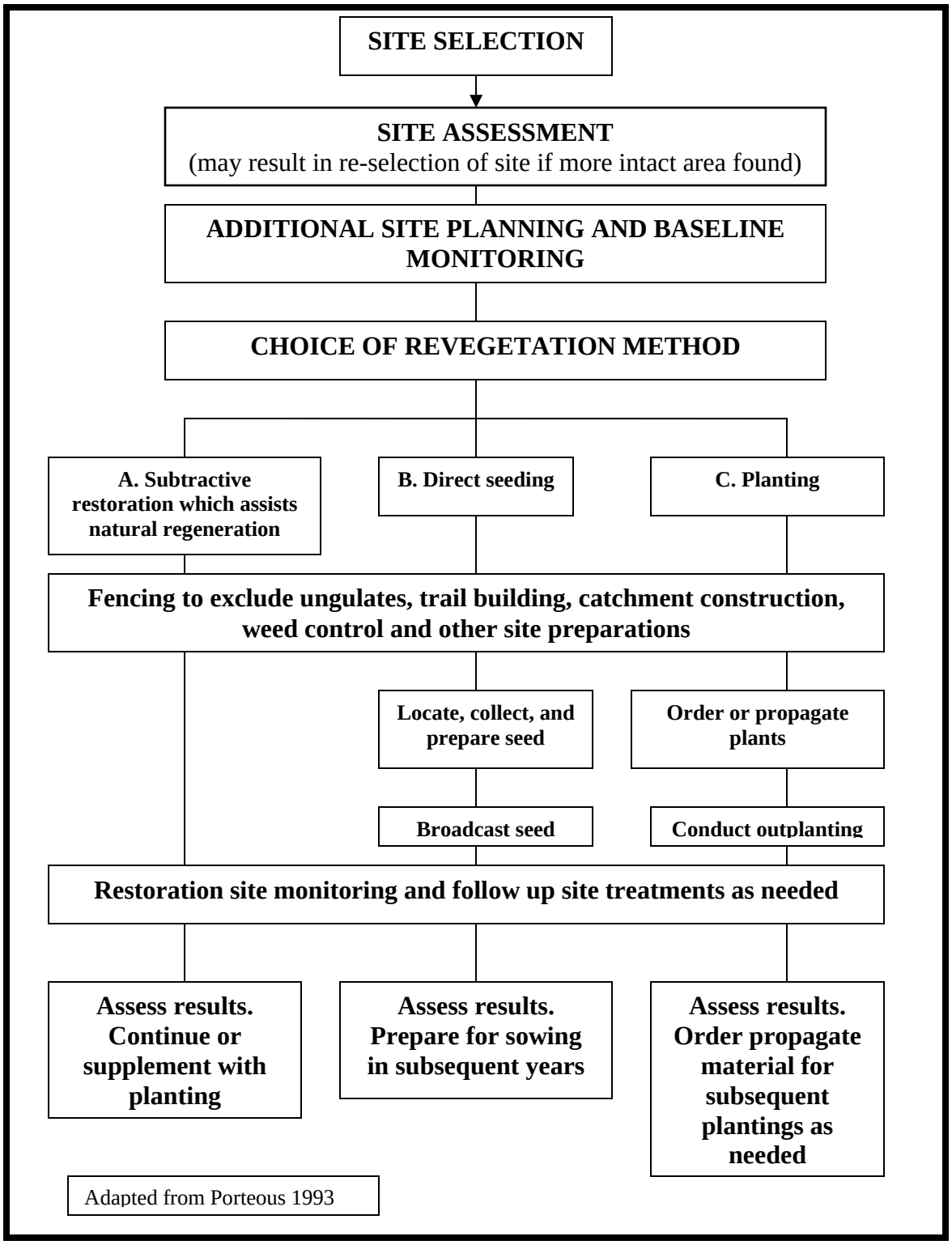
At the beginning of site management (Time 1), management costs are moderately high given the fairly degraded condition of a restoration site. As management efforts result in native canopy and understory closure, associated weed control and planting costs should drop (Time 2). Management costs will never be zero given the need for ongoing fence maintenance and vigilant monitoring for newly established weed populations.

8.1 PLANNING

Since restoration projects often span many years, the success or failure of a restoration site hinges on the level of thought and planning brought to an area. Proper planning will not only secure adequate financial resources, but will also ensure that other important aspects are not overlooked (Porteous 1993).

See also Chapter 2 on Restoration Site Planning for a more in depth discussion on site planning. Generally, your revegetation strategy will implement the goals for your restoration site. One way of determining goals is to ask what one is hoping to accomplish. The purpose of restoring an area should be made explicit from the onset. From those goals, specific objectives are generated dictating the methods of revegetation. Objectives detail how the area will be restored. In other words, objectives are the strategies used to implement the goals. For example, species selection, plant sizes, distribution patterns, and the method of planting are all important planting strategies. Decisions regarding these mechanics of restoration should flow directly from the goals and objectives laid out in a management or restoration site plan for an area. **Appendix 6A** is an example of a

restoration site plan which outlines the overall goals for a site at Honouliuli Preserve and the restoration objectives over a 3 year time period. The following flow diagram illustrates the essential stages and considerations of a revegetation program (Porteous 1993)



One often overlooked planning decision is the distribution of plantings. If one observes an intact native forest, plant species are commonly not distributed evenly. As with most vegetative and animal communities, plant species are instead naturally distributed across areas, regions, and landscapes in patches. Distributing plantings according to natural distribution patterns should bolster project success and increase the authenticity of restoration efforts.

6.2 RECORD KEEPING

The importance of recording as much information as possible about all aspects of a revegetation program cannot be overstated. This information will not only assist managers in their assessments of restoration efforts, it will also assist others who are embarking on similar efforts The following list highlights important aspects that need to be recorded in an organized database (Porteous 1993).

a) Restoration site assessment (see also **Appendices 6A** and **6B** for examples of a restoration site plan and a restoration site assessment form)
    - Site location
    - Size
    - Protected status, ownership
    - Goal of restoration
    - Baseline vegetative cover and composition (i.e. before management)
    - Surrounding vegetation, seed sources
    - Surrounding threats
    - Soil type
    - Rainfall levels
    - Aspect and wind exposure

b) Plant Material
    - Species and sources of propagules
    - Plant size and container size if using container grown plants
    - Condition of plants (e.g. healthy, moderate, poor)

c) Planting
    - Site preparations (weeds controlled, herbicides rates and quantities used, fencing etc.)
    - Planting dates
    - Weather and soil conditions
    - Treatment (e.g. fertilizers used and application rates)
    - Labor effort required (e.g. person hours)
    - Planting method (augered holes, hand dug dibble holes)

d) Follow-up maintenance requirements
    - Weed, rodent, ungulate control etc.
    - Labor required (person/hours)

e) Monitoring
    - Assessing success of the project
    - Survival rates after 12, 18, and 24 months
    - Lesson learned for the future

(Porteous 1993)

6.3 SELECTING THE REVEGETATION METHOD

There are three main methods to revegetate an area. A combination of the methods is often used given the levels of intactness of restoration sites.

1) Assisting natural regeneration.
2) Direct seeding.
3) Planting.

One could argue that a fourth method also works in Hawaii, establishing a nurse crop. A nurse crop is a temporary cover that eventually dies out on its own as trees and shrubs overtop it over time. As most native plants are fairly slow growing, the value of using a native nurse crop for forest restoration may be fairly limited in Hawaii. Non-native trees do harbor significant native diversity beneath their canopies (e.g. Sugi pines, Kukui trees). The utility of these non-natives for restoration (and other commercially valuable exotic trees) should be further explored in test plots. As being tried on Kahoolawe and other areas, sowing or planting shrubby native ‘weeds’ such as *Bidens* sp., *Chenopodium* sp., *Rumex* sp., and *Dodonaea* sp. can help to quickly stabilize sunny, disturbed areas, essentially copying natural native succession patterns. After these species are established at a site, canopy reaching elements can then be reintroduced to extend or re-establish forest cover.

6.3.1 ASSISTING NATURAL REGENERATION



As mentioned previously, this method of revegetation is essentially a subtractive approach to restoration. Practiced for decades in Hawaii by the State, National Park Service, National Wildlife Refuge Service, The Nature Conservancy and more recently by the U.S. Army and National Guard for their military training areas, natural regeneration is the most cost-effective form of restoration. Sometimes called threat abatement resource management or even 'passive restoration' (although ungulate removal is never passive), areas damaged by ungulates are naturally restored to their former state due to the resiliency of a relatively intact forest.

