Best Management Practices (BMPs) for Wildland Stewardship

Protecting Wildlife When Using Herbicides for Invasive Plant Management

California Invasive Plant Council
& Pesticide Research Institute

Controlling invasive plants is often a high priority when protecting wildlife habitat, and those working to protect wildlife from invasive plants want to be sure their approach is safe for wildlife. This manual of Best Management Practices focuses on how land managers can best protect wildlife when using herbicides to control invasive plants. While any invasive plant control method can potentially impact wildlife, chemical control methods are the focus of this report. The toxicology information presented shows data on herbicides most commonly used for invasive plant management in California natural areas. The Best Management Practices are drawn from methods used by experienced land managers. Along with providing guidance for land managers, this document is designed to inform the interested public about how herbicides are used to control invasive plants in natural areas.

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Top small photo: Herbicide applicator by Jim Dempsey, California State Parks
Bottom small photo: Pacific tree frog by Sandy DeSimone, Audubon Starr Ranch

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James Law of the Santa Ana Watershed Association treating tree of heaven.
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1. Introduction

Wildland Stewardship, Invasive Plant Management and Wildlife

Invasive plants impact wildlife habitat by displacing important native plant species that provide food and shelter. Some also change ecosystem processes such as wildfire frequency and intensity, hydrology or soil chemistry. The US Fish and Wildlife Service, the California Department of Fish and Wildlife, the National Audubon Society, and other organizations charged with protecting wildlife recognize the detrimental impact of invasive plants. California's Wildlife Action Plan lists invasive species as one of the major threats to wildlife diversity in the state (CDFW 2015).

Wildland stewardship is the practice of managing natural areas with particular goals, such as restoring habitat for particular wildlife or plant species and protecting ecosystem functions such as water storage or soil stability. Increasingly, wildland projects also aim to strengthen the ability of an ecosystem to be resilient to disturbances, such as fire, drought, flood, climate change, and pollution. Stewardship projects often include removal of invasive plants, and controlling invasive plants is an immediate action that can support ecosystem resilience, as described by the US Fish and Wildlife Service in its "National Fish, Wildlife and Plants Climate Adaptation Strategy" (USFWS 2013).

> *"'Invasive species' means an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." (Federal definition from Executive Order 13112 in 1999)*

*Local populations of the endangered least Bell's vireo in southern California increased dramatically after invasive giant reed (*Arundo donax*) was removed from the Santa Ana River and replaced with native plants, going from 19 nesting pairs in 1986 to more than 400 in recent years. Santa Ana Watershed Association, http://sawatershed.org Photo: B. Moose Peterson. USFWS.*

Wildland managers employ several key strategies for reducing the impact of invasive plants. Preventing the spread and establishment of invasive plants is one of the most important and cost effective steps. Early detection and rapid response to new occurrences can be very effective and efficient if new occurrences are detected early. Once an invasive plant has become established, it is important to eradicate outlying populations (outliers) that may spread into new areas. Finally, protecting vital assets such as endangered or threatened species can require site-specific projects to control invasive plants.

When designing a plan for invasive plant control, wildland managers consider factors including the biology of the invasive plant, other species that could be affected, type and stability of the habitat, site access, worker safety, public safety, and cost. Managers choose from a range of control methods depending on the situation. Chemical control using herbicides is one component in the wildland management toolbox. Herbicides may be used as a standalone tool or in combination with non-chemical methods. In most cases, when herbicides are used, a recommendation from a state-licensed Pest Control Advisor is required.

Many invasive plant management projects in wildlands are undertaken to protect wildlife, either as the primary goal or as a secondary goal in projects to restore ecosystem processes or vegetation communities (see Appendix A). Any potential impacts to wildlife from invasive plant removal are of concern to natural resource managers, and every method of invasive plant control has benefits and costs. For example, the disturbance caused by workers and mowing or excavation equipment can be more significant than impacts from herbicides. Mechanical methods of invasive plant control may result in even more disturbance. Although all control methods pose some level of risk, this manual focuses on the use of herbicides (chemical control). (See Appendix A for results from the survey.)

Like any tool, herbicides must be used properly. Herbicide users are required to follow the pesticide label approved by the US Environmental Protection Agency and, in California, the California Department of Pesticide Regulation regarding the type of herbicides appropriate for particular uses, application methods and timing, worker safety, and environmental protections. The Best Management Practices (BMPs) in this manual were developed to help wildland managers further minimize the potential impacts to wildlife from herbicide applications, based on practices developed by those in the field and on the latest toxicological information for particular herbicides.

The Importance of Best Management Practices

The term Best Management Practices, or BMPs, is used to describe techniques that have been found to be effective and practical in achieving an objective while making optimal use of resources. They are generally voluntary guidelines that may complement what is required by law. We consulted with a technical advisory team of experienced natural resource managers and surveyed 102 wildland managers to gain more information about current practices in the field. (See Appendix A for results of the survey.)

Removing Arundo donax biomass from a riparian area in San Benito County. Herbicide is typically used as part of an integrated approach for eradicating Arundo populations. Photo: Ron Ross

Effective implementation of BMPs for wildland management requires a process of continuous learning. These voluntary BMPs were developed with the understanding that each situation and entity has different needs, constraints, and resources. The applicability and effectiveness of BMPs will vary with existing land uses, degree of human disturbance, the objectives of the land managers, and the resources available for management activities. Some BMPs may be implemented with existing resources, while others may require allocation of additional resources. Readers who need more detailed information should refer to the Resources Section at the end of this manual. While this manual focuses on California, the BMPs are equally applicable elsewhere.

2. Invasive Plant Management and Wildlife

Management Methods Used in Wildlands

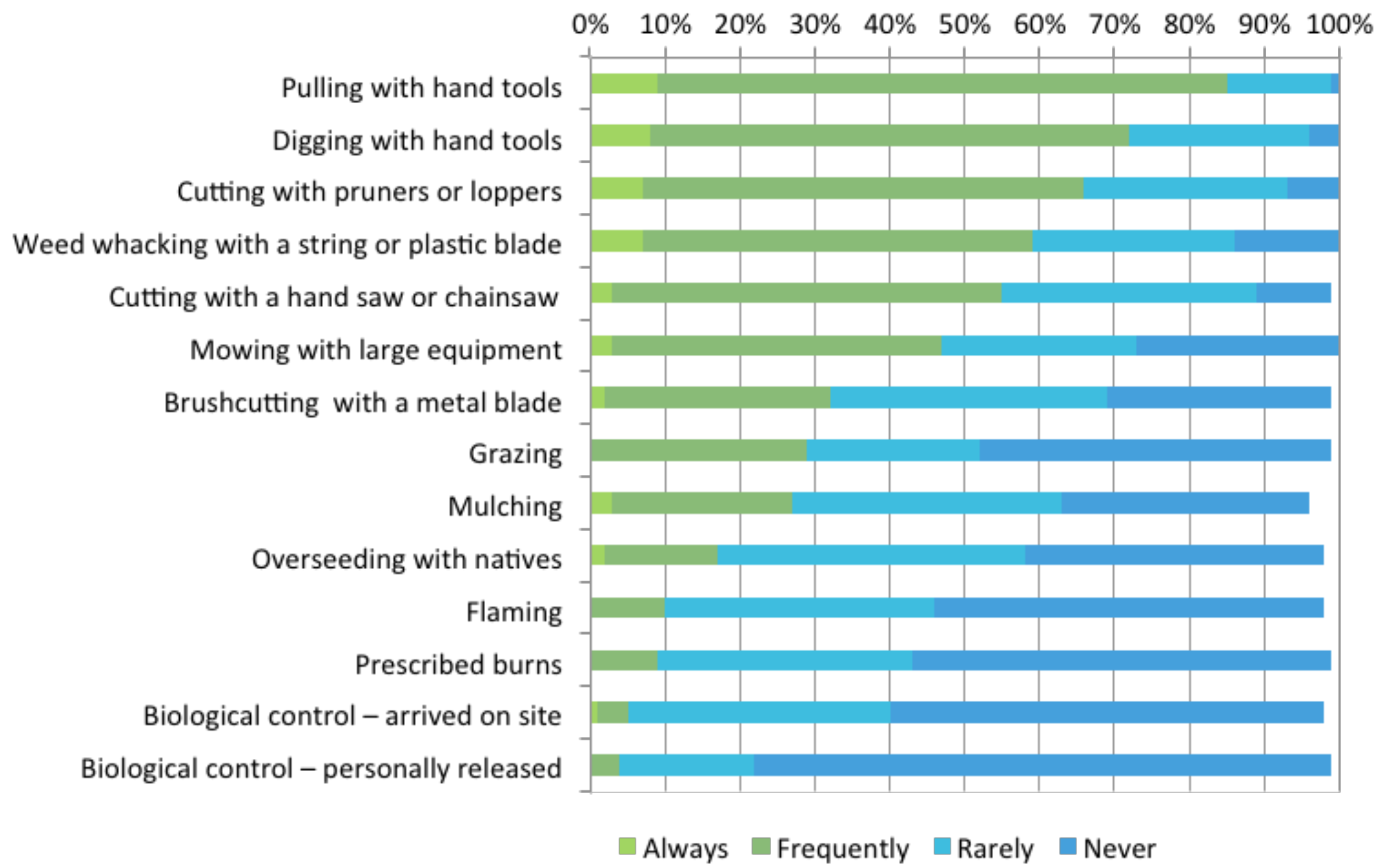
Wildland managers must balance many factors when choosing which invasive plant control methods to employ, including potential impacts to native plants, wildlife, workers, and the public, while ensuring that the method chosen will achieve the desired result. An Integrated Pest Management (IPM) approach allows managers to balance these many considerations.

When an invasive plant population is small, complete eradication may be an attainable goal, while in other cases suppression or containment may be the goals. Below, we describe methods typically used to control invasive plants. Wildland managers most often use manual or mechanical methods and chemical control methods. Grazing, prescribed fire, and biocontrol are less common. Each method has advantages and disadvantages, and each method has the potential for undesired non-target effects. Each is appropriate for particular situations but not others. “Non-target effects” refers to unintentional impacts to ecological processes or organisms other than those that are the intended target of a management action; for example,

The University of California defines Invasive Plant Management as “...an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment.” www.ipm.ucdavis.edu/GENERAL/whatisipm.html

Pipe vine swallowtail and native bee feeding on invasive bull thistle. Some invasive plants are used as a nectar source by insects. Photo: Brian Murphy, Walnut Creek Open Space Foundation

Non-herbicide tools used by land managers



From 2012 Cal-IPC survey (see Appendix A).

a frog that is accidentally trampled or a native plant that is accidentally sprayed with herbicide when a worker is treating an adjacent invasive plant. For more detailed information on methods used, refer to the survey results in Appendix A and the Resources Section at the end of this manual.

Mechanical: These techniques include pulling, cutting, excavating or physically damaging plants. Depending on the species and size of infestation to be controlled, mechanical control may use equipment ranging from hand saws, pruners, weed wrenches or spades to chain saws, power mowers, tillers, excavators or backhoes. Mechanical methods are the most commonly employed of all methods, and are part, if not all, of most invasive plant control approaches. Mechanical methods can usually be very precisely targeted, and many tools can be used without extensive training. There are challenges to using mechanical methods, however. Some plants are difficult to control using only mechanical methods because the plants resprout from roots or reproduce from fragments left behind. Use of heavy equipment can result in non-target damage and soil compaction, and pulling plants out by the roots results in soil disturbance that increases likelihood that invasive plants will re-grow or re-invade. Mechanical methods can be costly, physically demanding and labor-intensive, and some

Grazing with goats, sheep, or cattle can help control invasive plants. Photo: John Knapp

Controlling klamathweed in Yosemite National Park. Photo: National Park Service

tools require extensive training and can injure workers if used improperly. In some situations mechanical control may be specified by environmental conditions or landowner preferences, and in other situations these methods may be prohibited near threatened or endangered species of wildlife.

A weed wrench is a useful tool for mechanical removal of invasive plants. Photo: Doug Gibson, San Elijo Lagoon Conservancy

Chemical: Chemical control involves applying an herbicide to the invasive plant. This is discussed in more detail in a following section. Some of the reasons chemical control is widely employed (72% of wildland managers said they "frequently" or "always" use herbicides for invasive plant control; 28% said they rarely or never use herbicides) are that: it can be economical; highly effective in killing the target plant; it can generally be well targeted to the plants of concern; it avoids ground disturbance and other physical impacts to the habitat; it reduces risk of physical injury for workers. Some of the reasons chemical control is not used in certain circumstances are that: it can have non-target impacts; it requires particular expertise, capacity, and legal requirements; a landowner or community may not support the use of herbicides. In most cases, when herbicides are used, a prescription from a state-licensed Pest Control Advisor is required.

Grazing: Grazing by cattle, sheep, or goats can be successful depending on the species (of both invasive plant and grazing animal), duration, stocking rate, and intensity of grazing. Grazing to control vegetation requires high densities of animals focused in an area. Grazing is sometimes used in areas that no longer have the native animals that were once part of the ecological balance. Desirable plants may have to be protected from grazing. In some cases, however, grazing can increase infestations. This can occur with overgrazing or when weed seeds or other propagules are accidentally spread by livestock transported from infested areas to non-infested areas. Twenty-nine percent of the land managers we surveyed said they frequently use grazing.

Prescribed burns are not frequently used due to safety and air quality concerns. Photo: Jennifer Chapman, National Park Service

Biocontrol agents are released after years of host-specificity testing. Photo: Mike Pitcairn, California Department of Food and Agriculture

Prescribed burning: Prescribed burning is the intentional use of fire in a specified time and location to kill unwanted species, remove the thatch of dead plants, recycle nutrients, and stimulate desirable plant species. Fire can be used to destroy the seedbank of a particular species, or, on the other hand, to trigger germination deliberately so that managers can control a species strategically. However, fire can also stimulate the germination of some invasive species unintentionally. Equipment used to control prescribed burns can also spread weeds if not cleaned thoroughly. Due to fire safety and air-quality concerns, prescribed burning can only be used after obtaining necessary permits and under specific weather conditions. Therefore it is less common than other methods and not often used near heavily populated areas.

