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 <u>immediately</u> 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