For success, this method requires:

a) Sufficient adjacent seed sources of quick-growing colonizing species.
b) An absence of grazing animals, feral pigs, and control of other animal pests.
c) Control of competing grasses and weeds.
d) Absence of catastrophic fires. (Porteous 1993)

Protection of the largest, most viable, functioning native forest systems remains one of the highest priorities for Hawaii's resource managers. Unfortunately, as noted in the introduction to this manual, mesic forests suffer from a lack of more intensive management given their status as largely non-viable native forests as seen from a 100-500 year future time frame. Nonetheless, as with native upper elevation wet forest areas, mesic forest recovery following ungulate removal is often just as dramatic, giving hope to the linkage of mesic forest fragments within the larger landscape.

6.3.2 DIRECT SEEDING

This section is adapted from: Native Forest Restoration (Porteous 1993).

Direct seeding is a relatively cheap supplement to hand planting native trees and shrubs. For success, this method requires:

- Sufficiently large quantities of viable seed
- Right seasonal conditions for germination and seedling establishment
- Control of competing weeds (especially grasses)

Direct seeding involves the broadcasting or placing of seed directly into a prepared site suitable for the sown species. Because conditions are inevitably less suited to germination and seedling establishment than in a nursery situation, only a small percentage of seeds will 'take.' As with many seeds, especially larger ones, there is the risk of damage by insects, birds, rodents, and drying out. However, where seed material is plentiful and easily brought to a site, direct seeding can be a useful method for establishing a quick cover or for longer term tree establishment.

The most critical factors in direct seeding are the elimination of competing plants, and the maintenance of a climate suitable for seed germination and growth. The ground can be prepared by spraying with a knockdown herbicide, ripping or plowing. Good seed to soil contact and favorable temperature and soil moisture levels are essential for germination.

Finding large quantities of seed material is often problematic when collecting from the wild. Several agencies and nursery companies in Hawaii obtain their seeds from planter boxes and farmed fields of native species grown specifically for seed stock production.

Suitable species for direct seeding of mesic areas include:

Shrubs:	**Trees:**
Bidens sp.	*Acacia koa*
Dodonaea viscosa	*Metrosideros polymorpha*
Chenopodium oahuense	*Myoporum sandwicense*
Dubautia ssp.	*Myrsine*sp.
Rumex albescens	*Pisonia ssp.*
	Sophora chrysophylla
	Tetraplasandra sp.

The preceding species were chosen based on high seed production rates and observations of high germination and growth rates in protected mesic forest areas as well as in nursery conditions.

6.3.3 PLANTING

Planting as a method of revegetation is what commonly comes to mind when the term forest restoration is used. Hawaii has about a 70 year history of reforestation. Mostly non-native species were used to reforest watershed areas beginning around the 1930's. The following sections detail the issues surrounding planting as a method of revegetation. The following chapter on plant propagation discusses the issues of growing native plants for restoration purposes.

6.4 PLANTING SITE SELECTION


If you are unsure if a plant will thrive in its new home or are concerned about biological pollution of gene pools in the wild, do some research first. A plant in the wrong home may be able to stay alive in an inappropriate environment, but it will not thrive. Test trial plantings are a good idea if you are uncertain about the habitat requirements for a particular species.

6.4.1 IMPORTANT CONSIDERATIONS ABOUT SELECTING PLANTING SITES

- Think like a plant. Carefully observe where your desired plants naturally thrive and under what environmental conditions and match planting sites appropriately. Pay particular attention to where seedlings of your target species are germinating and surviving naturally. Also note the general distribution pattern of native species. The future composition of a forest can be determined by observing the age structure and seedling density of constituent species. Reference sites of intact native forest areas contain key information about forest composition, succession patterns, resiliency, soil composition, moisture gradients etc. Applying the lessons learned from intact areas to areas under restoration is a sound strategy for success.

- Microsites (the actual immediate growing environment) often determine the success or failure of plantings. For example, low spots naturally collect water and debris and can have higher humidity, cooler temperatures, and more nutrients than nearby raised, exposed areas. Soils along ridgelines and crestlines typically have had certain nutrients stripped away by weathering. Large trees with shallow root systems and grass often consume all the available surface moisture in their immediate area. However, other large tree species actually assist with surface moisture levels at night through a process of deep water uplift whereby root systems deposit excess water near the soil surface. Some species cannot tolerate growing immediately next to another tree; other shrub species may actually prefer growing at the base of large trees in deep shade. Again, careful observations of the life strategies of native plants will inform planting decisions and increase plant survival rates.

- Accessibility of planting sites is critical to regular site monitoring and maintenance. Trails, steps, and roads may need to be constructed or improved prior to planting in order to avoid site degradation and personal injury, particularly when planting on steep slopes in wet conditions.

- Soil for most plants should drain well. To test, dig a hole and pour water in. If it doesn't drain out fairly quickly, amendments may need to be added or another site chosen. Terrestrial plants and their root systems need oxygen gas for respiration, without air spaces in the soil, plants will not thrive.

- Testing the soil for nutrient levels is pretty cheap and could prove to be valuable information for matching plant species to specific soil conditions.

- Understanding the soil type and variations of soil condition within a site will also greatly assist the success of plantings. Plants and decomposers (soil microorganisms and bacteria) are the main driving forces behind energy transfers in an ecosystem. Soil fertility (including mychorrizal associations), decomposer diversity, and plant vitality are all inextricably linked in an ecological system.

- Ideally, water should be available for irrigation, hand watering, and follow-up weeding using herbicides. Relying on rainfall can be pretty risky and could lead to wasted plant material and resources.

- Appropriate sunlight levels should be considered not only throughout the day (e.g. north facing or south facing slopes), but seasonally as well. A moderate light gap in the winter months can become a brutal growing environment in the summer months for more shade loving species. Removal of canopy trees as part of prior or future restoration efforts should also be considered when planting high value species beneath large limbs or when using species intolerant of hot and sunny conditions.

- Long-term maintenance and protection of the planting site should always be taken into account. Acres of koa plantings were destroyed at one reforestation site on the island of Hawaii because cattle were inadvertently allowed into the planting area. Adequately plan for disasters to avoid catastrophic losses.

- On site invertebrate pests should also be considered. While ants can assist in pollination, because Hawaiian forests evolved without ants, ant infestations are generally detrimental for restoration efforts given the multitude of other plant pests like aphids, scales, and mealy bugs that are associated with ant colonies.

- Lastly, take the time to carefully plan logistics. It’s better to plant 10 trees correctly and have them all survive and flourish, than to plant 100 trees incorrectly and waste time, effort, and plant material.

6.5 SITE PREPARATION


Following site selection, usually some degree of site preparation is needed. **Appendix 6C** contains a checklist that TNC-Oahu uses for their plant reintroductions. In addition to infrastructural needs such as fences, trails and irrigation systems, restoration sites often require a fair degree of weed control. See also the chapter on weed control for planning and implementing weed control efforts. Some of the important considerations regarding site preparation follow:

- Determinations of when sites are ready for planting are dependent on the level of weed infestations and the status of any infrastructural improvements. At Honouliuli Preserve, 'high intensity' restoration sites with a solid understory of *Clidemia hirta* required 12-24 months of weed removal and follow-up weed control before native plants were reintroduced. This long period of time was needed for the exhaustion of much of the weed seed bank and to determine the levels of natural recruitment of native species at the site. This long preparation period also allowed for adequate planting stocks to be grown and for infrastructural improvements to be made such as trails, fences, and supporting irrigation systems. At other more intact native forest areas, 'low intensity' restoration sites required only minimal weed removals and native seeds were sowed directly onto favorable microsites.

- It is far easier and wiser to spray herbicides or conduct mechanical removal of weeds before plantings are done than afterwards. For example, 3 foot (1m) circles can be sprayed with Roundup® at least 1 month prior to planting to ensure that plantings do not have to compete with surrounding weeds. Additionally, it is much easier to use a gas powered auger in bare areas than through grass or vine choked areas which wrap around the auger bit.