Biological: Biological control, or biocontrol, uses the natural enemies of invasive plants. The US Department of Agriculture (USDA) oversees the collection of beneficial organisms like insects or pathogens from the native range of an invasive plant, and then conducts extensive tests to judge their effectiveness and to rule out possible effects on non-target plants, a process that takes years. Once it has passed all tests, a biocontrol organism can be released into populations of the invasive plants. Biocontrol can be an extremely effective method especially in those situations where widespread pest populations make other control strategies infeasible. However, biocontrol does not eradicate an invasive plant; successful biocontrol systems generally require a population balance of the two organisms that keeps the pest species suppressed while still maintaining sufficient pest populations to allow the continued survival of the biocontrol species.

In California, the Department of Pesticide Regulation (DPR), part of the California Environmental Protection Agency, regulates the sale and use of herbicides and other pesticides. DPR also works with the California Department of Fish and Wildlife to investigate any wildlife losses associated with pesticide use. County Agricultural Commissioners are responsible for local enforcement of pesticide laws and regulations for issuing permits for herbicide applications that involve the use of restricted pesticides. Herbicide applicators are required to be licensed by DPR when they conduct herbicide applications for hire. Some government agencies require that their herbicide applications be supervised by DPR-certified applicators. More information on California's pesticide regulations and licensing is available on DPR's website.

Some biocontrol organisms have been quite successful, while others have failed to establish populations in the wild or have not reduced the invasive plant as much as was hoped. Within California the state Department of Food and Agriculture (CDFA) has historically overseen biocontrol programs initiated by the US Department of Agriculture. County Agricultural Commissioners typically collaborate with CDFA to release and monitor biocontrol agents in their respective counties.

Herbicides and Application Methods

Herbicides are chemicals used to control plants through one of several "modes of action" for affecting the plant's metabolic processes. Most herbicides are synthetic chemicals, although some organic herbicides are available. Synthetic herbicides are typically designed to be systemic; they move through the plant to the growing root and shoot tips to damage the entire plant. In contrast, contact or "burndown" herbicides damage only the plant tissue with which they come in contact.

Some herbicides are selective, meaning they will affect a limited number of plant groups (i.e. only grasses or only broadleaf species), while others are non-selective. (Note that non-selective herbicides may be used selectively to control weeds by using directed applications or by making an application in a season when native plants are dormant and less likely to be affected.) Herbicides used for invasive weed management are generally applied to plant foliage but may also be applied to stems or cut stumps or even to the soil. The most effective herbicides are generally systemic.

The herbicide active ingredient is often formulated by the manufacturer with additional, non-herbicidal ingredients to improve its effectiveness. For example, a surfactant or penetrant may be added to help the herbicide cover and penetrate a leaf's waxy outside layer as a first step to absorption and translocation. Such adjuvants may also be added to the spray tank by the applicator.

Controlling milk thistle on Catalina Island. Photo: Catalina Island Conservancy

Herbicide use in wildlands has both similarities with and differences from herbicide use in other settings such as agriculture or along roadsides. Some of the same application techniques are used; however, spot applications of herbicides in a wildland situation are often used to control individual plants. In agriculture, broadcast applications to entire fields are more common. A limited number of chemicals are typically used in wildlands compared to those used in agriculture. In a successful invasive plant management program, the amount of herbicide used on a particular site will decrease over time as the invasive plant population declines. Table 2-1 lists the herbicides most commonly used for invasive plant control in wildlands.

Foliar applications: Foliar techniques involve the application of herbicide directly to the leaves of target plants, often from a backpack or other low-volume sprayer. Larger infestations may require the use of broadcast applications with boom-type equipment attached to land-based vehicles or aircraft. These larger-scale projects typically involve a single invasive species

TABLE 2-1: Herbicides used for invasive plant management in California wildlands

Active ingredient	Trade names (examples)	Used on	Survey respondents using
Aminopyralid	Milestone ®	Broadleaf species	41%
Clopyralid	Transline ®	Broadleaf species, particularly Asteraceae (sunflower family) and Fabaceae (pea family)	39%
Chlorsulfuron	Telar ®	Many broadleaf, both annual and perennial, some non-grass monocots (e.g. onionweed)	27%
Fluazifop-P-Butyl	Fusilade DX®	Grass species only	19%
Glyphosate	RoundUp ®, Aquamaster®, many others	Non-selective, affects both grass and broadleaf species	84%
Imazapyr	Chopper ®, Stalker®, Habitat®, Arsenal®	Non-selective, affects both grass and broadleaf species	35%
Triclopyr	Garlon 3A®, Garlon 4®	Woody and herbaceous broadleaf species	63%
2,4-D	Amine 4®, Weedar®	Annual and perennial broadleaf species, some woody species	10%

Based on 2012 Cal-IPC survey (see Appendix A). Herbicide trade names are examples and do not imply endorsement.

that has completely excluded native plants. Other foliar methods use a nozzle that drizzles or drips chemical on a targeted plant, or a nozzle that shoots a "fine line" accurately for some distance. Workers may carry the herbicide in a backpack with an attached nozzle that sprays or drips the chemical, or they may use a nozzle and hose attached to a tank on a vehicle. In our survey, 77% of wildland managers said they "always" or "frequently" use foliar spray for invasive plant control.

Stem treatments: Stem treatments apply herbicide to the stems of individual woody trees or shrubs. Often the stem is cut, either partially or completely, to allow the herbicide to penetrate to the cambial layer. Herbicides can also be injected into stems using custom tools. The cambium is the actively growing area of the woody plant's trunk, located inside the protective outer bark. For example, in a "cut stump" treatment, the main stem(s) of a shrub or tree is completely cut and then herbicide is painted or sprayed onto the cambium on the exposed stump to prevent regrowth. The advantage of this method is that it targets a specific plant, uses only a small amount of herbicide (though at a high concentration) that is absorbed into the stump, and usually does not require an additional treatment. In our survey, cut stump was the most commonly used stem treatment, with 52% of respondents saying they "always" or "frequently" use this method.

Organic Herbicides

Organic herbicides are typically herbicides approved for organic agricultural production. However, some herbicides considered "organic," like pelargonic acid, have not yet been approved for use in organic agriculture. Some of these herbicides are occasionally being used for invasive plant management in wildlands.

However, there are significant limitations to their effectiveness, practicality and cost. The organic herbicides damage the parts of the plant they touch, but none of them have the ability to move through the plant's vascular system. Thus they can kill young seedlings, but not more mature plants which can generate new growth from carbohydrates stored in their root system. Organic contact or "burndown" herbicides include products such as clove oil, pelargonic acid, acetic acid, caprylic and capric acids, and limonene.

The active ingredients in organic herbicides are typically substances that the US Food and Drug Administration (FDA) generally recognizes as safe (GRAS) when added directly to human food. However, these ingredients are highly concentrated when used as herbicides, and can pose hazards to wildlife or to the applicator, with some of these products having a DANGER hazard warning label due to the potential for irreversible eye damage if splashed into the eyes. Others have some toxicity

TABLE 2-2: Organic Herbicides

Active ingredient	Trade names (examples)	Used on	Survey respondents using
Acetic acid	Nature's Wisdom®, Weed Pharm®,	Non-selective, annual and perennial broadleaf species and grasses.	6%
Clove oil	Matran®	Non-selective, annual and perennial broadleaf species and grasses.	5%
Pelargonic acid*	Scythe®	Non-selective, annual and perennial broadleaf species and grasses.	2%
Limonene	Avenger®	Non-selective, annual and perennial broadleaf species and grasses.	0%
Caprylic and capric acids	Suppress®	Non-selective, annual and perennial broadleaf species and grasses.	0%

**Pelargonic acid is considered an organic herbicide, but is not approved for organic agricultural production. Trade names are examples and do not imply endorsement.*

to wildlife; for example, clove oil (active ingredient eugenol) is toxic to fish and aquatic invertebrates. Organic herbicides degrade rapidly in the environment (within a few days to a week) and do not pose any long-term risks due to runoff from a treated site.

Because organic herbicides are so limited in utility, and because so much less information exists on their impacts to wildlife, they are not included in our risk charts.

Adjuvants

Adjuvants are compounds added into an herbicide mix to improve efficacy. They perform various functions, including: enhanced plant uptake of the herbicide; better mixing of otherwise incompatible herbicides; increased adhesion of the spray to plant surfaces; and reduced spray drift. In many herbicide products, adjuvants are included as part of the pre-mixed formulation as purchased. Applicators can also add adjuvants to spray mixtures prior to application.

California requires registration of adjuvants as pesticide products, but the US EPA does not, so relatively less is known about adjuvants compared to pesticide active ingredients. Acute toxicity information is often available, with some of these compounds being labeled as strong eye or skin irritants, but information regarding chronic toxicity is sparse. Other states, such as Washington, and European countries require environmental toxicology data on adjuvants.

For many pesticide products containing adjuvants as part of the formulation, the compounds are not explicitly identified on the label or the Safety Data Sheet. Unless they are on one of US EPA's lists of more toxic chemicals, they do not have to be identified. The identity of these ingredients in a pesticide or adjuvant product is legally protected from full disclosure as "Confidential Business Information."

Without more detailed information, it is not possible to conduct a comprehensive risk assessment on adjuvants, so they are not included in the risk charts, which focus on herbicidal active ingredients. However, at least one adjuvant is known to pose hazards to wildlife—the surfactant used in the original formulation of RoundUp®, polyoxyethyleneamine (POEA). This surfactant is more toxic to aquatic life than the active ingredient glyphosate—so we include glyphosate with POEA as a separate entry in the risk charts. Adjuvants with low toxicity to wildlife include modified seed oils, alkyl ethoxylates, and silicones. Nonylphenol ethoxylates (NPEs), which are used in some adjuvants (and many consumer products), may be linked to endocrine disrupting effects in wildlife. Research is developing on this subject.

See the USDA Forest Service (USFS) website for a comprehensive 2007 review of the available information on adjuvants (link) and additional information on the commonly-used nonylphenol ethoxylates (NPEs) (link).

Potential Impacts of Herbicides on Wildlife

An herbicide's potential risk to aquatic and terrestrial wildlife is assessed by the EPA before the product is registered for use in wildlands. When using an herbicide registered for use in wildlands, any risk to wildlife can be further mitigated by following Best Management Practices, as described below and in Section 3.

Understanding Risk

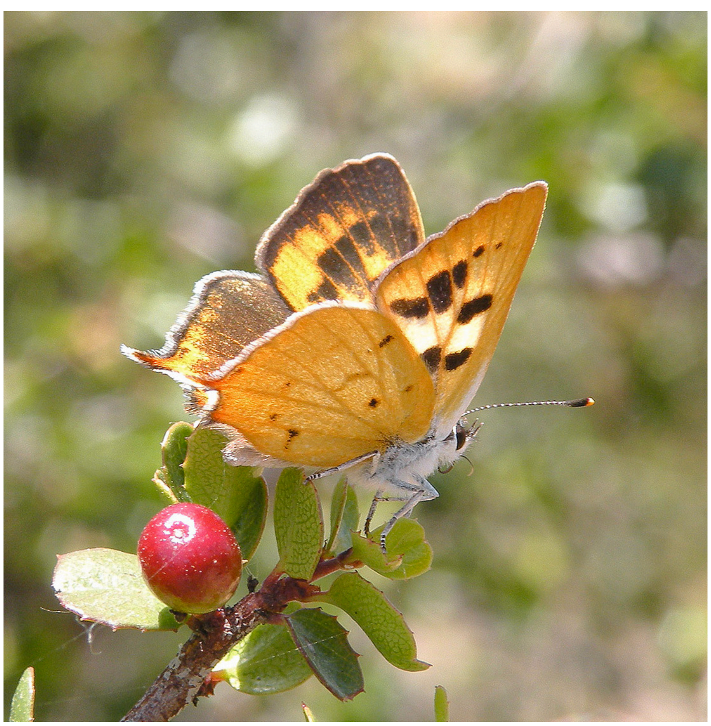
A clear understanding of the risk of using a particular herbicide requires knowledge of the toxicity of the herbicide as well as the likelihood of exposure. Toxicity is a measure of how harmful any chemical compound is. It can be measured in many different ways and evaluated for many different biological systems. However, even the most toxic chemical cannot have any effects on an organism without an exposure. Because wildland weed management with herbicides necessarily introduces chemicals into the environment, the challenge is to estimate the amount of exposure (the dose) for different types of wildlife, as well as non-target plants. The presence of an herbicide in the environment may not be a concern if the exposure for non-target organisms is sufficiently low that it is unlikely to have a negative impact.

An assessment of risk involves understanding the toxicity and likely exposure paths for various organisms that may be exposed to an herbicide. Risk assessments are used by project managers to identify those exposures that might be problematic. The project manager then uses this information to decide whether herbicides can be used without undue risk and to develop mitigation actions to reduce risks.

Most of the herbicides used in wildlands are of fairly low toxicity; however, not all herbicides have equal impacts on wildlife. For example, some pose greater risks to aquatic life and are therefore not approved for use in aquatic settings. Others have long-lasting pre-emergent herbicidal activity that may restrict plant emergence or growth for several months after treatment. In areas that are to be re-vegetated soon after treatment, these herbicides may not be the best choice if their residues remain biologically active in the soil after desirable plant species are seeded or transplanted.

Below, information is provided on herbicide toxicity and possible exposure scenarios for wildlife. The analysis presented in this document is based on the best available scientific data, but herbicide users need to keep in mind that risk analysis is a dynamic, ongoing process, as new data is generated on exposure potential and toxicity. Future studies or refined analyses may reveal risks that were previously unknown; alternatively, they may provide assurance that risks are actually lower than previously understood. With this in mind, invasive weed managers should stay informed about the latest technical developments about the chemical and non-chemical strategies they use.

