Risk Analysis of Various Weed Control Methods

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Nearly all weed control methods influence both the abiotic and biotic components of the ecosystem. These include the following: mechanical control techniques; cultural practices such as grazing, burning, flooding or revegetation, the introduction of biological weed control agents; and the use of chemicals. This paper reviews many of the risks of weed control and, in some cases, suggests preventative measures to minimize those risks' occurrences.

Mechanical Control Strategies

Hand pulling and hoeing

Hand pulling and hoeing are the oldest forms of weed control used by humans. Although labor intensive and relatively ineffective for the control of perennial weeds (with the exception of the weed wrench), they typically cause minimal environmental impact. However, soil disturbance around the removed plants can create an ideal site for re-establishment of new seedlings or rapid invasion of another undesirable species. In addition, trampling of habitat by large numbers of people in these sites can damage sensitive native species and further disturb the soil. The potential also exists for serious physical injury when removing plants with spines, prickles, or razor-like or spiny leaf margins, such as gorse (*Ulex europaeus*), wild blackberries (*Rubus* spp.), jubatagrass (*Cortaderia jubata*), and many of the noxious thistles. In other cases, handling plants which contain toxins or skin allergens can expose an individual to their poisonous effects. These risks can be minimized by wearing appropriately protective clothing and gloves.

Chaining or bulldozing

Chaining is a technique occasionally used to remove shrubs from rangeland ecosystems and to enhance grass populations (Bovey 1987, Jacoby and Ansley 1991). A more drastic technique involves bulldozers to remove larger shrubs or trees, such as saltcedar (*Tamarix* spp.), from infested habitats (Jorgensen 1996). These techniques dramatically alter soil structure, create large disturbed sites susceptible to re- or new invasions, and can have a negative impact on the associated animals and insects in the treated areas. Furthermore, heavy equipment increases soil compaction in the traveled sites and produces a considerable amount of exhaust from fuel consumption. Other motorized equipment, such as chainsaws, can present a significant human health risk.

Tillage or cultivation

Tillage is more common to agricultural areas than to non-crop areas. On occasion, tillage can be used in rangelands, along roadsides, and in utility rights-of-way. Tillage uses plows or discs to control annual weeds by burying plant parts. This is more effective on annuals than perennials. In contrast, harrows, knives, and sweeps can be used to damage root systems or to separate shoots from roots. This technique must be applied when the surface soil is dry, or fragmented plant segments will re-grow and possibly aggravate the problem. While a single till will often control annuals, repeated tillage is necessary for the control of many perennials.

Despite its effectiveness in the control of annual weeds, tillage can expose soil to both wind erosion, under dry conditions, and water erosion, under extremely wet conditions. It addition, it can alter soil structure, prolong the longevity of noxious weed seeds by burying their seeds deep in the soil profile, and in many cases, increase a perennial weed problem by spreading rhizome fragments or by stimulating emergence of new shoots from underground stems. This is often the case with perennial pepperweed *(Lepidium latifolium)* or Canada thistle *(Cirsium arvense)*. Heavy equipment produces fuel exhausts and can increase the atmospheric discharge of soil particles, commonly referred to as PM 10 (particulate matter $\leq$ 10 microns in diameter).

Mowing

Mowing is a popular control technique along highways and in recreational areas. It has less impact on the environment than tillage. However, like tillage, it can also lead to fuel exhaust and increase in PM10. In this case, the particles are very small plant fragments, often detached hairs. Perhaps the greatest risk associated with mowing is the impact on plant community composition. Proper timing can minimize these risks, whereas mowing at the wrong time can increase noxious weed populations. This is typically observed with yellow starthistle *(Centaurea solstitialis)* when mowing is conducted too early in its life cycle. Mowing can also be detrimental to insect populations. For example, the proper time to mow yellow starthistle is during the early flowering stage. However, at this time, damage to seed-feeding biocontrol agents can be significant.