- Both chemical and mechanical removal of understory weeds can have damaging effects on delicate groundcovers and soil microorganisms. Herbicides if used inappropriately will kill beneficial soil microorganisms such as springtails and bacteria. Similarly, ripping up understory weeds with large surface root systems can also destroy slow growing moss, fungi, and lichen growth.

- The type of weed removal must be appropriate to the site conditions and the overall restoration goals. For example, at Honouliuli Preserve, a fairly intact ohia/pukiawe shrubland area also contained an infestation of *Clidemia hirta*. Rather than ripping up the dense mat of lichen and moss in order to mechanically remove the *Clidemia,* the *Clidemia* was first cut at the base using loppers or a chainsaw. Upon re-sprouting, the flushing regrowth was carefully sprayed with Roundup®. This was far more cost-effective than tediously treating each stump with Garlon 4® and only minimal non-target overspray effects occurred. Importantly, the mat of moss was left in place for ohia and pukiawe seeds to fall on and germinate.

- Herbicide treatments of overstory weed trees should also be done well before plantings go in to ensure that subsequent leaf and limb drops do not smother or crush plantings below. For example, it may take 9-16 months for large 50 foot guava trees to completely die following 20% triclopyr ester product in crop oil basal bark frill treatments. Planting beneath that large guava tree only 3 months after treatment can simply overwhelm plantings with leaf litter and harmful tannins.

- Large dead limbs that will crush plantings or pose hazards to work crews will also need to be removed or simply avoided.

- To encourage native seedling recruitment and outplanting success in former guava or eucalyptus stands, removal of the leaf litter by raking or by using a gas powered blower can improve microsite conditions over small ($1/8^{th}$ acre) areas. This raking action can also stimulate koa and mamaki germination if mature trees grow nearby.

Former guava stand now being filled by endangered. *Solanum sandwicense* plantings and *Pipturus albidus* recruits. Note the koa litter suppressing weed growth.

- Controlled burns are a common practice in agricultural and military training areas to quickly remove undesirable brush. While technically difficult in densely

forested conservation areas, low-intensity controlled burns are an attractive tool to cheaply remove groundcover weeds while leaving canopy trees intact or to prepare a site for less intensive chemical weed control and eventual reforestation with native species.

- If feasible, heavy mechanical equipment can also quickly clear understory growth, construct roads and trails, and dig planting holes. For example, at one riparian restoration site in Vermont, backhoes were fitted with a 10 ft. disc that digs 50 one foot deep planting holes for willow slips in one movement.

6.6 COMPANION PLANTING OR CO-PLANTING

Companion planting or co-planting involves planting two species together in the same hole at a restoration site. This technique proved to be very successful in promoting the survival of slow growing common and endangered woody species in dry and degraded reintroduction sites on Oahu. For example, planting the slow-growing ohia lehua in the microclimate created beneath bushy *Bidens sp*. allowed for the outplanting of younger nursery stock of ohia, while dramatically improving ohia survival and vigor during the first 2 years (Garnett pers. com. 2003).

6.7 PREPARING PLANTS FOR PLANTING

All plant material should ideally be hardened off at least three weeks prior to outplanting by acclimating it to similar light, nutrient and soil water levels as the outplanting site. Plants should not be pot bound (repot well beforehand) and the outplanting site should be carefully chosen based on appropriate soil, sunlight, and climate for the particular plants. Fertilizations which encourage leaf growth should generally be stopped two months prior to outplanting to encourage more woody tissue (lignification) and root growth. A large amount of leaf and reproductive tissue usually means higher transpiration rates and potential transplant shock after plants are placed into forests with less available water. Pruning plants of their larger leaves or spraying the leaves with a wax designed for large tree plantings will also lower transpiration rates and lessen transplant shock.

Choosing the most vigorous plants for outplanting is important for long-term success. For example, using well-grown plants in 1 and 2 gallon Stuewe® tree pots, The Nature Conservancy-Oahu Program had survival rates above 85% for all but one rare species. As with most large living organisms, the health of a tree later in life is tied to the growing conditions early in life. Tree seedlings that are nutrient, water, and heat or cold stressed early on will not be able to grow quickly and become large healthy trees.

Before putting plants into the wild, plants need to be pest free. Plants should be closely inspected for ants, mites, mealy bugs, nematodes, undesirable fungi and other pests. If plants are small enough, one can even pull the plants out of the pots to inspect for root coiling, diseases, root mealy bugs, snails, and slugs. Healthy roots should look white with numerous root hairs. Soil drenches with systemic insecticides and fungicides at least three weeks prior to planting are one method of ensuring that nursery grown stock are

pest free before being brought to the field. Fungicides should be used with caution as they may also kill desirable fungi that assist with plant nutrient uptake (e.g. vesicular arbuscular mychorhizal fungi). Growing plants in field nurseries is another means of ensuring that contaminants are not brought into uninfested areas.

MATERIALS NEEDED FOR OUTPLANTING:

- Pick
- Shovels
- Gas powered auger
- Buckets/crates/jugs (for water and mulch)
- Mulch
- Stakes/flags/tags
- Fertilizer
- Knife/shears (to cut away pot if plant is stuck)
- Gloves and eye protection
- Plant record forms

6.8 TRANSPORTING PLANTS TO THE SITE

Transporting large quantities of plant material to remote locations is a laborious and costly enterprise. Field nurseries offer the benefit of having plant material located at or near where they will actually be planted. Various other means have been used for decades for forestry efforts. Two of the most common methods are described below.

Hand carrying: If roads are too far from planting site, material will need to be carried in on ATVs, horses, mules, or on worker's backs. Freighter packs available from Forestry Suppliers Inc. are well suited for carrying heavy material. Taller plants can be carried parallel to the ground in crates to avoid damage from overhanging brush. Shoulder sacks to carry dibble tubes are also handy when moving plants from staging areas to actual planting sites. These are also available from Forestry Suppliers Inc..

Helicopter sling loading: While expensive at around $800/hour, helicopters are very useful in bringing large amounts of plant material and gear into remote areas. Plants can be transported in containers placed into slingnets, strapped directly to open sided or closed paneled pallets, or placed into large synthetic bags designed for dock operations.



Helicopter slingloading and power augering holes, tools of the trade for more intensive restoration efforts, Honouliuli Preserve, Oahu.

6.9 DIGGING THE HOLE

Pick a spot in an area friendly to plants. This could be a natural drainage area, away from foot traffic, out of strong winds, and not immediately next to another tree or plant. Use a pick to break up earth or a D-handled shovel for hole digging. If using hand picks or digging in rocky areas, use eye protection. Dig a hole twice just as deep as original pot. If the sides of the hole become smooth, break it apart to avoid a flowerpot effect (i.e. roots cannot grow through smooth hard walls). Large holes are important to trap more water and keep roots aerated. Plants need oxygen for respiration too. Keep excavated material in a pile to make it easier to refill hole.

Because some natives (e.g. ohia) are better planted at a larger size, larger ½ gallon or even 1 gallon sized pots and planting holes are needed to accommodate them. For some tree species as indicated in the planting table, The Nature Conservancy-Oahu Program recommends planting at these larger sizes to ensure survival and quicker initial growth. Digging these larger holes without power tools is very time consuming and physically demanding. In these situations, the use of a power auger can be very effective. In Hakalau Forest National Wildlife Refuge, a gasoline-powered engine drill (Echo model EDR-2400, $435, www.echo-usa.com) with a specialized planter bit (Power Planter bit #528H, $82, www.bradleysales.com) is used to dig holes for larger `ohi`a, as well koa and other understory plants. Stihl also makes a much heavier, but more powerful gas powered auger. Using the power auger increased the productivity of Hakalau volunteer crews from planting 200-300 trees in an 8 hour day, to planting 500 plants in a 6 hour day. Echo also makes smaller 9 lb. gas powered auger drill which can be used for smaller

dibble tubes (2” diameter). The same Echo gas powered auger drill can also be used for tree injections for herbicide work using a different bit.
When using an auger or any other power machinery, appropriate safety measures should be taken to prevent injury. Particularly in root bound and rocky areas, only individuals with good upper body strength and healthy spines should operate an auger.

6.9.1 FERTILIZING THE HOLE

Once the hole is dug, check the drainage by pouring some water inside. If the water doesn't drain out within 20 seconds the soil probably has a lot of clay. Rocks and gravel may be needed at the bottom to provide better drainage. Some advocate a tough love stance by recommending that no fertilizer or compost be added as this will create an artificially high nutrient rich zone that the roots will never grow away from, leaving them stunted in the long-term after the fertilizer is depleted. Weeds may also use the fertilizer faster than the target plant.