Several unifying concepts are important in minimizing adverse effects. These ideas will be discussed in detail in the context of BMPs in Section 3 and the charts in Section 4. At a minimum, herbicide users should be familiar with:



The Hermes copper butterfly inhabits coast sage scrub and chaparral in San Diego County. Photo: Michael W. Klein, Sr. USFWS

Striped skunk at a spring. Photo: Cindy Roessler, Midpeninsula Open Space District

1. The types of wildlife and vegetation present, including endangered species. The wildland weed manager should learn enough about each species (life cycle, breeding habitat, food supply, shelter needs, etc.) to avoid impacts.
2. The relative risk posed by the herbicide to different wildlife and plant taxa that may be present and the anticipated exposure scenarios. Consideration should be given not only to the active ingredient, but also other compounds added to an herbicide formulation or added to the "tank mix" to be applied, such as surfactants.
3. The relative persistence of the herbicide in the environment, primarily in soil. Herbicide persistence is measured in terms of "half-life." One half-life is the amount of time it takes for the herbicide to break down to 50% of its original concentration in soil or water. A good rule of thumb is that it takes five half-lives for more than 97% of the herbicide to be fully degraded. Herbicide persistence is discussed in more detail in Appendix D.
4. The mobility of the herbicide in runoff water. Off-site movement in surface water and leaching to groundwater are both primarily influenced by the herbicide's water solubility and its tendency to adsorb to soils. Factors affecting herbicide mobility are discussed in more detail in Appendix D.

Coast Horned Lizard on rock near creek in Hot Springs Canyon. Photo: Audubon Starr Ranch

Slender salamander. Photo: Cindy Roessler, Midpeninsula Open Space District

Insects

Insects are a diverse class of animals that are part of the food web on which many vertebrate species depend. Butterflies, bees, wasps and even mosquitoes pollinate plants that then provide fruits and seeds for other animals. Flies and beetles eat rotting debris, which helps recycle nutrients in the ecosystem. Aphids and many other soft-bodied insects suck the juices of plants and are themselves a high-protein food for other insects, reptiles, amphibians, birds and mammals.

Most insects are so small and so intimately connected to vegetation that it is difficult to avoid spraying them directly, along with the invasive plants being treated. Honeybees are routinely tested for sensitivity to herbicides and are broadly representative of other insects. While most herbicide active ingredients used in wildland weed management pose very low toxicological risks to invertebrate species, some of the inert ingredients in formulated herbicide products may pose a greater risk. For example, some oil-based emulsifiable concentrate formulations may be harmful to soft-bodied adult or larval insects like aphids or caterpillars.

Reptiles and Amphibians

Lizards, snakes, turtles, frogs, newts and salamanders are frequently residents of areas where invasive plant management is planned. These species can be exposed to herbicides through direct sprays and spray drift, and through consuming herbicide-contaminated water, prey, or plants. Amphibians may be especially vulnerable, since they spend a portion of their life cycle as aquatic organisms and often only need small puddles or seasonal streams for growth. The inert ingredients in a formulated herbicide product may be as important to evaluate as the active ingredient in terms of the risk they pose to amphibians.

Fish and Aquatic Invertebrates

Fish and aquatic invertebrates are often more sensitive to herbicides than terrestrial animals because of their physiology or the increased exposure potential that may result from herbicide movement into aquatic sites. Aquatic species can be exposed to herbicides through

Black-tailed jackrabbits, like this one at Bitter Creek National Wildlife Refuge in Kern County, consume large quantities of vegetation, both fresh and dried, relative to their size. Photo: Scott Rheam, USFWS

Wilson's warbler. Photo: Audubon Starr Ranch

Phainopepla. Photo: Audubon Starr Ranch

direct spray, spray drift, spills or surface runoff. Though few commonly-used herbicide active ingredients are highly acutely toxic to aquatic organisms, toxic effects can result from the exposure to other ingredients in formulated products, such as surfactants. Treatment of aquatic vegetation presents its own challenges, since decomposing plant matter can reduce the dissolved oxygen content enough to suffocate aquatic life in the treated area; this potential should be considered when treating large areas of lakes and ponds. With the current suite of herbicides typically used in invasive plant management, bioaccumulation of herbicides in fish tissue is not a problem, since these herbicides are typically metabolized and/or excreted fairly quickly.

Mammals

Deer, coyotes, mountain lions, wood rats, gophers, and mice are just a few of the mammals that populate wildlands. These animals may be exposed to herbicides through contaminated food or water, as well as direct sprays, spray drift, and contact with treated vegetation. The toxicity of herbicides to mammals has been better studied than for most other species because they are used as surrogates for human toxicity assessments. Studies on mammals allow for evaluation of a wide variety of parameters, including reproductive, developmental, and neurological effects in exposed populations, as well as effects on blood chemistry, organ weights, and body weight gain or loss.

Bird nest in artichoke thistle. Photo: Janet Garcia, UC Riverside

The most abundant mammals in a typical wildland area are rodents. They are small enough and abundant enough that they may be directly sprayed or exposed to drift during an herbicide application, particularly with ground spray equipment.

Deer and other herbivores may browse on treated vegetation. Once the vegetation is dead, it becomes less attractive to eat; however, in situations where a selective herbicide is used that kills only broadleaf plants or only grass plants, the treated, but unaffected plant species may pose a dietary exposure risk.

Birds

Birds in wildland areas include large carnivorous birds like hawks or ospreys, herbivorous species like geese and ducks, small insectivorous birds, and small fruit and seed-eating birds. All of these species can be exposed to herbicides through their food and drinking water. The highest risks are typically for birds eating sprayed vegetation, since that is often the target of the application, and the likelihood of being exposed is higher than for those species eating contaminated prey. In general, the herbicides used to control invasive plants do not pose significant acute toxicity risks to birds when used under typical use scenarios; however, less is known about chronic and reproductive effects. To minimize risk, applications during nesting season should be avoided if possible.

3. Best Management Practices

The Best Management Practices (BMPs) listed below help minimize the potential impact of herbicides to wildlife and their habitats.

Federal and state regulations restrict activities where certain species are present or near certain types of habitat such as streams or wetlands. Wildland managers are responsible for obtaining and following the proper permits. Wildlife species that are listed by federal or state agencies as threatened, endangered or special status may require specific protocols for surveys or avoiding impacts. Other species, such as migratory birds or salmon, are protected by law. This section provides BMPs that complement legal requirements for applying herbicides and that are intended to strengthen general protection for all wildlife and their habitats. They should be used where they do not conflict with legal requirements for particular species or sites.

These BMPs are compiled from the collective field experience of longtime wildland managers. The General BMPs are broadly applicable to all herbicide treatments. These are followed by BMPs for foliar applications and stem treatments. Many of these BMPs are straightforward and can be easily integrated into standard practice. Others may require additional resources. A few may even conflict with each other (for instance, seasonal timing considerations) and require careful evaluation to balance multiple factors. Solid program design helps reduce potential for impacts to wildlife. For instance, treating plants before a new crop of seeds has matured can reduce the number of treatments needed, which in turn reduces the potential for impact. In a successful weed management program, the amount of herbicide used will often decrease over time as the infestations become smaller.

Flagging plants to be treated or those to be avoided helps ensure a more targeted application. Photo: Noa Rishe, California State Parks, Angeles District

General Wildlife BMPs

GW1: Know your site.

1. Know how to identify the plants you are controlling and how to distinguish them from similar species.
2. Map or flag the locations of surface water (streams, lakes, ponds, springs, etc.) and their current status (flowing or not). Maps of groundwater may be available from the local water district. Some herbicides are mobile in both surface and groundwater and may pose risks to aquatic organisms or water quality.
    a. Be aware of water sources just outside your boundary.
    b. Many of the BMPs listed that apply to surface water will also protect groundwater.
3. Map areas that are sensitive to soil compaction and vegetation trampling. This will influence decisions about the number of workers and types of equipment used on a particular site.
4. Be mindful of soil conditions that could affect herbicide use, such as soil types, infiltration rates, slope, aspect, and hydrology of the site.
5. Identify resources available for your site, such as databases that catalog background data on conserved lands in your region.

GW2: Record wildlife observations.

1. Track the types of wildlife present on site. This information is important for understanding any potential impacts of herbicide treatment and for designing protocols that protect wildlife.
    a. Consult with state and federal wildlife agencies regarding special status species (for instance, those that are federal or state- listed as threatened or endangered) at your site that require a qualified biologist to survey with specific protocols.
    b. Use the California Department of Pesticide Regulation Endangered Species PRESCRIBE database to learn if there are endangered species in the vicinity of the application site and if there are any recommended use limitations on specific pesticide products used in those areas.

Very young fawns are vulnerable because they will not move even if people or equipment approach them. Photo: Cindy Roessler, Midpeninsula Open Space District

2. Train treatment crews and others who work in the field to identify and report wildlife observations. Consider working with a local wildlife organization to create training materials. Have a clear system for recording wildlife observed in nesting or rearing behaviors.
    a. Training crews on basic wildlife life cycles and behavior will help them generalize that information to new situations.
    b. Smartphone applications such as iNaturalist may be useful for creating species lists.
    c. Observations of threatened, endangered or special status species should be reported to the California Department of Fish and Wildlife for inclusion in its Natural Diversity Database.
3. Watch for birds exhibiting nesting behavior, such as carrying nesting material or food or consistently singing in one spot. Look for nests in trees or evidence of nests such as whitewash on stems or scat on the ground. Be aware that many grassland birds nest on the ground and their nests are difficult to see.

4. Look for signs of active mammal or reptile burrows in grasslands. Signs include fresh tracks or scrapes near the burrow, remains of prey, and scat.
5. Determine routes for any heavy equipment to avoid impacting wildlife.
6. Monitor wildlife during treatments to identify and mitigate any apparent potential for impact, if feasible. During post-treatment monitoring, document any observed shifts from baseline conditions as feasible. This can be used both to gauge positive impacts on wildlife from restoration and to spot any negative impacts from herbicide treatment.

GW3: Create separation between wildlife and treatment areas

1. Create buffer zones around habitat as appropriate to provide untreated areas for wildlife. (This is typically more important with a broadcast treatment than with spot treatments.) These buffers can be around the perimeter of the entire site, but may also include sensitive areas such as bird nesting sites or game trails. Mark any "do not treat" areas clearly ahead of time to guide field work.
2. Have a clear protocol to avoid trampling sensitive species or habitats.
3. If treatments are extensive, consider treating your site in stages or in rotation, leaving a portion untreated during each stage so that wildlife can move to these areas as needed.

A helmet used as a quick place to protect a juvenile California mountain kingsnake during medusahead treatment Photo: Cindy Roessler, Midpeninsula Open Space District

4. Be aware that the presence of workers walking or driving on-site can be a greater risk to wildlife than the herbicide itself. Have a crew member walk slowly in front of mechanized equipment (when this is not hazardous) to alert or spot wildlife.
   a. Snakes flushed by equipment can be moved a short distance outside the treatment area or placed in a bucket with a locked lid in the shade so they do not move in front of equipment.
   b. Very young fawns will not move from their hiding place and are vulnerable to being run over.

General Herbicide BMPs

GH1: Consider the full range of control tools.

1. When conducting an Integrated Pest Management (IPM) assessment, look at all potential treatment methods, and assess the potential wildlife and habitat impacts of each.
2. When using herbicides, use the most specifically targeted application method that can effectively achieve program goals.

GH2: Consult a licensed PCA and use Qualified Applicators

1. Licensing by the California Department of Pesticide Regulation ensures the highest level of knowledge about herbicide application. A Pest Control Advisor, or PCA, is authorized to write official recommendations for treatment, and an experienced PCA will help you understand herbicide labeling, keep you updated on bulletins from the US EPA, and bring extensive background on real-world considerations for herbicide applications.
2. California state-certified applicators (e.g., those with a Qualified Applicator Certificate (QAC) or License (QAL)) oversee treatment on the ground, and the more of your crew that has undergone training and licensing with DPR, the better you will be able to successfully implement the BMPs in this manual.

GH3: Consider timing of herbicide application.

1. Know the effective timing of the herbicide and application technique you are using based on its "mode of action" and the target plant's annual growth cycle. Success in treating the target, which reduces the amount of treatment needed and therefore potential for impact, should be a top priority.

Flax leaf broom threatens endemic St. Catherine's lace on Catalina Island. Removal of broom involves cutting at the base and treating the stump with glyphosate to prevent resprouting. Photo: Catalina Island Conservancy.

2. Consider adjusting herbicide application by season to avoid sensitive times for wildlife species, such as bird nesting season or bloom periods for plants that are important for pollinators. Application timing can also enhance efficacy and selectiveness of the treatment, which can decrease potential for non-target impact. Different wildlife species may be susceptible at different times, so wildland managers need to find a balance that protects wildlife species at their site while still meeting invasive plant management project objectives.
    a. Treatments that avoid nesting season will impact fewer birds. Some projects, such as streambed alteration projects, legally require treatment outside of nesting season (California Department of Fish and Wildlife Section 1600 permitting), and other projects can minimize impacts to birds by observing a similar black-out period. Treatments at the very beginning or end of the nesting season will impact fewer birds than those in the middle. Concentrate your applications in a few days rather than spreading throughout the season, if possible.
3. Consider adjusting time of treatment to a particular time of day; for instance, bees tend to be less active before the sun rises and after it sets, or at temperatures below 50°F.
4. Avoid herbicide applications if rainfall is expected within 24 hours. (This is conservative since many formulations may be "rain-fast" in substantially less time; refer to the herbicide label for detailed information). Avoid treating when temperatures are too high or low (refer to label for restrictions). Extreme temperatures may reduce efficacy by reducing herbicide absorption and translocation in target plants. Further, herbicide applications made during hot weather can increase the potential for a few herbicides to volatilize (change from liquid to gas). Of the herbicides commonly used in wildlands, only the ester forms of 2,4-D and triclopyr pose significant volatilization risks when air temperatures exceed 85°F. Silicone-based surfactants may evaporate at high temperatures before they have adequately facilitated penetration of the plant's cuticle.
5. Do not treat when wind speed and direction may cause herbicide drift to sensitive sites.
    a. While drift prevention measures should be based on site-specific factors, wind speeds that are less than 12 mph do not generally cause substantial drift, especially when low volume or hand-held equipment is used.
    b. In some cases, wind speeds that are less than 3 mph indicate the presence of a temperature inversion. These still conditions can also have the potential to contribute to off-target herbicide damage by trapping airborne pesticide vapors or spray aerosols close to the ground rather than allowing them to disperse. However, damage caused by temperature inversion is almost always associated with large-scale agricultural pesticide applications, especially those applied by aircraft.