Cultural Control Methods

Grazing

Grazing with cattle, sheep or goats can be an effective method of controlling noxious weeds. The success of this method often depends upon proper timing. For example, the density of yellow starthistle increased when sheep grazed plants in the rosette stage (Thomsen et al. 1993). Intensive overgrazing has also led to the invasion of weeds into many of our rangeland s (Billings 1994). In some cases, grazing can select for a particular weed or group of weeds. For example, soon after bolting, purple starthistle *(Centaurea calcitrapa)* develops stiff sharp bracts that protect the flower heads. Animals forage around these plants, eliminating its plant competitors. This selective pressure can lead to more rapid infestation. In contrast, grazing can be very non-selective and may endanger sensitive non-target species. Goats are typically generalist browsers and can effectively control certain noxious species. However, when confined they can intensively forage on both desirable and undesirable species and may even strip the bark off trees. Livestock can also trample desirable sensitive species and can spread noxious weeds over a wide area when seeds become attached to hair or when they remain intact after passing through the digestive system.

Competitive reseeding programs

Reintroducing competitive species into infested non-crop areas as part of a control program is essential to the sustainable management of noxious weeds. In the most desirable cases, competitive, endemic, native species should be re-established. For example, native willows (*Salix* spp.) and cottonwoods (*Populus* spp.) have been used to replace saltcedar in riparian areas. However, in most cases, particularly rangeland environments, endemic native species do not appear to be capable of outcompeting noxious weeds. In yellow starthistle infested areas, many studies have used more competitive species, such as crested wheatgrass *(Agropyron desertorum)*, pubescent or intermediate wheatgrass *(Elytrigia intertnedia)*, orchardgrass *(Dactylis glomerata)*, rose clover *(Trifolium hirtum)* or subterranean clover *(Trifolium subterraneum)* (Borman et al. 199 1, Ferrell et al. 1993, Prather and Callihan 199 1, Thomsen et al. 1996). These species are not native to California, but provide good livestock forage and are a sustainable option for rangeland maintenance.

Even in areas where California natives are reintroduced, they may not be genotypically endemic to these habitats. In addition, once established, many of these species, especially the perennial grasses, develop into near monocultures. This can have a dramatic impact on total plant and animal diversity within these sites. Finally, successful re-seeding programs often utilize drills attached to tractors. Like tillage and mowing, this process produces exhaust fumes and can lead to increased soil compaction.

Burning

Three major risks are associated with prescribed burning as a method of controlling non-crop weeds. First, air quality issues, including PM10 emissions, can be a significant problem when burns are conducted adjacent to urban areas (Campbell and Cahill 1996). This potential problem can be avoided or reduced by conducting burns only in more isolated regions not adjacent to urban areas. Public relations problems can be minimized by educating residents about the intended goals of the project prior to the burn.

Second, a major risk of prescribed burning is the potential for loss of control of the fire. Particularly true when burns are conducted during the summer months, this can be minimized by proper preparation and thorough involvement of local fire departments and the California Department of Forestry (CDF).

Third, perhaps the most overlooked risk of burning is the impact fire may have on small animals and insects unable to escape the burn. For example, burning for control of yellow starthistle during the summer undoubtedly damages seedhead feeding biocontrol insects and their larvae.

Additionally, continuous burning as a control strategy may increase soil erosion and impact the plant composition within a site. Species that complete their life cycles before the burn will be selected for, while those with later flowering times will be selected against. Although this is a potential concern, data has shown that while a few plants are negatively impacted by continuous burning for yellow starthistle control, the survival of most native species is enhanced by the burns (Hastings and DiTomaso 1996).

Biological Control

Biocontrol is typically considered to be environmentally safe, energy efficient, cost-effective, and often self-sustaining (McMurtry et al. 1995). Unfortunately, only about 29% of the biocontrol efforts in the United States have demonstrated some level of success (DeLoach 1991). Despite the overwhelmingly positive aspects of biocontrol, some risks do exist. Most biocontrol agents introduced to the United States are native to other continents. Although we often study the host specificity of these organisms under quarantine conditions, little is known of their impacts on the ecosystem as a whole, including on other insect populations. In addition, our understanding of the nature of host specificity is poor. Consequently, no guarantee exists that the introduced biocontrol agent will not itself become a pest by changing its food preference from weeds to desirable plants after it is released. This has only rarely occurred with plant biocontrol organisms (Rees 1978) but has arisen on a number of occasions with the introduction of animal control agents.