However, The Nature Conservancy-Oahu Program does amend their planting holes (particularly on nutrient depleted ridgeline areas) with a balanced slow release fertilizer with micronutrients (Apex 9-12-16). Among other benefits, fertilizer encourages root growth upon planting, assisting with plant survival and growth. Upstart or Vitamin B1 (a transplant hormone) can also be mixed into water jugs used for watering at the time of planting. Other agencies have found potassium (potash form), phosphorus and bone meal also produced favorable results. Roughly a handful of potash and phosphorus each mixed into the soil at the bottom of the hole is adequate. If available, thoroughly rotten tree log bits can be mixed in as well as compost. Excessive amounts of fertilizer may encourage too much foliar plant growth or even be toxic to the plant (e.g. ammonification). Therefore, fertilizers for native plants should generally be used at the lowest recommended amounts on the product labels with test trials to determine optimum rates. See also the propagation chapter for a discussion on the use of mychorhizal inoculated soil.

6.9.2 GETTING THE PLANT OUT

It is very easy to damage a plant when transporting it, handling it and extracting it from its pot. Transplant shock can occur when root hairs are damaged to the point where they

are less able to efficiently absorb water and nutrients from the surrounding media. To make extraction easier, squeeze the sides of the pot to loosen the soil. If the plant can be easily lifted, turn the pot on its side or completely over to let gravity drop it out. You of course need to be ready to catch the root ball when it does slide out. If it is really stuck, try slapping the bottom to jar it out. Pulling on the stem is generally a bad idea as this may damage surface roots. If need be, cut the plant out of its pot with a sharp knife. Keep the root ball (soil around the roots) as intact as possible. If roots are severely coiled at the bottom its probably best not to cut them as this will only severely stress the plant. Gently tug and free the roots from the pot as best as possible. For larger 1 gallon pots, pulling the plant out onto a 'shooter' spade shovel will help support the root ball as it is lowered into the ground.

6.9.3 PLANTING

1) As mentioned at the beginning of the chapter, the distribution of plantings can be critical to their success. Many shrubs and groundcovers are better able to establish themselves if planted in clumps or clusters. Cluster planting allows plants to trap organic matter much better as well as form more substantial mychorrizal associations in the soil. The immediate microclimate is also often improved facilitating germination and native seedling establishment.
2) If the soil in the hole is excessively dry and water is available, water the hole first before planting. This ensures that the soil that contacts the roots is sufficiently wet and will help prevent transplant shock.
3) Place the plant in the soil so that the original soil surface level in the pot is now level with the ground. If it is planted too deep, the stem may rot as debris and other matter collect in the hole. If it is planted too shallow, surface roots will become exposed as water flows over the surface.
4) Lightly pack soil back in around plant roots and thoroughly water if the ground is not already saturated. See also the discussion on watering in the following chapter.
5) For plants exposed to high winds or cold temperatures, some type of wind shield may be needed.
6) For plants planted on steep slopes, erosion from excessive surface runoff (overland flow) is of concern. Rocks or other available dead branches can be placed as a mini-dam around the lower edge of the plant to help stabilize it until fully rooted as well as collect debris and surface runoff.
7) Plantings should also be mulched with available leaf litter, rotten logs, or rocks. The amount of mulch depends on the size of the plant. A general rule is that a one foot in diameter ring of mulch is needed for every foot in plant height. Kukui logs when fully rotted make great mulch. Ancient Hawaiians planting their food crops in dry, arid and at times rocky fields, also commonly used rocks as mulch.
8) If desired, mark all plants with stake flags or other means for ease of relocation.
9) Conduct follow-up maintenance as needed. Post planting site treatment is described in the following chapter.



It takes a community to raise a forest, sometimes one tree at a time.

6.9.4 REFERENCES

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Appendix 6A: PALIKEA FENCE RESTORATION SITE PLAN

Timeframe: FY2004-FY2006

Vegetation communities: Oahu Diverse Mesic Forest with a Sugi Pine/Ohia lehua canopy

Size of site: 2.5 acres

Overall management goal: In the next three year period, utilize staff and volunteer assistance to restore a moderately degraded 2.5 acre highly diverse mesic community to provide a high quality habitat for rare plant species stabilization and rare animal protection.

Overall management objectives:

1. In three years reduce all habitat modifying canopy species cover by 80% while maintaining adequate habitat requirements for Elepaio, Apapane, Amakihi and Achatinella snails in the area.
2. Habitat modifying understory weed species cover will be reduced by 100% in three years.
3. Continue monthly rat baiting and maintain a pig free fenced and surrounding area through various ungulate control methods.
4. Plant 1000 canopy reaching trees and 1700 understory shrubs on west slope. Plant rare species in accordance with stabilization plans.

Overall monitoring objectives:

1. Using the Restoration Site Assessment form, over three years monitor the reduction in non-native canopy and understory cover and increase in native understory cover in two 50 x 50 m plots on the east facing and west facing slopes of the fence area.
2. Also, over three years, monitor the survival, vigor and reproduction of various rare elements in the area including naturally occurring rare plant populations, reintroduced plant populations, and rare bird and snail species.

General description: At 2800’ below Puu Palikea, the 2.5 acre Palikea fence is a microcosm of Honouliuli Preserve. Several microhabitats exist within this small area. The gulch bottom consists of a mamaki riparian shrubland. The eastern and western facing slopes consist of a lowland diverse mesic community with over 40 fern and flowering plant species beneath a predominately Sugi pine canopy. Access is a 30 minute hike along the Palikea Trail at the southern end of Honouliuli Preserve. A 125 gallon catchment tank and two 55 gallon storage tanks are also on site. The fence was completed in the fall of 2000 allowing substantial recovery of the native understory in the gulch bottom.

Baseline conditions

- **Native canopy species include:** *Metrosideros polymorpha, Acacia koa, Pouteria sandwicensis, Psychotria sp., Zanthoxylum sp., Charpentiera obovata,* and *Ilex anomala*.
- **Rare canopy species include:** *Exocarpus gaudichaudii, Zanthoxylum dipetalum var. dipetalum,* and *Nothocestrum longifolium*.
- **Non-native, habitat modifying canopy species include:** *Psidium cattlelianum, Psidium guajava, Schinus terebinthifolius,* and *Morella faya.* The *Sugus pinus* canopy is not actively recruiting and while the pine litter is thick in areas, numerous native understory fern and flowering plant species are persisting and recruiting. Thus, the Sugi pine canopy will be left intact long into the future.
- **Dominant native understory species include:** *Pipturus albidus, Dianella sandwicensis, Hedyotis terminalis, Carex wahuensis,* and *Diplazium sandwichianum.* Numerous other native understory species exist in low-medium densities. Hoio fern cover in the gulch bottom has recovered to nearly 100%. For comparison, the neighboring unfenced gulch bottom hoio fern cover is about 10% with numerous weeds species present.
- **Dominant non-native habitat modifying understory species include:** *Clidemia hirta, Passiflora suberosa, Rubus rosifolius, Sphaeropteris cooperi, Melinus minutifolia, Oplismenus hirtellus,* and *Paspalum conjugatum.*
- **Rare understory species include:** *Cyanea grimesiana var. obatae, Cyanea calycina, Clermontia persicifolia, Schiedea pentamera,* and *Neraudia melastomifolia.* Notably, the *Cyanea grimesiana var. obatae* population is the largest, healthiest naturally occurring population left.
- **Reintroduced common native understory species include:** *Dodonaea viscosa, Hedyotis terminalis,* and *Bidens torta.*
- **Reintroduced rare plant species include:** *Cyanea grimesiana var. obatae, Cyanea superba, Urera kaalae, Silene perlmanii, Urera kaalae, Lobelia yuccoides,*and *Schiedea pentamera*.
- Common and rare plant reintroductions have been ongoing since the fall of 2002.
- Weed control for non-native canopy and understory species has also progressed somewhat sporadically since 2001, but more intensively since the summer of 2003.
- Rare bird and inverterbrate species also inhabit the fence and surrounding area. Two elepaio males and possibly one female are present in the fence area. The same elepaio pair nested successfully in the fence area in the spring of 2002. Additionally, a small, but genetically significant populations of *Achatinella mustelina* and *A. concavospira* are extant just outside the fence line. *Philonesia* sp. (snails) are also fairly common in the area. Rat baiting to protect these animal and rare plant species is done throughout the year.