GH4: Consider herbicide formulations.

1. Consult the risk charts in Section 4 to assess the potential for wildlife impacts for different herbicides. While still meeting your project objectives determine if you can select the herbicide with the least potential for impacts for your situation. Otherwise,

determine whether additional protections are needed to mitigate any potential effects. Discuss these concerns with the state-licensed Pest Control Advisor preparing recommendations for your site.

2. Surfactants may increase the toxicity of an herbicide formulation, especially to aquatic organisms and terrestrial insects. Consider using products formulated for aquatic use and adding a low-toxicity surfactant when working in upland areas where amphibians may be present. This can reduce potential for impact from surfactants. Be aware of water features, drainage ditches, springs, saturated soils, or depressions that may hold water and support wildlife.
3. Be accurate with calibration rates and use the minimum concentration that will be effective. Follow label instructions and incorporate information on effective rates for the particular plant species and treatment method (see Resources Section). Over-application that results in persistent residuals of soil-active herbicides can reduce the recruitment of desirable plant species. Under-application can be ineffective in killing target plants, requiring follow-up treatment.
4. Conduct as few treatments as possible, since the act of entering the area to be treated may itself have the most significant potential for impacts to wildlife. Treating once with an herbicide with slightly higher potential for impact may have less overall impact than multiple applications with a lower-impact herbicide.

GH5: Follow safe procedures for transporting, mixing, and loading herbicides.

1. Herbicide spills have the greatest potential for harm. Take great care to avoid spills. You can also establish protocols that limit spill potential such as:
    a. Limit the amount of herbicide that can be transported in a vehicle (e.g. carry no more than 5 gallons of concentrated herbicide or 100 gallons of diluted herbicide).
    b. Transport concentrated herbicides in a spill-proof, non-food container in addition to the container that comes with the product.
2. Mix and load herbicides only in pre-designated areas. Select areas where a potential spill would be most easy to contain and will have the least impact.
    a. Mixing areas should have few native plants or other desirable species; not be susceptible to erosion or run-off; have easy access for containment and clean up of spills; and be located away from water bodies.
    b. Use a basin or other container under the mixing containers to keep spills off the ground in the mixing area.
    c. Load spray equipment away from any body of water.
3. Add a marker dye to the herbicide mixture so workers can readily see any spills. Dye also helps workers see any drift or mis-application to non-target plants, and to monitor where they have sprayed previously.
4. Carry a spill kit to contain and remove any spills immediately and train crews on procedures for doing so.
5. Carry soap and water to wash spills off of hands, feet and legs, and bring extra gloves.
6. Designate dry stream crossings for workers in areas where treatments occur on both sides of a wet stream to avoid wash-off of herbicide from applicators' shoes.

See calibration videos online and the book Weed Control in Natural Areas in the Western United States *for information on treatment rates for particular plants and herbicides. Both are from the University of California's Weed Research and Information Center at http://wric.ucdavis.edu.*

The National Park Service on Anacapa Island uses herbicides labeled for aquatic use plus added low-toxicity surfactants even in terrestrial situations to protect sensitive amphibians and reptiles. When treating iceplant, for instance, rather than employing terrestrial-use glyphosate products with higher-risk surfactants, they employ aquatic glyphosate formulations that do not contain surfactants and then mix in an aquatically-approved surfactant like Agridex® or Competitor® that lessens the potential for impact on ground-dwelling salamanders. This is due to concern over the surfactant, not the active ingredient glyphosate.

45% of natural resource managers actively revegetate sites after herbicide application. Native vegetation returns unassisted in many situations.

7. Do not leave herbicides unattended. Herbicides (either concentrated or diluted) must be stored in locked enclosures or containers when unattended.
8. Triple-rinse emptied herbicide containers into the sprayer at the time of use and utilize these spray rinsates in areas allowed by the herbicide label.

GH6: Plan for what happens after treatment.

1. Keep detailed records that include the plants and area treated, amount and type of herbicide used, application method, and date of application in order to evaluate the effectiveness of the control program and to help document and analyze any impacts to non-target species.
2. Plan thorough post-treatment effectiveness monitoring.
3. Consider revegetating with desirable species to restore ecosystem function and habitat, provide benefits to wildlife, prevent the regrowth of weeds, and reduce the number of follow-up treatments needed. However, if enough native plants are at the site, allowing them to grow back naturally may be enough. Consider herbicide half-life and the particular needs of wildlife species when planning revegetation efforts.

The need for active re-vegetation of a site depends on the situation. Here native meadow barley comes back from the seed bank following a prescribed burn to control barb goatgrass at the University of California's Hopland Research and Extension Center. Photo: Joe DiTomaso, UC Davis

4. Follow herbicide product label warnings about using herbicide-treated plant material as compost or mulch. Residues from herbicide products containing clopyralid or aminopyralid may continue to be toxic to plants in compost or mulch into the next growing season, and in some cases for as long as several years. Applicators should consult product labels for information about this issue.

BMPs for Foliar Applications

FA1: Choose appropriate equipment.

1. Determine whether spot treatment or broadcast treatment will be most effective and least impactful. Spot treatment is appropriate for isolated plants, while broadcast treatment is appropriate for dense infestations and may use a lower rate of herbicide active ingredient
2. Use directed sprayers with low-pressure, large-droplet nozzles. Larger droplet size is less susceptible to drift.
3. Use tools that create less worker fatigue to reduce the chance that tired workers will make mistakes. For example, a truck-mounted spray rig with a long hose creates less fatigue on workers than a heavy backpack sprayer. It also requires fewer trips to refill the container, which reduces the chance of spilling herbicide.
4. Use a pulsed application where practical, which gives a burst of product, rather than a constant trigger spray. This method reduces the amount of herbicide leaving the nozzle, especially when using a spray rig, and can help the applicator wet the target plant without over-spraying which can lead to dripping on plants below and increased herbicide residues in soil.

FA2: Protect non-target vegetation.

1. Always be on the lookout for any drift or accidental application to non-target plants. Use a spotter to monitor the application.

For detailed information and checklists of what to carry into the field and what to do if there's a spill, see Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas *and the UC IPM guide on* The Safe and Effective Use of Pesticides, *listed in the Resources Section at the end of this manual.*

2. Flag native plants and/or plants to be treated if feasible. Use plant guards to protect desirable plants in the application area. This can be in-place protection, such as inverted empty plant containers or tarps, or hand-held protection like a spray shield.
3. Use tools such as brush hooks to concentrate target foliage so you can move it away from non-target species and reduce overspray. In tight situations, trimming non-target plants may be useful for keeping them clear of contact with herbicide.
4. Consider the possibility of cutting or mowing target vegetation first then either treating the cut stem or treating the resprouting vegetation. This may reduce the total amount of herbicide required to do the job and reduces the potential for drift to non-target plants.
5. Consider direction of spray. Spraying downward can reduce horizontal drift to non-target plants and applicators. A longer wand can be attached to the hose of a spray rig to reach out over dense stands of vegetation and spray downward onto the target plant. For very tall vegetation, like twenty-foot giant reed (*Arundo donax*), consider using a truck-mounted lift bucket in order to direct spray downward.
6. Walk around the target plant to judge the best direction from which to spray. If possible, applicators should position themselves so that non-target plants are behind them. When spraying along a riparian corridor spray from the direction of the creek towards the bank to reduce spray into the creek. Spraying from multiple angles will help ensure good coverage on foliage.
7. A certain amount of non-target plant damage may be acceptable, but if a non-target plant is accidentally sprayed, you can take steps to reduce damage.
    a. Wash off herbicide. Give each staff person a spray bottle with water when working around sensitive species habitat to rinse off any herbicide that accidentally contacts a non-target plant.
    b. Break off the part of the plant that was sprayed so the herbicide will not spread to the rest of the plant.
8. Consider less obvious pathways that can damage nearby non-target vegetation, such as volatilization of certain herbicides under certain conditions, as well as potential soil migration and root zone uptake of persistent herbicides (like imazapyr and aminopyralid) that are slower to degrade.

*A hook fashioned to maneuver giant reed (*Arundo donax*) away from native vegetation while treating with herbicide. Photo: Mark Newhouser, Sonoma Ecology Center*

BMPs for Stem Applications

Stem treatments usually require cutting the stem partially or completely. A partial cut may be made with a hatchet or machete ("hack and squirt" treatment) or a drill, providing direct access to the cambium layer. A "cut stump" treatment involves completely cutting off the plant at the base and applying herbicide to the cambium (interior growing layer) on the stump surface. "Basal bark" treatments apply herbicide to the bark around the base of the stem when the herbicide is able to penetrate the bark into the cambium. Injection treatments use a tool that powers an herbicide capsule through the bark and into the cambium underneath. All of these treatments use a smaller amount of a more highly concentrated herbicide.

SA1: Make an effective cut.

1. When undertaking a cut-stump treatment, make a flat cut so that herbicide will not run off of the stump and cut stems do not become a hazard if workers were to fall on them. If herbicide treatment is not done quickly, the cut may scar over or dry out, and fresh cambium will need to be re-exposed for the herbicide to be maximally effective. If you do not have means accessible to make a new cut through the entire stump, consider cutting a groove around the cambium to serve as a "moat" to contain herbicide and contact live cambium. (For instance, the edge of a 2-inch hole saw on a power drill can be used.)

2. Make sure that herbicide makes substantial contact with the plant's cambium, and take care to minimize application of herbicide to adjacent heartwood and bark. Make cuts to support this (for instance, hatchet cuts should be just deep enough to provide access to the cambium).

SA2: Use a suitable application tool.

1. Use tools that allow for highly-targeted application to the cut surface.
   a. Consider containers that facilitate applying herbicide onto a stump. Generic plastic containers with closable tops can be purchased at hardware stores or nurseries. Containers made of higher density HDPE plastics are more durable than those made of thin clear PET or PETE plastics. Never place herbicides into the type of containers used for food, beverages, or household products. Label all containers appropriately.
   b. Consider containers with sponge applicators for brushing on herbicide. Containers such as those used for adhesives or paints can be effective. These should have a cap to block inadvertent exposure when not in use, and should have a holder that keeps them upright when not in use to avoid drips.
   c. Consider high-quality spray bottles with adjustable settings, which can give accurate control of herbicide.
2. Use application tools that do not involve open containers to reduce the risk of spills. Containers should fully close when not in use.
3. Label all service containers clearly as required by DPR regulations. Include the name of the herbicide (common or product name), the signal word from the original container and the name of the company, organization, or agency that is responsible for that container.

SA3: Plan for biomass management after treatment.

1. Fell shrubs and trees in a way that does not crush other vegetation or wildlife habitat features such as burrows. Taking down the plant in sections may help reduce impact. Leaving the plant in place rather than felling it can provide benefits: a tree killed during treatment may provide benefit to wildlife, and when it does eventually fall it will be far lighter due to loss of moisture. However this can only be done where the unplanned tree-fall will not create a hazard for people or property or a risk of fire.

In a "cut-stump" treatment, a dye is used to help the applicator ensure full contact between the herbicide and the cambium layer of woody plant. Photo: Cindy Roessler, Midpeninsula Open Space District

2. Determine whether leaving biomass on site will be useful for providing wildlife habitat. If so, decide how finely biomass should be chopped, and how large piles should be. Consider the fire risk of leaving the biomass on site when making this decision.
3. Biomass can be used as mulch when it will help reduce weedy plant cover and future site maintenance, as long as it does not contain any viable reproductive structures (e.g., seeds, rhizomes). Remember that biomass from plants treated using herbicides like clopyralid that are slow to degrade may have residual herbicidal effect
4. When working in an aquatic environment, decaying plant material will result in reduced levels of dissolved oxygen needed by fish. Limit the amount of decaying biomass at any one time.

4. Herbicide Risk Charts

The charts and tables in this section provide information on the potential herbicide risks to wildlife. The charts include the most common herbicides used by wildland managers for invasive plant management (see Table 2-1). (Fluazifop was not included in the risk charts because the data needed to conduct the analysis was not available at the time the risk charts were completed.)

The risk charts in this Section provide information on the comparative risk of each herbicide to each type of wildlife from selected exposure scenarios. Appendix B summarizes the methods used to generate these charts and refers the reader to the primary sources for more detail. Each chart summarizes potential risk for a specific exposure scenario and is based on a risk assessment model developed by the USFS. See the spreadsheet of calculations on the PRI website for detailed information on risk charts. Using the spreadsheet, you can modify application rates to assess changes in risk profiles.
It is important to note that many of the scenarios are "worst case" and do not represent typical real-world situations. The assumptions for each scenario, with a description about how they relate to typical real-world situations, are listed on the risk charts.

Risks that fall outside an acceptable zone should prompt the land manager to consider steps to mitigate the risk. The BMPs in Section 3 describe steps that can reduce risks associated with herbicide use.

Risk to Wildlife Depends on Both Toxicity and Exposure

Risks to wildlife are dependent on the herbicide's toxicity to that particular taxonomic group and the animal's exposure to the herbicide. Toxicity is described using Toxicity Reference Values (TRVs), which represent the dose of herbicide generally assumed to be without adverse effects. Lower TRVs indicate a more toxic herbicide for the particular taxonomic group. The TRVs used to develop the risk charts for the different wildlife taxa are summarized in Appendix C.

A dye helps an applicator track where the herbicide has been applied.
Photo: Martin Hutten, Yosemite National Park

An important determinant of exposure is the herbicide application rate. For the risk charts, the application rates were set to half of the maximum application rate as indicated on the herbicide's product label. This "half-max" application rate was used to better approximate typical wildland herbicide applications. For example, invasive plant management typically involves portions of acres to be spot treated, but not entire acres. Alternatively, entire acres might be treated via broadcast spray, but at rates below maximum allowable rates. Since application rate is directly proportional to risk, the risk values at maximum application rates would simply be twice the values shown in the charts (likewise, lower rates would have proportionally less risk)—with the exception of spills, where application rate is not relevant. Table 4-1 provides the application rates used to estimate exposure for each herbicide in terms of pounds of the active ingredient (or the acid equivalent of the active ingredient) and the equivalent rate per acre for the formulated product.