In some cases, accidental introductions of pathogens or insects can occur when biocontrol agents are released. For example, the pathogen *Nosema* was accidentally introduced as a contaminant of *Trichosirocalus horridus,* a weevil introduced for the control of musk thistle *(Carduus nutans)* (Andres and Rees 1995). More recently, a second species of peacock fly *(Chaetorellia succinea)* was identified as a contaminant of released populations of *C. australis* for the control of yellow starthistle (Villegas et al. 1997).

Weed biological control agents pose other potential risks. Grass carp *(Ctenopharyngodon idella),* native to the Amur River of China, is a herbaceous fish which provides excellent control of aquatic weeds, particularly hydrilla *(Hydrilla verticillata).* Each individual fish can eat enough aquatic plants to grow 3 to 5 lb. per day and adults may weight as much as 100 lb. at maturity (per. comm., L. Anderson). However, the presence of this bottom feeding species in aquatic environments can reduce water quality. In addition, their rapid growth rates often lead to crowding out of desirable game fish and elimination of protective cover for young fish. For this reason, they are banned in many states and in most counties in California. As another example, the endangered willow flycatcher, *Empidonax traild extimus,* uses saltcedar to nest in areas where willows have been displaced. The release of *Diorhabda elongata,* a leaf feeding beetle specific for saltcedar control, has been delayed because of concerns that it will further threaten flycatcher populations (DeLoach et al. 1996).

Herbicides

Herbicides are the most widely used method for controlling weeds, both in agricultural and non-crop environments, and are generally considered the most economic and effective. The potential risks associated with herbicide use have been widely publicized both in the scientific literature and the public press. Although these risks are often greatly exaggerated, improper use of herbicides can lead to several potential problems, including spray or vapor drift, water contamination, animal or human toxicity, selection for herbicide resistance in weeds, and reduction in plant diversity.

Spray and Vapor Drift

Herbicide drift may injure susceptible crops, ornamentals, or non-target native species. Drift can also cause non-uniform application in a field and/or reduce efficacy of the herbicide in controlling weeds.

Several factors influence drift, including spray droplet size, wind and air stability, humidity and temperature, physical properties of herbicides and their formulations, and method of application. For example, the amount of herbicide lost from the target area and the distance it moves both increase as wind velocity increases. Under inversion conditions, when cool air is near the surface under a layer of warm air, little vertical mixing of air occurs. Spray drift is most severe under these conditions since small spray droplets will fall slowly and move to adjoining areas even with very little wind. Low relative humidity and high temperature cause more rapid evaporation of spray droplets between sprayer and target. This reduces droplet size, resulting in increased potential for spray drift.

Vapor drift can occur when a herbicide volatilizes. The formulation and volatility of the compound will determine its vapor drift potential. Potential of vapor drift is greatest under high temperatures and with ester formulations. Ester formulations of 2,4-D and triclopyr are very susceptible to vapor drift and should not be applied at temperatures above 80°F.

Herbicides are applied by airplane, helicopter, ground sprayer, or roller and rope-wick applicators. Nozzle height controls the distance a droplet must fall before reaching the weeds or soil. Less distance means less travel time and less drift. Wind velocity is often greater as height above ground increases, so droplets from nozzles close to the ground would be exposed to lower wind speed. Applications are more likely to be above an inversion layer when herbicides are aerially applied. This will not allow herbicides to mix with lower air layers and will increase long distance drift.

A number of measures can be taken to minimize the potential for herbicide drift. Chemical treatments should be made under calm conditions, preferably when humidity is high and temperatures are relatively low. Ground equipment reduces the risk of drift, and rope-wick or carpet applicators nearly eliminate it. Use of the correct formulation under a particular set of conditions is important. For example, applying an ester formulation of a postemergence herbicide during the hotter periods of the summer is not recommended because of the potential for volatilization.

Groundwater and surface water contamination

Most herbicide groundwater contamination results from "point sources." Point source contaminations include spills or leaks at storage and handling facilities, improperly discarded containers, and rinses of equipment in loading and handling areas, often into adjacent drainage ditches. Point sources are discrete, identifiable locations that discharge relatively high local concentrations. These contaminations can be avoided through proper calibration, mixing, and cleaning of equipment.