Summary of Management Objectives:

Year	Canopy weed control	Understory weed control	Reforestation objectives	Rare plant objectives	Monitoring objectives
1	50% removal of xmas berry and strawberry guava	100% removal of non-native grass species, 100% removal of Clidemia hirta species	Continue Kookoolau, Aalii, and Manono plantings in sun bowl on west slope with 200 plants in FY04.	1) Continue augmenting Cyagrioba population w/ mixed founders 2) Continue Silper, Urekaa, Solsan reintroduction at rate of 50 per year	1) Complete restoration site assessments for two 50 x 50 m plots (east and west slopes) 2) Quarterly fenceline inspections 3) Monthly rat baiting 4) Complete rare plant monitoring as planned
2	30% removal of xmas berry, strawberry guava, and faya tree	Follow up removals of grass and Clidemia, 100% removal of Passion vine and Thimble berry	1) Plant 200 canopy trees on west slope 2) Plant 500 understory shrubs on west slope	Continue augmentations and reintroductions in accordance with rare plant stabilization plans	1) Complete restoration site assessments 2) Quarterly fenceline inspections 3) Monthly rat baiting 4) Complete rare plant monitoring as planned
3	Followup control of above habitat modifying canopy species	Follow up control of above habitat modifying understory species	1) Plant 500 canopy trees on west slope 2) Plant 300 canopy trees in guava kill area on east slope 3) Plant 1000 understory shrubs on west slope	Continue augmentations and reintroductions in accordance with rare plant stabilization plans	1) Complete restoration site assessments 2) Quarterly fenceline inspections 3) Monthly rat baiting 4) Complete rare plant monitoring as planned

Strategies and Tactics:

1) Canopy weed species control:

Year 1:

- Begin guava, faya tree, and xmas berry removal on east facing slope in, and work toward back bowl upgulch.
- Leave 25% of largest guava trees and faya trees but conduct 100% removal of xmas berry. 100% removal of basal resprouts and saplings of target trees.
- No chainsawing, strictly Garlon 4 at 20% with or without girdling depending on girth of tree.

Year 2: Continue same strategy, but shift to west facing slope.
Year 3: Conduct followup herbicide treatments of target trees that remain alive.

2) Understory weed species control:

Year 1:

- Continue followup grass control on east and west facing slopes at 100% removal.
- Continue Clidemia, Passion vine, and Lantana control on east facing slope, focusing on area upgulch of Cyagrioba population first and moving toward back bowl and then west facing slope (Plot 1). Use clip and drip method for more native areas, cut and spray regrowth for less native areas.
- Continue Thimble berry removals at 100% in planting areas and focusing on area upgulch of Cyagrioba population first (Plot 1).
- Ensure all plantings are released from weed competition.

Year 2:

- Continue followup grass control on back bowl, east and west facing slopes at 100% removal.
- Remove remaining Clidemia, Passion vine, Lantana, and Thimbleberry at back bowl and on west facing slope (Plot 2).
- Ensure all plantings are released from weed competition.
- Begin wholescale Clidemia and Molasses grass removals from areas immediately outside of the fence. Use chainsaw and spray regrowth method for woody species, or foliar Roundup® without cutting as appropriate.

Year 3:

- Conduct followup removals of all understory weeds in fence area, focusing around outplantings first.
- Ensure all plantings are released from weed competition.
- Continue wholescale Clidemia, Lantana, and Molasses grass removals from areas immediately outside of the fence. Use chainsaw and spray regrowth method for woody species, or foliar Roundup® without cutting as appropriate.

4) Planting strategy

Year 1:

- Continue Cyagrioba augmentation on lower east slope
- Continue Silper reintroduction in sunnier, wet cliff area
- Begin Urekaa reintroduction on west face, sun bowl
- Begin Cyasub reintroduction on lower slope, west slope

Year 2 and 3: Plant in accordance with Rare Plant Stabilization Plans

Common Natives Outplanting Palette:

Canopy	Subcanopy	Understory/groundcover
*Acacia koa *Metrosideros polymorpha *Pouteria sandwicensis *Pisonia brunoniana	*Charpentiera obovata *Pipturus albidus *Urera glabra	*Hedyotis terminalis *Bidens torta *Dodonaea viscosa *Nephrolepis cordifolia *Rumex albescens *Dianella sandwicensis
Psychotria mariniana	Labordia kaalae	Carex wahuensis

* = Species planted in the highest numbers

Rare Natives Outplanting Palette:

Canopy	Subcanopy	Understory/groundcover
None	*Cyanea grimesiana var. obatae *Urera kaalae *Solanum sandwicense	*Silene perlmanii *Cenchrus agrimonioides var. agrimonioides *Schiedea hookeri
	Cyanea calycina Cyanea superba	Schiedea pentamera Neraudia melastomifolia Dissochondrus biflorus

Appendix 6B: Restoration Site Assessment

Site Name/Plot #:		**Date:**	
Location:		**Aspect: (N/S/E/W)**	
Observer:		**Elev.(in ft. at photopoint):**	
GPS of photopoint (or nearest control point):	**N:** **E:** **Accuracy:**	**Baseline Condition: (yes/no)**	
Directions/flagging:		**Plot size (sq. meters)**	

HABITAT CHARACTERISTICS (CIRCLE):

Overstory Closure >2m	**Overstory height (All that apply)**	**Understory Closure <2m**	**Topography**	**Moisture Class**	**Slope (degrees)**
Closed 75-100%	2-5m	Closed 75-100%	crest	**Dry** <25"/yr	Flat 0-10°
Intermediate 25-75%	5-10m	Intermediate 25-75%	upper slope	**Dry-Mesic** 25-50"/yr	Moderate 10-45°
Open 0-25%	>10m	Open 0-25%	mid slope	**Mesic** 50-75"/yr	Steep 45-70°
			lower slope	**Wet-Mesic** 75-100"/yr	Vertical 70-90°
			gulch bottom	**Wet** >100"/yr	
			plateau-flat		

PHOTOPOINT DATA:

Date:	**Toward (bearing):_____** **List file name below:**	**Description:**	**Yes**
		Before weed removal (baseline):	
		After weed removal:	
		After outplanting:	
		Yearly monitoring (year 1-10)	Year:

COMMUNITY COMPOSITION:

List native and non-native species by six letter code and in order of abundance for each class. See species checklist for reference.

Overstory (>2m):

Classes:	**1000-101**	**100-11**	**10-1**
Species:	1)	1)	1)
	2)	2)	2)
	3)	3)	3)

Understory/ground cover (<2m):

Classes:	**1000-101**	**100-11**	**10-1**
Species:	1)	1)	1)
	2)	2)	2)
	3)	3)	3)

OVERALL RANK OF NATIVE INTEGRITY (CIRCLE):

Percentages reflect species composition and not percent cover. Overstory (>2m). Understory/ground cover (<2m). Habitat modifying species are asterisked in the checklist.

Good	**Fair**	**Poor**
>75% native overstory	50-75% native overstory	0-50% native overstory
>75% native understory	50-75% native understory	0-50% native understory
<25% habitat modifying weeds species in understory	25-50% habitat modifying weeds in understory	>50% habitat modifying weeds in understory

List and estimate/count all naturally occurring rare elements at site (by species code) :

Plants:_____

Animals:_____

List/count all species of outplanted rare plants at site (see rare plant forms for totals):

_____

List/count all species of common natives outplanted. Date of outplanting: _____

_____

_____

Appendix 6C: OUTPLANTING CHECKLIST FOR COMMON NATIVES AND RARE PLANTS

Note: For general guidelines, see Hawaii Rare Plant Restoration Group Guidelines for Reintroduction. For very specific guidlelines, see Rare Plant Reintroduction Appendix in the Makua ImplementationPlan.

THREE WEEKS PRIOR TO OUTPLANTING

PLANT PREP:

- Re-inventory nursery as needed to plan outplanting list.
- Inspect plants for pests, disease and remove weak ones from outplanting inventory.
- Apply systemic insecticide drench (Merit).
- (optional) apply fungicide (Subdue/Banrot).
- Apply Amdro and/or spray down nursery shadehouses with general insecticide (Sevin) for ant control as needed.