While hazard assessment for most chemicals typically involves investigating the relationship between increasing exposure and increasing observed adverse effects in laboratory studies, some chemicals may have the potential to cause impacts at very low doses. Examples of this are the endocrine disrupting chemicals (EDCs), which can interfere with an animal's endocrine (hormone) system, potentially at very low exposure levels. Certain chemicals such as the plasticizers found in plastic bottles are suspected to be EDCs. At the present time, there is no evidence that any of the herbicide active ingredients used in invasive weed control are EDCs. The US EPA studied glyphosate and 2,4-D through their Endocrine Disruptor Screening Program and determined that no convincing evidence exists that either substance disrupts estrogen, androgen, or thyroid pathways. Studies have not been conducted for the other herbicides discussed in this manual, but none are on the European Union list of suspected endocrine disruptors.

Hazard Quotients Defined

The Hazard Quotient (HQ) is a measure of risk and is defined as the ratio of the predicted exposure to a Toxicity Reference Value (TRV) for the particular type of wildlife being assessed. HQ values >1 indicate that exposure exceeds the "No Effect" level, and wildlife may be at risk of adverse effects. For these exposure scenarios, action should be taken by the land manager to reduce exposure.

Table 4-1: Half-Maximum Application Rates Used in Risk Charts

Herbicide Active Ingredient	Half-Max Application Rate (lbs AE or AI per acre)	Half-Max Application Rate (rate per acre)
Aminopyralid	0.055	3.5 oz of Milestone®/acre
Chlorsulfuron	0.061	1.5 oz of Telar®/acre
Clopyralid	0.125	0.335 pints Transline®/acre
Glyphosate	4.0	3.5 quarts RoundupProMax®/acre (with surfactant) 4 quarts Aquamaster®/acre (no surfactant)
Imazapyr	0.75	3 pts Habitat®/acre
Triclopyr BEE	4.0	4 quarts Garlon 4®/acre
Triclopyr TEA	4.5	1.5 gals Garlon 3®/acre
2,4-D	2.0	4 pts Weedar®/acre

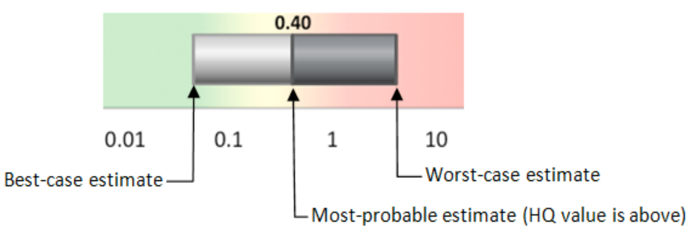
AE = Acid Equivalent; AI = Active Ingredient.

**Fluazifop (Fusilade®) is the one widely-used active ingredient not included in the risk charts because USFS risk analysis was completed after the risk charts were developed.*

How to Read the Risk Charts

In the risk charts that follow, risk is expressed as a Hazard Quotient (HQ), which is the ratio of the predicted exposure to a Toxicity Reference Value (TRV), a level of exposure that is anticipated to be without adverse effects.

Each bar on the chart shows a range of estimated risk for a specific exposure scenario based on three estimates of exposure—best-case (low exposure), most-probable (the most likely exposure), and worst-case (high exposure). Each estimate is based on a set of assumptions, such as the amount of herbicide residue on food (such as foliage, fruits, and insects) and the amount of food eaten or the amount of runoff into a water body. Factors used to estimate exposure specific to each scenario are listed in the caption for each chart.



The **best-case risk estimate** is at the left end of each bar and assumes the lowest exposure. The **most-probable risk estimate** (HQ=0.40 in the example above) is located at the point at which the bar changes color from light gray to dark gray, and assumes the most likely exposure. The **worst-case risk estimate** is at the right end of the bar and assumes worst-case exposures.

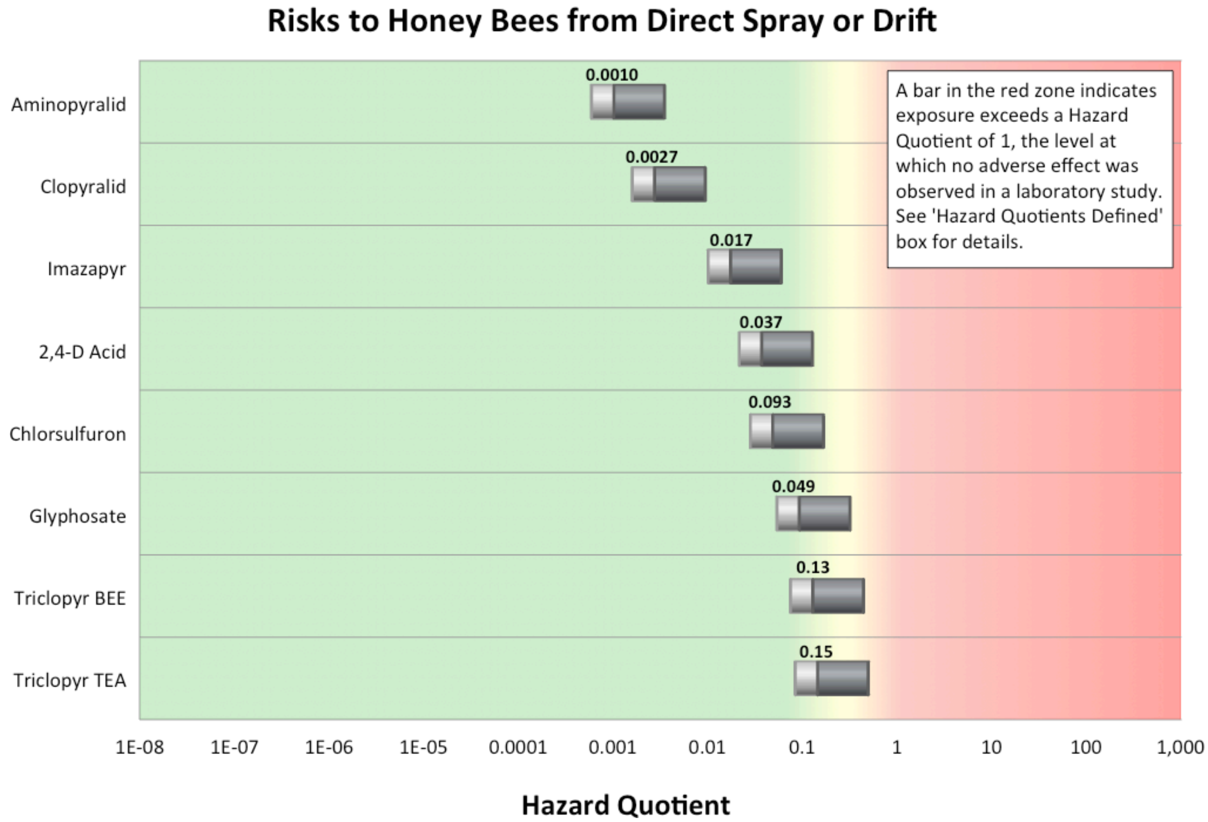
The background of each risk chart is color-coded, with a HQ in the green zone indicating low risk, an HQ in the yellow zone indicating that anticipated exposures are approaching a level of concern, and an HQ in the red zone indicating that the predicted exposure will exceed the TRV, and adverse effects may result. Because wildlife TRVs are derived from No Observable Adverse Effect Levels (NOAELs), a bar in the red zone does not necessarily mean that harm will occur, but risks that fall in this zone should prompt the land manager to consider steps to mitigate the risk. The further the bar is into the red zone, the more likely it is that adverse effects will occur. The BMPs in Section 3 describe steps that can be taken to reduce risks when HQ values risk calculations exceed a level of concern.

The scale of the charts is logarithmic, which allows for the display of values that differ by many factors of ten. The logarithmic scale also visually compresses the bars and skews plots slightly to the right—for example, a HQ value of 0.5 is not exactly in the middle between 0.1 and 1, but slightly to the right of the halfway point.

Overview of Risks to Wildlife from Use of Common Herbicides

Overall, the risk estimates shown in the charts demonstrate that for the majority of the most-probable acute exposure scenarios, the herbicides pose low risks to wildlife. An exception to this involves fish and aquatic invertebrates exposed to glyphosate formulations that contain certain higher-toxicity surfactants such as polyethyleneamine (POEA). These products cannot be legally applied directly to water, and applicators should also use caution when making applications near aquatic sites, such as ephemeral pools that may be used as breeding areas for amphibians and insects. Using glyphosate products that do not contain POEA in these settings can reduce the potential for impacts. A second example of risks that may exceed the level of concern under the most-probable exposure scenarios involves products that contain either triclopyr BEE or triclopyr TEA. In these cases, the HQ values can exceed the level of concern for chronic exposure scenarios when large, herbivorous mammals consume vegetation that contains residues of these herbicides.

With regards to the worst-case (highest) exposure level scenarios, 2,4-D acid, glyphosate/surfactant combinations and triclopyr BEE and TEA can all pose risks that exceed the level of concern. These scenarios include both acute and chronic exposures for aquatic invertebrates, fish, mammals and birds.



Taxa: Adult stage honey bees are used as a surrogate for all terrestrial insects.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 50% of the bee's body surface is covered with herbicide; 100% of herbicide is absorbed; the distance between the bee and the sprayer is 0-10 feet.

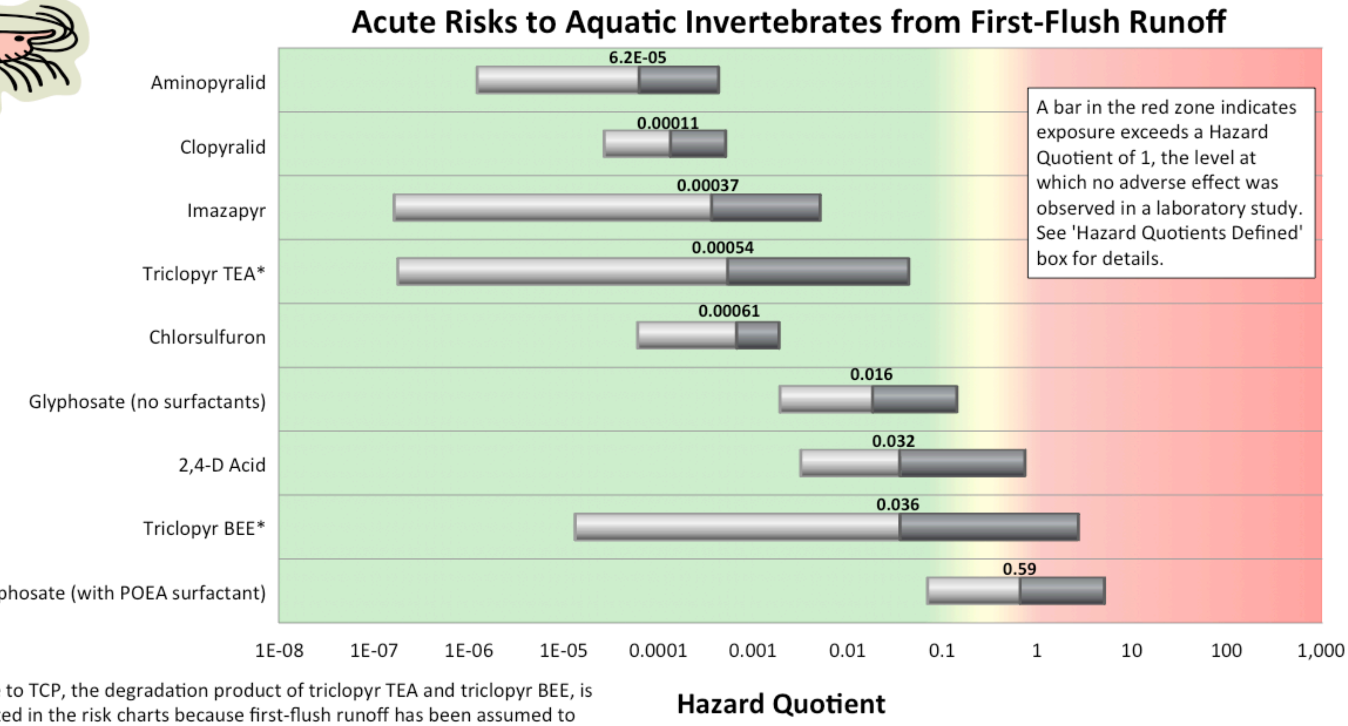
Likelihood: Most likely with spray-to-wet applications on blooming plants or those with extrafloral nectaries.

Mitigation: Do not apply to blooming plants. Apply early in the morning or close to sunset when insects are less active. Use low-volume applications and reduce the amount applied per acre.

Risk calculated as a function of: The inherent toxicity of the herbicide to honey bees; the amount of active ingredient sprayed; and the distance between bee and applicator. Risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.



*Exposure to TCP, the degradation product of triclopyr TEA and triclopyr BEE, is not reflected in the risk charts because first-flush runoff has been assumed to occur soon after application, before significant amounts of TCP have formed.

Taxa: Aquatic invertebrates.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-acre treatment with no buffer zone between treatment area and water body.