Non-point source groundwater contamination of herbicides is relatively uncommon. However, it can occur when a mobile herbicide is applied in areas with a shallow water table. In this situation, the choice of an appropriate herbicide or an alternative control strategy can prevent contamination of the water source.

Surface water contamination with herbicides can occur when herbicides are applied intentionally or accidentally into ditches, irrigation channels or other bodies of water, or when soil-applied herbicides are carried away in runoff to surface waters. Direct application into water sources is generally used for control of aquatic species. In these cases, a restriction period is required prior to the use of this water for human activities. Accidental contamination of surface waters can occur when irrigation ditches are sprayed with herbicides or when buffer zones around water sources are not wide enough. In many situations, alternative methods of herbicide treatment, including rope wick application, will greatly reduce the risk of surface water contamination.

Loss of a preemergence herbicide through erosion may occur when a heavy rain follows a chemical treatment. It is possible to minimize herbicide runoff to surface waters by carefully monitoring weather forecasts before applying herbicides. Applications of preemergence herbicides should not be made when forecasts call for heavy rainfall. Precipitation between 0.5 and 1 inch should allow a preemergence herbicide to percolate into the soil profile, thus minimizing the subsequent risk of surface runoff. Interaction of water and soil type and texture is also important.

Toxicology

When used improperly, herbicides can pose a health risk. This can be minimized with proper safety techniques. Applicators should follow label directions and wear appropriate safety apparel. This is particularly true during mixing, when the applicator is exposed to the highest concentration of the herbicide.

Although animals can also be at some risk from herbicide exposure, most herbicides registered for use in non-crop areas, particularly natural ecosystems, are relatively non-toxic to wildlife. To prevent injury to wildlife, care should be taken to apply these compounds at labeled rates.

The trend in herbicide toxicity of the past 25 years has been toward registration of less toxic compounds (Table 1). From 1970 to 1994, the percentage of herbicides with an LD50 value (lethal dose in mg herbicide/kg fresh animal weight which kills 50% of male rats) of between 1 and 500 mg/kg decreased from 15 to 7%, while herbicides in the least toxic category (>5000 mg/kg) increased from 18 to 42%. In addition the average LD50 of herbicides registered in the United States increased from 3031 to 3806 mg/kg.

Table 1. Trends in herbicide toxicology, based on acute male rat LD50 values (mg herbicide/kg animal weight) for herbicides registered in the United States in 1970, 1983, and 1994.

		Percentage of herbicides in LD50 category			
Year	Avg. LD50	1-50	51-500	501-5000	>5000
1970	3031	5	10	67	18
1983	3281	3	9	61	27
1994	3806	2	5	52	42

LD_{50} values obtained from Herbicide Handbook (1970, 1983, 1994).

Herbicide Resistance

Selection for herbicide-resistant weed biotypes is greatly accelerated with the continuous use of herbicides, particularly those with a single mode of action. For example, widespread resistance to the sulfonylurea herbicides (sulfometuron and chlorsulfuron) has been reported for Russian thistle (*Salsola tragus*) along Califomia highways (Holt and Prather 1996). These compounds all inhibit a single enzyme (acetolactate synthase) involved in the production of branched-chain amino acids. In Washington, continuous use of picloram led to selection for resistance in yellow starthistle (Callihan and Schirman 1991). This population was also cross-resistant to clopyralid (Valenzuela-Valenzuela et al. 1997). Integrated approaches for the control of invasive weeds can greatly reduce the incidence of herbicide-resistant biotypes.

Effects of herbicides on plant diversity

Continuous broadcast use of one herbicide or a combination will often select for plant species demonstrating greatest tolerance. Since even selective herbicides tend to injure several species, repeated use will eventually have a negative impact on plant diversity. This can be minimized or avoided by employing an integrated weed management approach.

Conclusion

Prior to the employment of any weed control method, or combination of methods, several criteria should be considered including:

1. efficacy of the techniques to be employed;
2. financial considerations;
3. physical or political limitation imposed at that particular site;
4. desired objectives of the management program;
5. the potential risk of each technique.

When pursued properly, most control strategies pose less environmental risk than employing no management strategy. An integration of several weed control strategies will generally provide the best long term approach with the least impact on the ecosystem.

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