SITE PREP:

- Designate outplanting areas (flag) and mark locations for outlplanting species at site with marker stakes (pin flags).
- Cut and flag service trails.
- Designate and flag staging areas.
- Re-cut drop zones and flag as needed for helicopter operations.
- Follow up weed control as needed.
- Install/prep irrigation lines and/or stage enough water on site.
- Drill holes as needed. Note for drier areas, double holes needed.
- Bring in water jugs as needed.

TAGGING PREP FOR RARE PLANTS:

- Purchase marker flags, pvc posts, metal tags.
- Engrave tags with 1) Species code, 2) Population code 3) Date of planting.
- Update database.
- Cut pvc down to 1 m lengths.
- Drill holes in pvc.
- Spray paint tips with flourescent orange or red.
- Cut enough tagging wire.
- Drill holes in plant pots.
- Attach tags to pots.

ONE WEEK PRIOR TO OUTPLANTING

- Schedule heliops with vendor if flying in.
- Prepare heliops plan using template.
- Finish site prep, plant tagging as needed.
- Prepare outplanting site plan and maps for outplanting crew.
- Bundle pvc posts and rig plant carriers if walking in.
- Re-inspect plants carefully, pulling sample plants out of pots to look for root mealy bugs etc.
- Confirm with any volunteers and/or other agency staff and give overview of plan for the day.
- Complete schematic drawing of planting plan (outplanting layout, distribution of plantings)

DAY OF OUTPLANTING

- Prep heliops equipment (plant boxes, sling nets, carabiners, PPE, radios, flight plan etc.).
- Final inspection of plants and crates. Especially check bottom of pots and crate bottoms for snails, slugs and other undesirables.
- Rig plants to carriers or arrange in plant boxes for fly in.
- Label/flag crates as needed in accordance with outplanting site plan.
- Prepare final outplanting species list and tally plant numbers (before plants leave nursery).
- Prep outplanting tools (hammer, shovels, digging cups/bowls, gloves, plant wire, flagging, extra write-on metal tags, water jugs. etc.).
- If loading plants in vehicles, secure well to prevent spillage and lay down crates or drive slow to prevent windburn/leaf stripping.
- Brief crews on heli-ops plan, outplanting plan, and timetable for the day.

7.0 POST PLANTING TREATMENT

Cyanea grimesiana subsp. obatae, a critically endangered lobelia.

Some of the following guidelines are primarily geared toward ensuring the survival of rare plants given the expense of collecting, growing and planting them in the wild. However, the techniques can also be readily applied to common natives planted in the wild. As mentioned in Ch. 2, monitoring is a critical component of measuring outplanting success.

7.1 MULCHING

Mulching involves spreading loose, readily permeable material, such as wet straw, bark, rocks or sawdust, around newly planted trees and shrubs to protect the roots, trap moisture, and prevent weed growth.

The advantages of mulching are:

- Controls weed growth
- Considerably reduces loss of moisture from the soil surface, helping to keep planted trees and shrubs alive during a dry summer or drought
- Provides insulation and thus stabilizes soil temperature
- If organic, may add nutrients to the soil and make the soil more friable

- Prevents excessive soil and water runoff which would otherwise expose and damage surface roots.
- Helps to identify plant locations and prevent trampling

There can be disadvantages to mulching as it:

- May be a source of plant diseases or a home for insect pests (e.g may cause stem rot if mulch placed directly against stems and trunks)
- May prevent water from reaching plant roots if mulch is too impermeable
- Takes time and money
- Can increase frost damage
- Decaying leaves (e.g. guava) may suppress growth because of tannins or other plant chemicals
- May prevent desirable seeds from making good seed to soil contact and germinating

Well drained mulches (e.g. wood chips) are best as they allow rain to filter down and do not rapidly break down. Rock mulches were traditionally used by Hawaiians in agricultural plots in dryland areas. Rotten kukui logs make great mulch as they hold considerable amounts of water creating a favorable microclimate as the water slowly evaporates or is released to the ground.

Commercially available jute netting may also serve as a mulch in addition to anchoring the soil along steeper slopes.

Mulching should ideally be done when the soil is moist in order to trap in available surface moisture, therefore thoroughly water the ground around the plant before applying the mulch. The immediate area should also be relatively free of weeds. After planting, apply a ring of mulch of around the plant, being careful not to bury the stem. About three inches deep is plenty. The width will vary with the size of the plant; generally the mulch ring should be as wide as the width of the crown or width of the plant (although this is often impractical for large trees).

7.2 WATERING

Most forest revegetation sites are unlikely to have a readily available water supply, making the task of watering very difficult. At the initial planting, water that is hand-carried or brought to the site in a tank can be helpful in stimulating plant growth and ensuring plant survival. In the long-term however, watering is usually impractical and shallow watering can be undesirable, because it encourages only surface root growth, when deeper root systems are needed for trees to survive through drought periods. The combination of using well-conditioned and appropriate nursery stock, skillful planting technique, and mulch usually makes follow-up and long-term watering unnecessary. The best solution is often to plant the correct species for the site at the right time of year, and the need to water can often be avoided.

If the ground is not saturated by rain at planting time, watering is needed to alleviate planting shock. Generally, plants can become stressed and wilted when outplanted because the fine root hairs which do most of the water and nutrient uptake become physically damaged or even dry out during planting. See also the planting chapter for techniques to avoid transplanting shock. To ensure that the root hairs remain functional, water and careful handling is needed when planting stock in the earth. At the time of planting, about two liters is plenty for a gallon sized plant. Be careful to slowly pour the water out to allow the soil to become saturated while minimizing wasted runoff. Water above plants if on a slope and water more slowly if soils are hydrophobic (repells water). Thereafter, each plant will have different watering needs and should be watered accordingly. Generally, deep infrequent soakings are better than frequent shallow waterings, as this encourages deeper root growth. Plantings should be regularly monitored for the first four to six weeks to ensure that sufficient water (about the equivalent of a minimum of 1 inches of rain per week) is provided.

7.2.1 CATCHMENT SYSTEMS

Catchment systems can be a relatively inexpensive means of obtaining water in remote field sites. Systems can be as simple as a tarp over a 55 gallon plastic barrel or as complex as a large tank gravity feeding several smaller holding tanks all connected by an extensive irrigation line network.

A large 1500 gallon tank feeds a smaller 250 gallon tank which is also rigged for catchment.

Whatever the chosen catchment system, the initial effort in setting up the system can offer the rewards of having water always available for planting in the dry season as well as for herbicide use.

As with any outdoor water storage tank, consideration must be given also to preventing problems associated with disease carrying mosquitoes, algae clogging lines, and rodents using the tank or becoming trapped inside. Regular maintenance using larvicides, algaecides, gutter covers, and wire meshing at intake areas should resolve most of the above problems.

7.2.2 SLOW-DRIP IRRIGATION

In remote, drier areas slow-drip irrigation systems may be a favorable option. Trickle or dripper irrigation systems are two such examples. A trickle system is comprised of a low pressure water supply which feeds a main line. The main line delivers water to lateral lines, which feed the microtubes, which water the plants. Dripper heads or soaker lines have the advantage that they do not block up as often as microtubes. Numerous other delivery systems are possible. The reference section at the end of this chapter provides a useful website describing some of the more elaborate systems employed at desert sites in the U.S. southwest.

The Pahole Natural Area Reserve Program successfully implemented the use of individual ice-drip watering systems to promote the survival of slow-growing woody natives in dry and degraded reintroduction sites on Oahu. This simple deep-pipe system is comprised of a 1/2 inch PVC pipe with the open base set 15 to 22 in. below the soil surface and an equal amount extending above ground. Two nylon zip-ties attach an inverted 2 liter bottle of frozen water or nutrient solution to the pipe. A short section of drip irrigation hose is attached to the bottle by a threaded junction in the bottle cap, and fed into the pipe through a drilled hole just above the ground. The slowly thawing water drips directly to the root zone, avoiding soil surface moisture and thereby reducing weed competition. Six gallon water jugs can also be converted to a drip system by running feeder lines from the base of the jug.