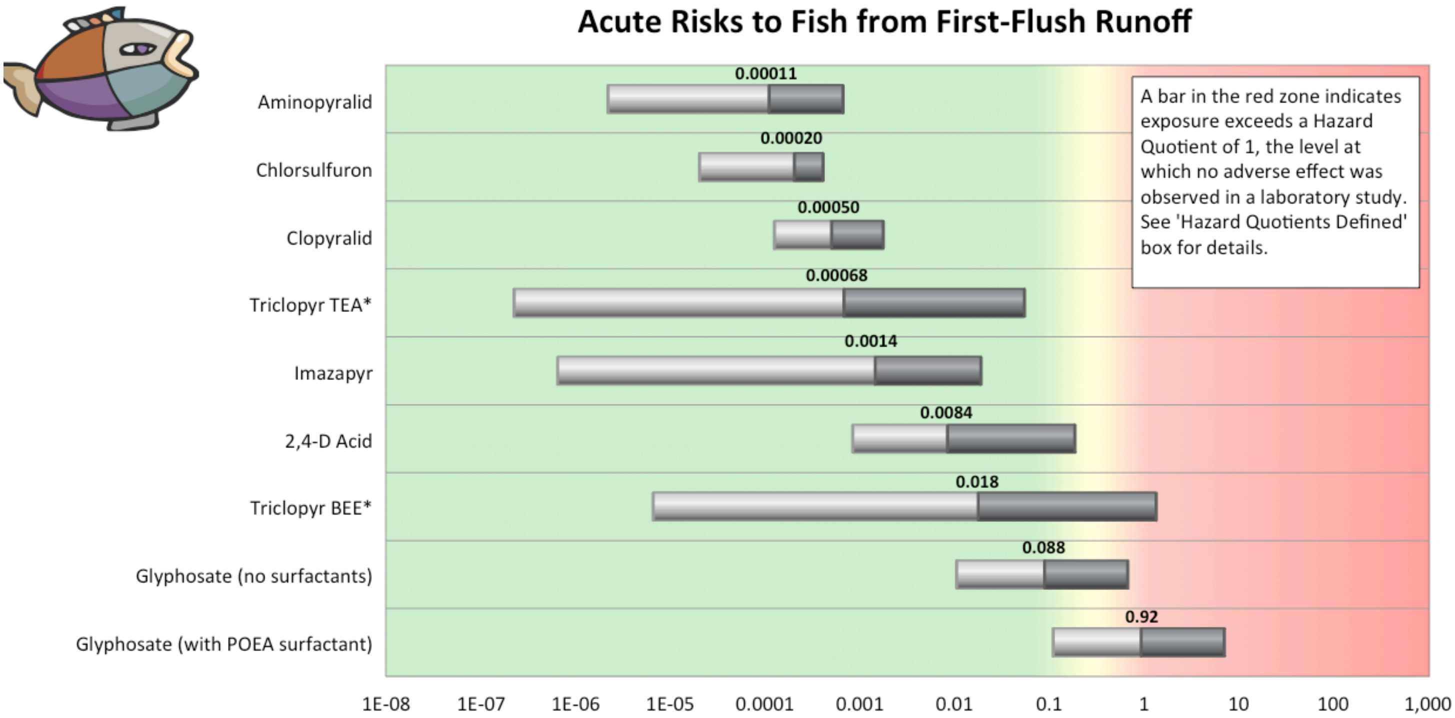
Likelihood: Buffer zones may be required on some water ways and are common practice when using herbicides not approved for aquatic use. Dry season applications in California will result in long intervals before a rain event, resulting in lower residues for runoff.

Mitigation: Use low-volume applications and reduce the amount applied per acre. Use buffer zones (see Bakke (2001) to help gauge effective buffer distances). Make applications during the dry season to avoid runoff. For applications near waterways, consider using herbicide formulations intended for use in aquatic systems.

Risk calculated as a function of: The inherent acute toxicity of the herbicide to aquatic invertebrates; herbicide characteristics that affect transport through soil to water (water solubility, ability to adsorb to soil); soil type; and the application rate. Herbicide degradation is not considered, as the estimate is for runoff occurring soon after the application. Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.



Hazard Quotient

*Exposure to TCP, the degradation product of triclopyr TEA and triclopyr BEE, is not reflected in the risk charts because first-flush runoff has been assumed to occur soon after application, before significant amounts of TCP have formed.

Taxa: Fish are also used as a surrogate for amphibians.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-acre treatment with no buffer zone between treatment area and water body; rain within 24 hours of application.

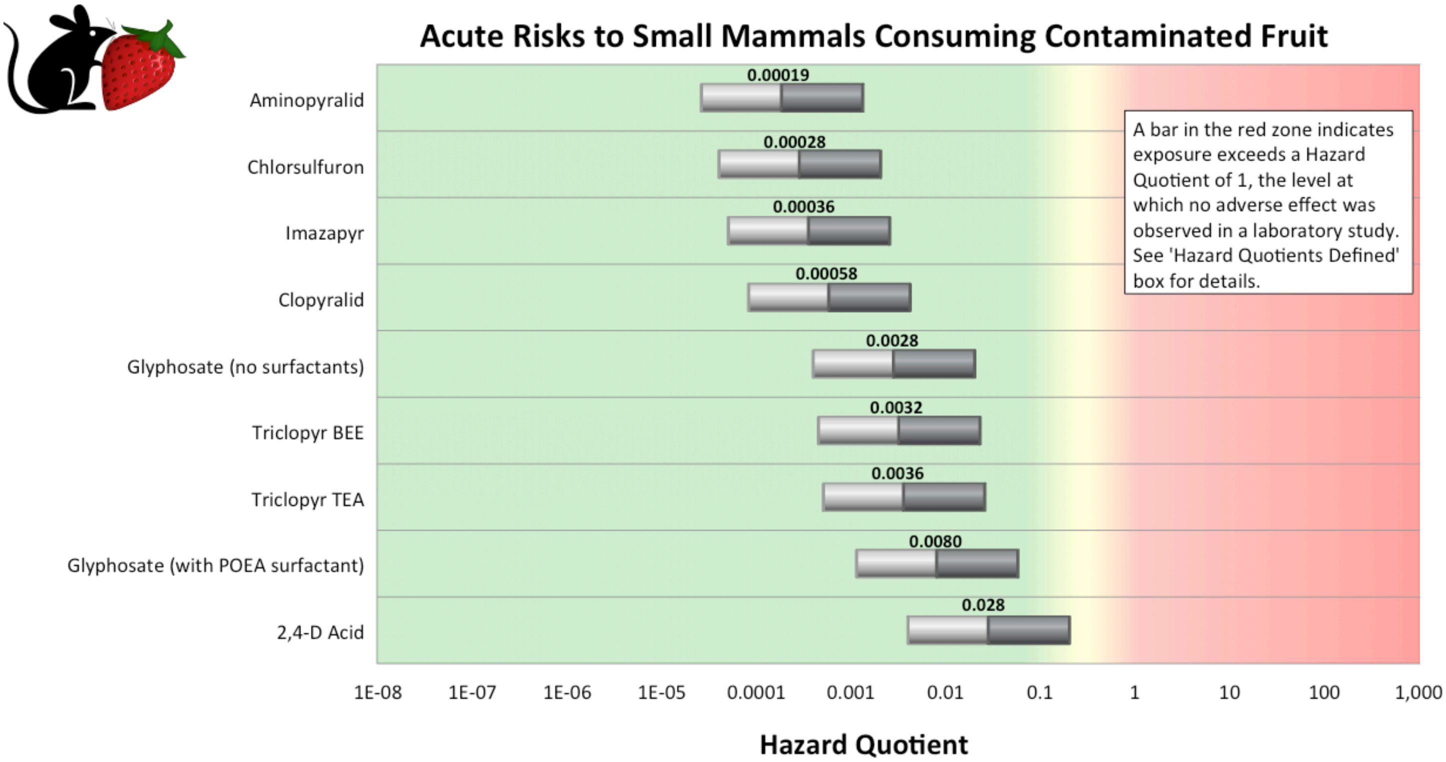
Likelihood: Buffer zones may be required on many water ways and are common practice when using herbicides not approved for aquatic use. Dry season applications in California will result in a long interval before a rain event, resulting in lower residues for runoff.

Mitigation: Use low-volume applications and reduce the amount applied per acre. Use buffer zones (see Bakke (2001) to help gauge effective buffer distances). Make applications during the dry season to avoid runoff. For applications near waterways, consider using herbicide formulations intended for use in aquatic systems.

Risk calculated as a function of: The inherent acute toxicity of the herbicide to fish; herbicide characteristics that affect transport through soil to water (water solubility, ability to adsorb to soil); soil type; and the application rate. Herbicide degradation is not considered, as the estimate is for runoff occurring soon after the application. Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.



Taxa: Small mammals.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-100% of diet is contaminated.

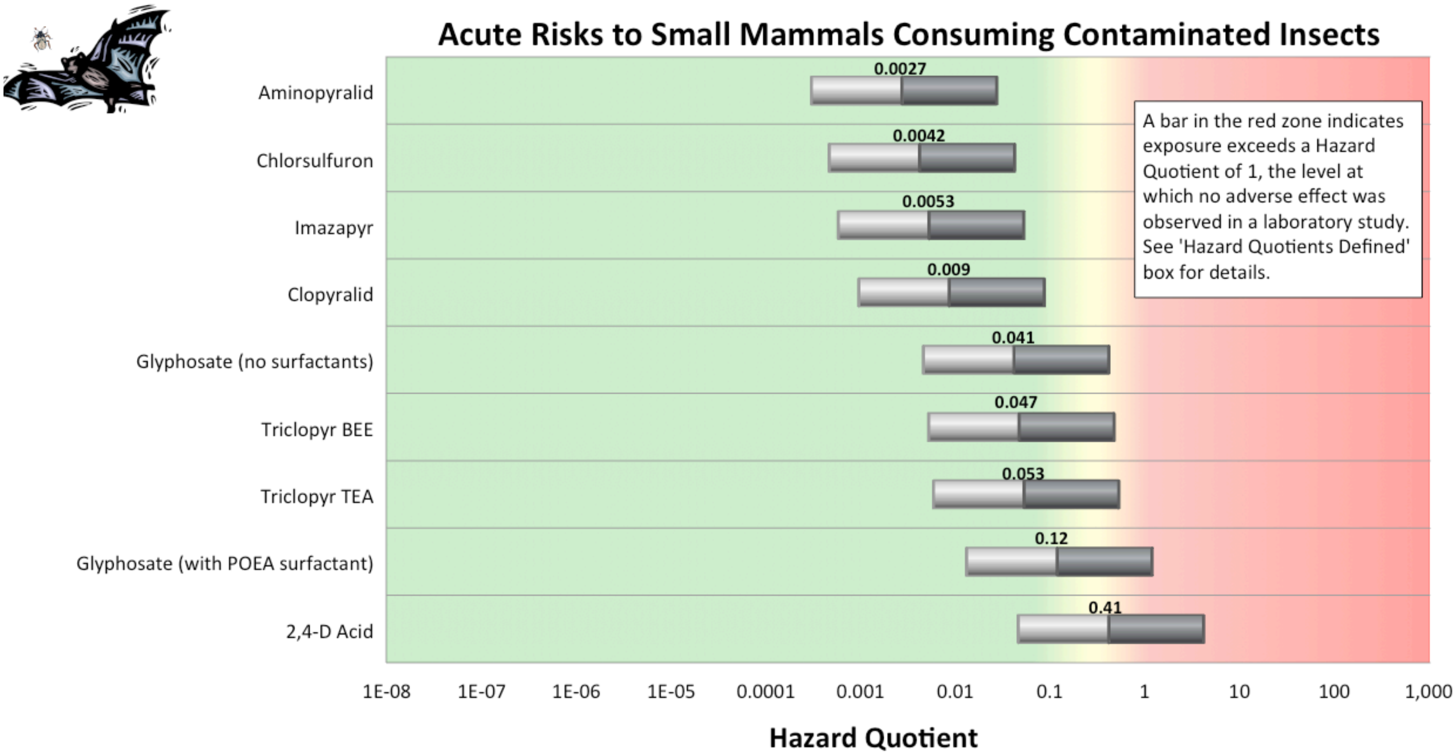
Likelihood: Under spot applications it is possible that a significant portion of a small mammal's diet could be contaminated. With broadcast applications over any sizable area (unusual for wildland management) contamination is likely for some small mammals.

Mitigation: Use low-volume application and reduce the amount applied per acre. If possible, don't treat large contiguous areas all at once. Avoid contamination of plants used as food sources by small mammals.

Risk calculated as a function of: The inherent acute toxicity of the herbicide to mammals; the residue rate of herbicide on fruit (which is proportional to the application rate). Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.



Taxa: Small mammals.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-100% of diet is contaminated.

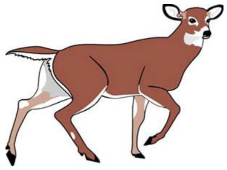
Likelihood: Under spot applications it is unlikely that a significant portion of a small mammal's insect-based diet could be contaminated. With broadcast applications over any sizable area (unusual for wildland management) contamination is possible for some small mammals.

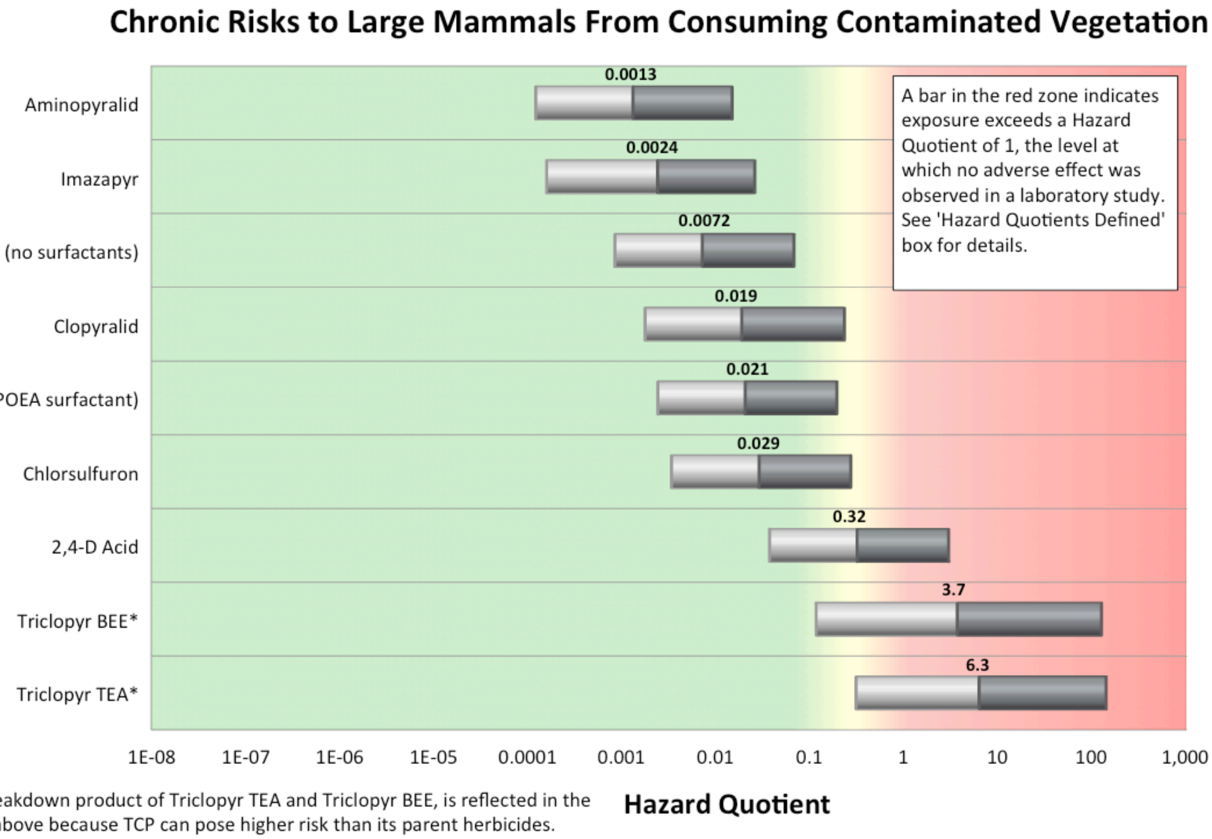
Mitigation: Use low-volume applications and reduce the amount applied per acre. If possible, don't treat large contiguous areas all at once. Avoid treating plants when feeding by insects is likely, if known.