A simple ‘double hole’ technique is used when planting in the dry season by The Nature Conservancy-Oahu Program. Two planting holes are dug next to one another (about 2 feet apart for gallon sized pots) on a slope with a power auger. The outplant is placed in the lower hole. In the upper hole a one gallon plastic jug is essentially buried below ground but with a pinhole pierced on the downhill side. The spout of the jug is left open at the surface to receive water which then drips out slowly at the root zone of the plant below. Two-liter frozen water bottles can also be inverted and stuck into the spout of the jug for even slower drip watering. The plastic jug should be removed from the ground following plant establishment.

Systemic insecticides approved for use in conservation areas can also be applied to the root zone using this method for particularly valuable plantings susceptible to twig borer or other pest insect damage. An additional benefit of watering ‘below’ ground is that game birds like Erckel’s Francolin are less likely to damage seedlings and plantings as they seek out and peck around moist surface areas which also attract invertebrates. Numerous sandalwood seedlings were systematically uprooted by Francolin birds at one trial planting site in Honouliuli Preserve after followup surface waterings were done.

7.3 FOLLOW-UP WEED CONTROL

As noted above, mulching can be an effective way of ensuring the outplants are not lost to weed re-growth. Hand-weeding in a 3 foot diameter around the base of outplants will do much to prevent strangling and surface water competition. Also, herbicides that are grass specific such as Fusilade® or more non-selective such as Roundup® can be carefully sprayed around the base of outplantings. A low volume spray with a funnel over the nozzle to minimize herbicide drift is a quick and effective means of ensuring target plant establishment. Ideally however, most of the troublesome weeds should have been removed prior to planting. Herbicide users should be careful not to overapply herbicides as some herbicides may also kill valuable soil microflora which assist plants through soil creation and nutrient uptake.

7.4 REFERENCES

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8.0 UTILIZING VOLUNTEERS AND NEIGHBORING COMMUNITIES

Because of the magnitude of restoration work and its associated funding limitations, volunteers can significantly contribute to the progress and long-term success of a restoration project.

8.1 RECRUITING VOLUNTEERS

Leaders of every volunteer organization are challenged with recruiting a steady flow of eager and active participants. The group with an effective recruitment program has vitality and clout; it seems attractive and fun to outsiders.

The following is a list of the types of people who volunteer:

- Parents whose kids just left for college
- Retired people, particularly those recently retired and looking for new interests
- College graduates who, after a couple of years of establishing themselves in a job, begin to look for after-work activities
- Single people with extra time
- Parents with kids in school
- Couples looking for a common activity to share
- People in organizations with related interests, such as the Audubon Society and Sierra Club
- Locals interested in preserving their "own" backyard
- Workers with jobs that give them free time at unusual hours
- Organizations such as the Jaycees, Rotary, Lions Clubs, Women's Club, etc.
- College and high school students (Some instructors give extra credit for participating. Be aware, however, that students are transient and rarely leaders.)
- Youth groups, such as Boy Scouts or Girl Scouts

ADDITIONAL WAYS TO RECRUIT VOLUNTEERS TO HELP YOU IN YOUR EFFORTS:

- Post fliers in neighborhood businesses.
- Send the information to local newspapers and radio and television stations.
- Develop your own newsletter to be distributed locally.
- Set up booths at community fairs, county fairs and other local events.
- Present slide shows to community groups.
- Recruit on field trips or community expeditions to other natural areas.
- Hand out brochures to interested people you meet in the preserve.

8.2 RECRUITING WORKSHOP

A recruiting "workshop" is really just an informational meeting to acquaint potential volunteers with the particular preserve and the opportunities to help there. It is one of the most effective and time-efficient tools for getting large numbers of people involved. Here are steps to follow for workshops that get results:

8.2.1 PLAN

Plan the meeting well in advance so that it is well-organized, meaningful and brief. Start planning in the summer for a workshop scheduled in fall, when people return from vacations and are ready to make a new commitment. Spring is also a good time for holding recruiting events.

8.2.2 PUBLICIZE YOUR WORKSHOP IN AS MANY PLACES AS POSSIBLE

Contact related local groups—the Audubon Society, Sierra Club, Malama Hawaii, local garden clubs, college organizations—to publicize the workshop in their newsletters; in turn offer to list them as sponsors. Send out news releases and flyers. Post at universities, libraries and other meeting places.

8.2.3 MAKE THE MEETING INTERESTING

Make the meeting interesting with slides and discussions. Provide potential volunteers with materials so they can easily learn about the unique feature of the preserve and what they can do help manage them. Talk about specific projects and volunteer success stories. Emphasize that, in this day and age, natural areas can't take care of themselves,

and that each volunteer can have a fun, educational and satisfying experience from the work.

8.2.4 PLAN A FOLLOW-UP MEETING, TRAINING SESSION, OR WORK DAY

Schedule it within a week or two, if possible. Don't make the recruits wait; they may go somewhere else. Give them some meaningful work to do.

8.3 PLANNING VOLUNTEER PROJECTS

8.3.1 PRE-PROJECT SURVEY

Before bringing volunteers out to the preserve for a work project, make sure you are familiar with the area in which they will be working. If you have not been to the area recently, do a walk through prior to the work project, or at least get a report from someone who has been there. Note any possible safety hazards, and get an idea of how much work needs to be accomplished.

8.3.2 SET A ROSTER AND NUMBER OF PARTICIPANTS

Prior to the work trip, set a roster of participants. Decide on an appropriate number of participants for the project based on the scope of the work to be done, available transportation, tools, level of supervision necessary, etc. Try to match the number of participants needed with volunteers and groups who are interested in helping out. Make sure you screen potential volunteers who are unfamiliar with the preserve by providing them with a description of the area, the approximate amount of time they can expect to spend, and the physical effort that will be involved. Call the volunteers to confirm 2 – 3 days before the work trip and at that time give them the details on where and when to meet, what to bring etc. Make sure work trip leaders have a list of the names and phone numbers of participants, so they do not have to wait around to see who will show up.

8.3.3 SCOPE OF WORK FOR THE DAY

Decide on a scope of work for the day, and outline it for the participants. Describe what needs to be accomplished and why the work is important. Try to set a scope of work that is achievable in the amount of time available: If it is part of a larger project, define it in terms of a set of smaller projects that can be accomplished. For example, rather than having the volunteers spread through the entire site to pull weeds, you can define smaller areas where they can work, then have them move on if they finish. Prepare a list of the tools that will be used and provide instructions on how to use them.

8.3.4 DIVIDE WORK INTO SEVERAL, WELL-DEFINED TASKS

Decide what tasks need to be accomplished to complete the project. Make sure every detail of the task is clearly understood. For example, with a weed control project, make sure the control treatment methods are simple, and that the target weeds are readily recognizable and in a localized area. Provide a thorough demonstration for the group and ask for questions. Carefully monitor volunteers, especially when they are just getting started, to make sure they understand and properly carry out the task at hand. Provide gentle correction, when necessary.

Determine if some tasks can be done at the same time in different areas, or if they will need to be done sequentially (e.g. weeding can often be done at the same time as taking photographs, but holes have to be dug before posts and signs can be installed). Try to have tasks for people with varying physical abilities. See what other things can be accomplished at the project site if there is extra time.

8.3.5 HAVE INITIAL PRIORITY TASKS, THEN ADDITIONAL TASKS TO ACCOMPLISH

If the group finishes the initial objectives and there is time and they are willing to keep on going, plan for additional tasks that can be accomplished in the area. A good idea is to plan to work until lunch, then take a break and assess whether to continue with the main tasks, start new ones, or end for the day.

8.4 MAKING WORKDAYS FUN AND PRODUCTIVE

In order to make workdays fun and productive, consider the following:

- Have the work effort planned ahead of time. If you expect more than 10 volunteers, have additional leaders identified and trained.

- Bring everything volunteers forget. Bring extra water, bug spray, and sun screen.

- Have the right tools. When possible, it's best to get a supply of the safest and sturdiest tools, gloves and safety glasses to be used by volunteers as required. It is OK to ask volunteers to bring their own tools, but be very specific about what and what not to bring.

- Get everyone aquainted with each other. At the beginning of the day, stand in a circle and introduce everyone. Make all feel welcome and part of the group. Let people know who is experienced and able to answer questions.

- Explain goals of the day's work effort. Discuss the task involved. Clear up items like what to do with lunches, what happens if someone leaves early, etc.

- Explain the potential safety hazards of the workday, and the steps you are taking to minimize them. Have everyone sign a waiver and make sure adults sign for minors. If anyone is uncomfortable with the risks and does not want to participate, let them know that it's OK, and give them an opportunity to leave gracefully.

- Demonstrate the use of tools. Show how to use tools safely and in a manner that keeps them in good condition. Watch how tools are used and correct the volunteer's technique gently and as soon as possible.

- Speak with new volunteers individually, or assign a specific person to take them aside and talk about the work and the site. Find out how the new recruits heard about you. It is important that everyone has a good time; the social aspect gives individuals a sense of loyalty and belonging.

- Make sure that you or someone else is providing on-the-job education and training at each workday, if necessary. Show newcomers how to identify the plants that they're cutting. Repeat the lesson often with different people during the workday.

- Schedule time for lunch and/or snacks. Many people don't eat breakfast. Keep an eye out for people who run out of gas; newcomers, particularly, may feel uncomfortable about speaking up.

- Give a short tour at the middle or end of the work session, if people are in the mood. Volunteers should get a chance to enjoy the area and see what they are working for. In fact, this learning experience is why many volunteer. Consider doing some whale watching or bird watching in season and seek other opportunities to make the experience special.

- Take time at the end of the work day to reflect on what you've accomplished and thank volunteers for their help. Point out the difference the day's work has made, and explain how it fits into the overall management picture.

- At the end of a long hot day in the sun, a cooler of cold drinks and a few snacks will go a long way toward making volunteers feel appreciated.

8.5 MOTIVATING VOLUNTEERS

A recent issue of *Audubon Activist* explained: "Ask not what volunteers can do for you. Ask instead what you can do for them." Management often means motivating. Factors that motivate are:

- *A sense of accomplishment*

- *A sense of belonging*: We like to think of an organization as "my chapter," or "my school." As we prepare to go to a workday we like to think: "When I get there I'll see Helen and Bob and the whole crew! Together we'll work on the preserve, watch birds and eat desserts."

- *A sense of ownership*: People like personal responsibility, their own project or "turf." Yet they want to be part of the big picture and see how their efforts are contributing to an end result. Note: teams of people can also have turf.

- *The authority to think and make decisions*: People want to feel they are part of the decision-making process. Whether or not every suggestion is used isn't nearly as important as the volunteer knowing the steward is sincerely listening.

- *Obtainable goals*: People want to see their efforts come to fruition. Realistic goals are important to keeping a sense of momentum and accomplishment among volunteers. They must be able to see progress.

- *Purposeful, defined activity*: Volunteers like to feel their efforts are accomplishing something worth their investment of time, talent and effort. They also want to know exactly what is expected: figure out in advance how much time a job requires, and if it requires working alone or with others.

- *Challenges within abilities*: An assignment should be challenging, but if it is totally beyond one's abilities, the person is likely to give up. Be available to give volunteers advice and periodic training in the subjects applicable to their assignments. If a job seems huge, then break it down into two or three smaller jobs, or form a committee to do it.

- *Information*: This is probably the single most important duty of the steward. Too many times we've all heard someone say with a touch of bitterness: "No one tells me what's going on around here." It takes time to make that phone call or write a note, but it's worth the investment. Keep volunteers updated with newsletters and invitations to attend meetings and conferences, and encourage them to submit information and stories to the newsletter.

- *Confidence*: Some folks run the whole show, not because there is no one else to do it but because they don't trust others and may have conveyed that feeling. It takes patience to break in a volunteer with little experience. But you may have a volunteer whose skills will exceed your own. Let them know you think they can do the job, then give them the freedom to do it.

- *Recognition*: It takes only seconds to say: "Thanks for your help. I really appreciate it." No matter how self-effacing people appear, most appreciate a little pat on the back. Think of ways to publicly thank volunteers as well.

Also, realize that not all volunteers are going to stay. It's part of the process. But the recruitment process should be continuous. Keep it going and be creative. Be nice, be consistent—and have fun.

8.6 SAFETY CONCERNS WHEN WORKING WITH VOLUNTEERS

Safety is everyone's concern. You should seek opportunities to discuss it, and volunteers should be encouraged to report safety concerns.

8.6.1 BASIC SAFETY CONSIDERATIONS

- Tell volunteers that safety is a priority. Be specific. Identify potential risks and hazards before volunteers encounter them. Also, provide an opportunity for

volunteers to “bow down” gracefully, particularly before performing an activity which could be dangerous.

- Have every volunteer sign a volunteer waiver form. Minors must have an adult sign the form for them. While waivers are not necessarily legally binding, having volunteers sign them gives you an opportunity to review hazards and safety procedures and have volunteers acknowledge that they understand them.

- Insure that first aid kits are present, well equipped, and readily available at all scheduled and impromptu work days. Learn the principles of first aid and encourage other volunteers to do the same.

- Carry a cell phone and radios. Know the location of the nearest hospital. Leaders should also have emergency contacts for all participants.

- Carefully “match” the work plan with the ability and health of the volunteers present and the weather conditions.

- Always check on volunteers throughout the day. Make sure everyone remains hydrated, fed, and not overly fatigued.

8.6.2 SAFETY CONSIDERATIONS WHEN USING POWER TOOLS

- Only trained, experienced and responsible volunteers should be allowed to use power equipment. The operator should know how to safely operate the machine and recognize when the equipment must not be used, such as in the case of a dull blade or defective safety shield.

- The use of the equipment should be planned so that there is minimal interaction between operators and other volunteers. This can be accomplished by scheduling different types of workdays or separating work parties. Inexperienced volunteers must never be allowed to work in the immediate vicinity of power equipment.

- Power tools should only be used when weather conditions allow for safe use. For example, rain and wet conditions, which prevent safe footing, would often preclude their use.

- Operators should always use the appropriate safety gear, including goggles, hearing protection and, for chain saw operators, safety pants.

- Power equipment operators should work in groups or pairs, so they can "trade off" when fatigued and provide an additional margin of safety if someone is injured.

- Operators should use appropriate PPE, including eye and hearing protection, and chaps for chain saw operators.

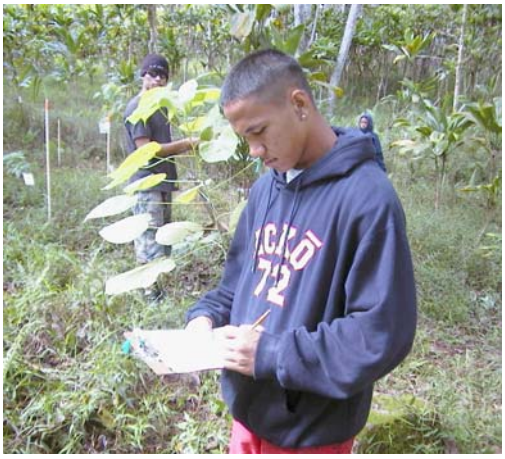
- Do not use power tools when fatigued. "Trade off" with another qualified operator when necessary.

- Always stop power tools when putting them down or carrying them. Carrying a power tool with the engine running is dangerous. Stop string trimmers and brush cutters when you moving from one work area to another and not actually cutting. Stop power tools if anyone enters your work area unexpectedly or if you are signaled to do so. Stop power tools if you need to communicate with others. Don't try to make yourself understood over engine noise.

- Carry gasoline only in an approved safety can. Use separate, marked containers for straight gas and oil/gas mix. Refuel power tools in a clear, level area, away from your work area. Move away from the refueling area before restarting power tools. Do not carry gasoline inside an enclosed vehicle.

- Maintain an awareness of what you are doing at all time and that you are operating a machine that can cause serious physical injury to yourself and others.

8.7 RECORD KEEPING



After each workday, or series of workdays, you should report your progress. Include your work activities on reports. Make sure every work group and subgroup has one or more experienced volunteers, depending on the task involved.

For each workday, have that volunteer write a brief description of the work completed, along with any other information that would be important for future use. Specifically, make note of the:

- Work accomplished that day
- Location of the worksite
- Number of participants
- Start time and the end time of the day
- Actual time on the job site
- Tools used
- Problems, obstacles encountered
- Any recommendations for follow up work

Write or tally up the information and save it in a dated file, along with your management schedule. It will prove useful for grant reports, and marking trends and accomplishments. Summarize your workday with a workday report and keep it for your records. Photo documentation is also very useful for reports, presentations, and for the recruitment of new volunteers.

8.8 REFERENCES

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Nukuiiwi, *Stronglyodon ruber*