Risk calculated as a function of: The inherent acute toxicity of the herbicide to mammals; the residue rate of herbicide on insects (which is proportional to the application rate). Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.





*Exposure to TCP, the breakdown product of Triclopyr TEA and Triclopyr BEE, is reflected in the tricplopyr risk estimates above because TCP can pose higher risk than its parent herbicides.

Taxa: Large mammals.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-100% of diet is contaminated for several months.

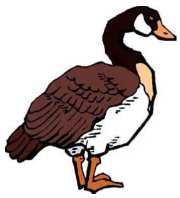
Likelihood: Under spot applications it is unlikely that a significant portion of any large mammal's diet would be contaminated. With broadcast applications over any sizable area (unusual for wildland management) consider the feeding range of the wildlife relative to the treatment area.

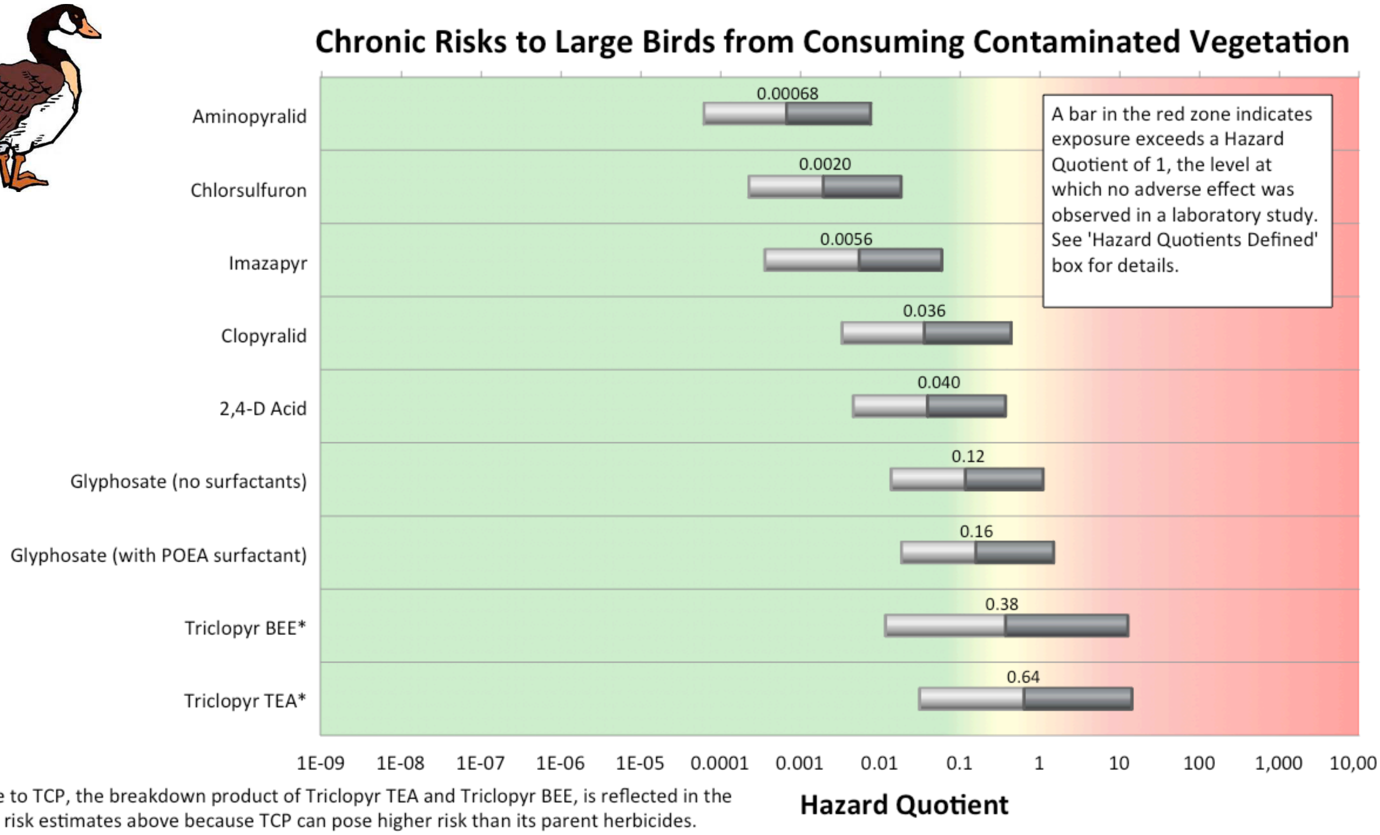
Mitigation: Use low-volume applications and reduce the amount applied per acre. If possible, don't treat large contiguous areas all at once. Avoid contamination of plants known to be used as food sources by large mammals.

Risk calculated as a function of: The inherent chronic toxicity of the herbicide to mammals; the residue rate of herbicide on vegetation (proportional to the application rate). Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.





Exposure to TCP, the breakdown product of Triclopyr TEA and Triclopyr BEE, is reflected in the icplopyr risk estimates above because TCP can pose higher risk than its parent herbicides.

Taxa: Large birds.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-100% of diet is contaminated for several months.

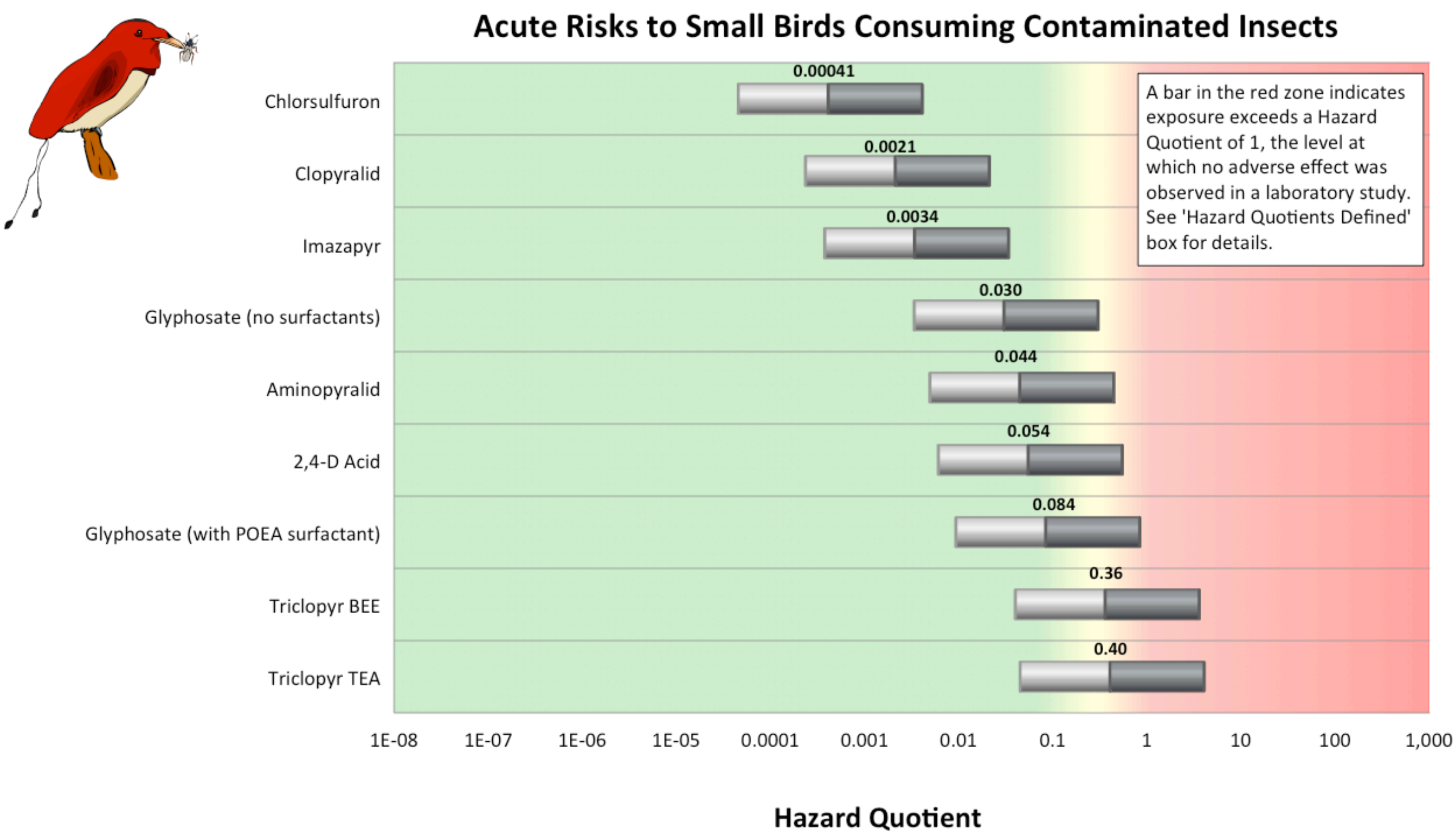
Likelihood: Under spot applications it is unlikely that a high portion of any bird's diet would be contaminated. With broadcast applications over any sizable area (unusual for wildland management) consider the feeding range of the wildlife relative to the treatment area.

Mitigation: Use low-volume applications and reduce the amount applied per acre. If possible, don't treat large contiguous areas all at once. Avoid contamination of plants known to be used as food sources by birds. Avoid treatments during nesting season.

Risk calculated as a function of: The inherent chronic toxicity of the herbicide to birds; the residue rate of herbicide on vegetation (which is proportional to the application rate). Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.



Taxa: Small birds.

Assumptions: Terrestrial application of herbicide at half of the maximum rate on a representative product's label (see Table 4-1); 10-100% of diet is contaminated.

Likelihood: Under spot applications it is unlikely that a high portion of any bird's insect-based diet would be contaminated. With broadcast applications over any sizable area (unusual for wildland management) consider the feeding range of the wildlife relative to the treatment area.

Mitigation: Use low-volume applications and reduce the amount applied per acre. If possible, don't treat large contiguous areas all at once. Avoid treating plants when insects are feeding. Avoid treatments during nesting season.

Risk calculated as a function of: The inherent acute toxicity of the herbicide to birds; the residue rate of herbicide on insects (which is proportional to the application rate). Except for glyphosate with the POEA surfactant, risks in this chart do not account for potential toxicity of any surfactants that are part of the product formulation or added to spray mixtures.

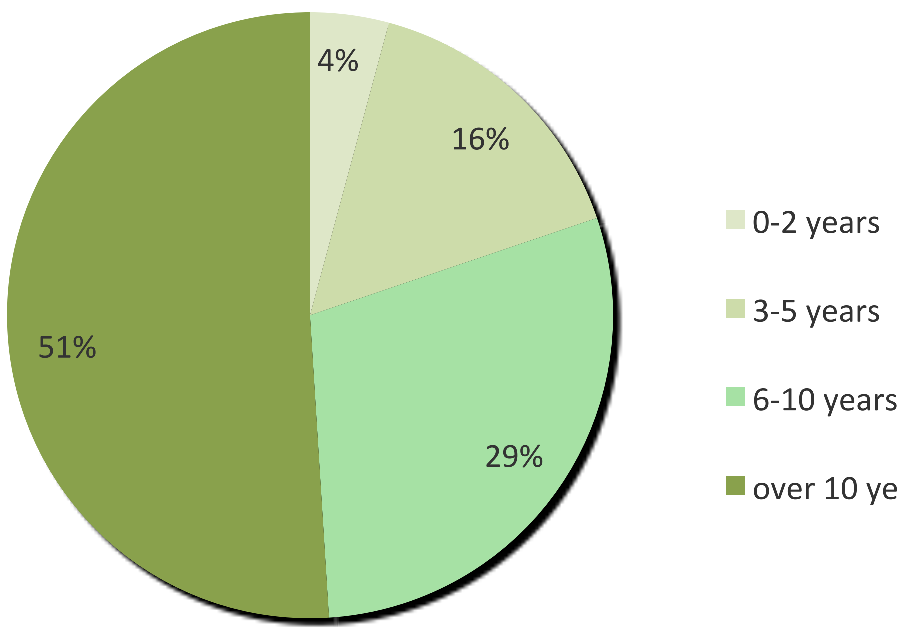
Methodology and sources: See Appendix B and PRI website, where you can access a spreadsheet for adjusting application rates and other variables.

Reading the chart: For each bar, the labeled central value is the most likely estimate. The right end of the bar assumes worst-case conditions for all underlying variables; the left end of the bar assumes best-case conditions. Mitigation is advised if risk enters the red zone.

Appendix A. Wildland Manager Survey

In 2012 we surveyed wildland managers on the practices they use to control invasive plants, the types of herbicides and methods of application they use, and ways in which they reduce impacts to wildlife. One hundred and one people responded to the survey. Almost all of the respondents live and work in California. The survey consisted of multiple choice questions with options for respondents to add more information. Questions asking how often wildland managers performed certain activities gave them options of "Always", "Frequently", "Rarely", or "Never". Many questions allowed wildland managers to choose multiple responses so some numbers in the graphs below add to more than 100%.

How many years have you worked in the field of invasive plant management?

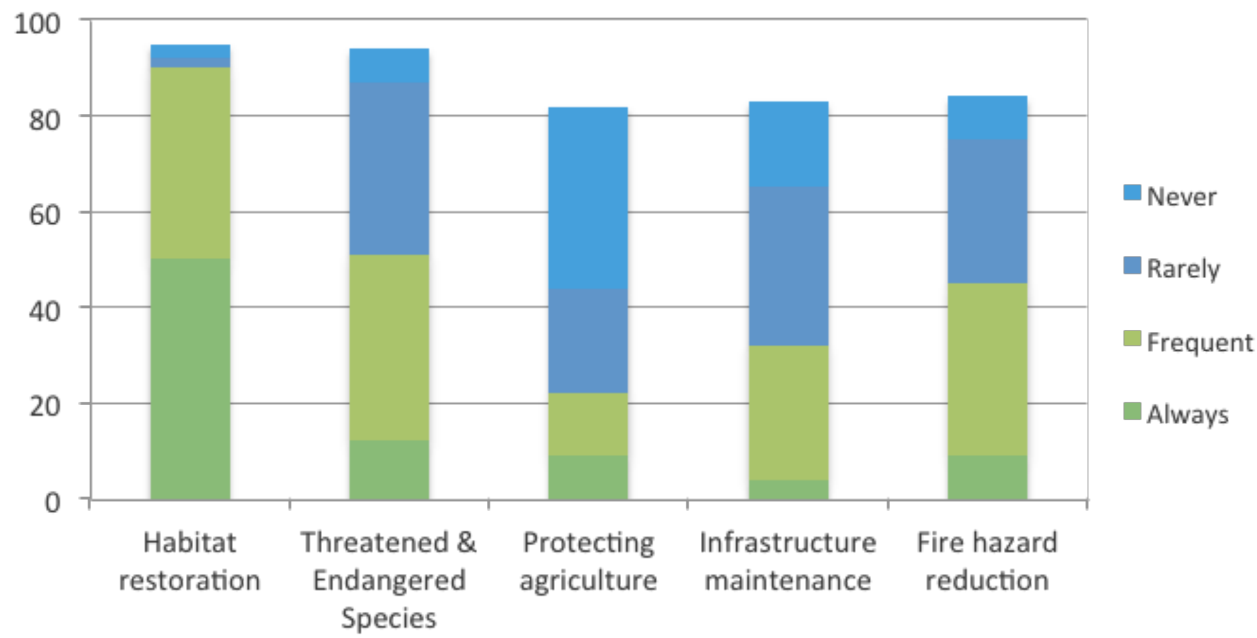


What types of organizations or agencies have you worked with during that time?

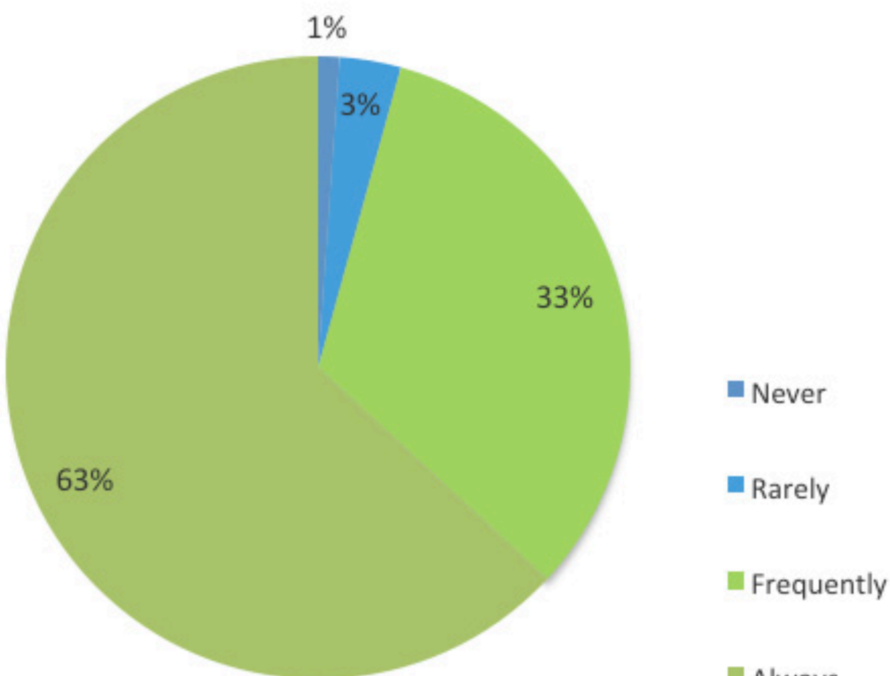
Method	Response
Local agency	54%
Federal agency	53%
State agency	48%
Land trust or other private landowner	40%
Private consultant	26%
Other*	27%

**Includes nonprofit organizations, forestry companies, utilities, regional park districts, Resource Conservation Districts, etc.*

How frequently are the following objectives part of your reason for managing invasive plants?



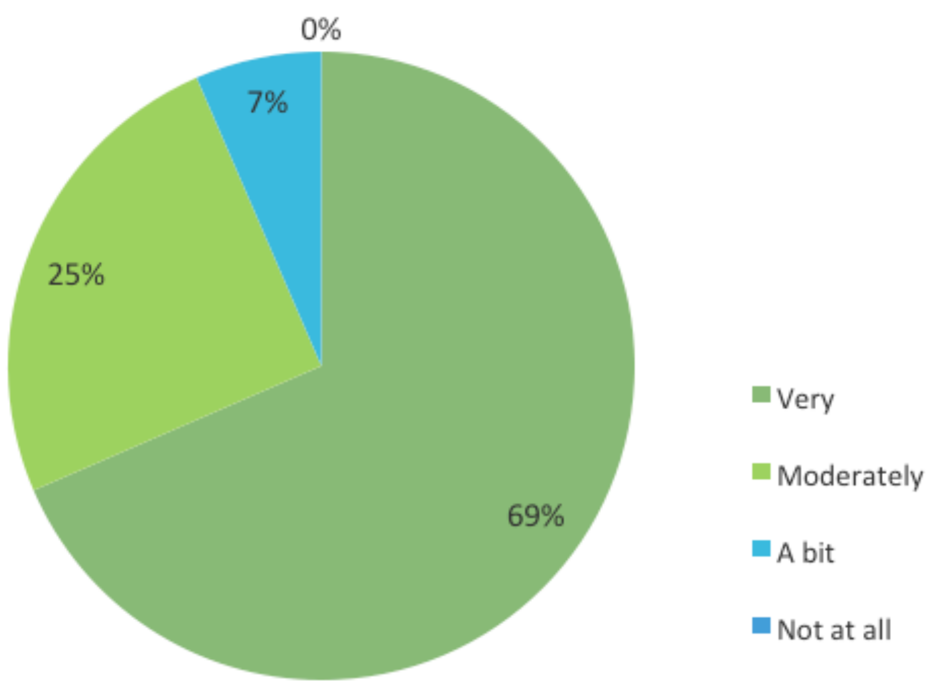
How often do you consider the potential impact of your invasive plant control on wildlife?



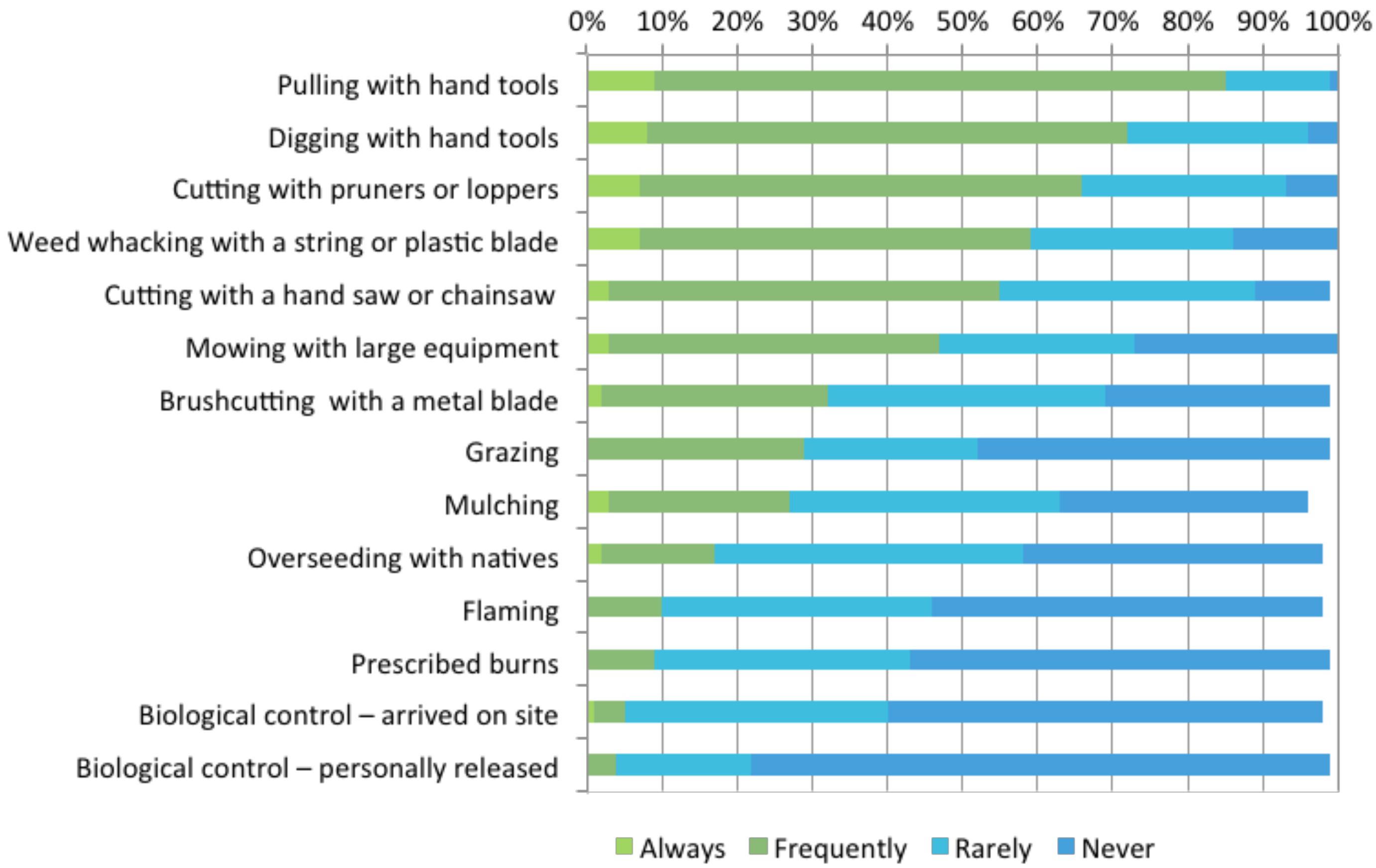
What methods have you used to reduce the impacts of your invasive plant management to wildlife?

Method	Response
Adjusting the timing of field work to minimize impacts on species reproduction (for example: not cutting vegetation during bird nesting season).	87%
Avoiding application of herbicides near water.	83%
Using targeted herbicide application methods (like cut-stump techniques or spot spraying) instead of broadcast spraying.	81%
Using mechanical methods instead of herbicides to avoid wildlife exposure to herbicide.	73%
Adjusting the timing of field work to occur during the dry season to avoid herbicide runoff to waterways.	65%
Using herbicides instead of mechanical methods to avoid physical damage to habitat.	56%
Setting limits on the amount of herbicide to be used and/or the number of acres to be treated.	47%
Leaving untreated “reserves” in the treatment area to maintain wildlife habitat.	18%

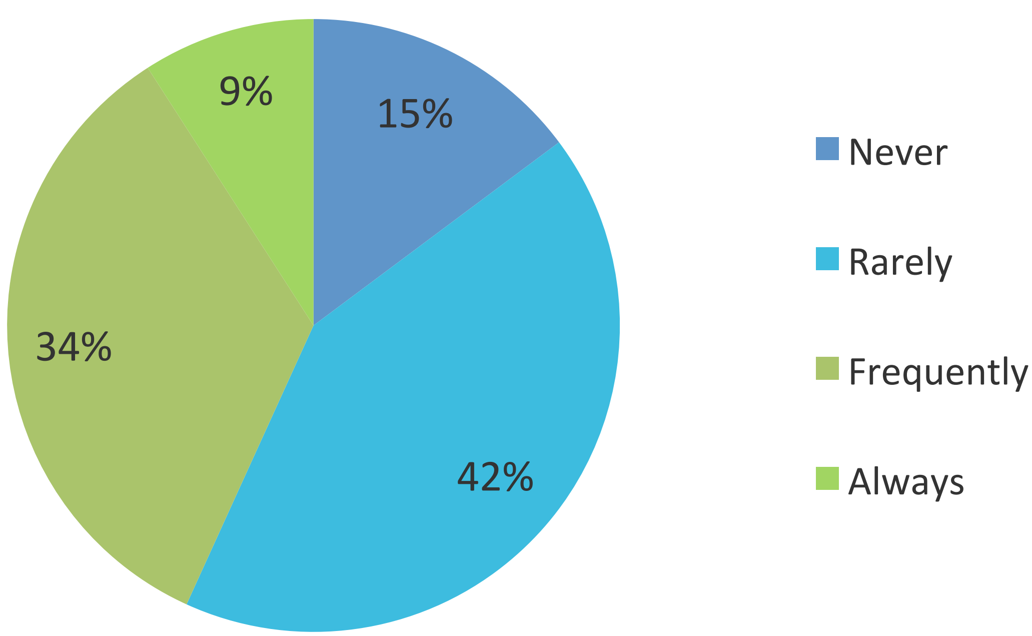
How interested are you in additional information on ways to reduce potential impacts of invasive plant control measures on wildlife?



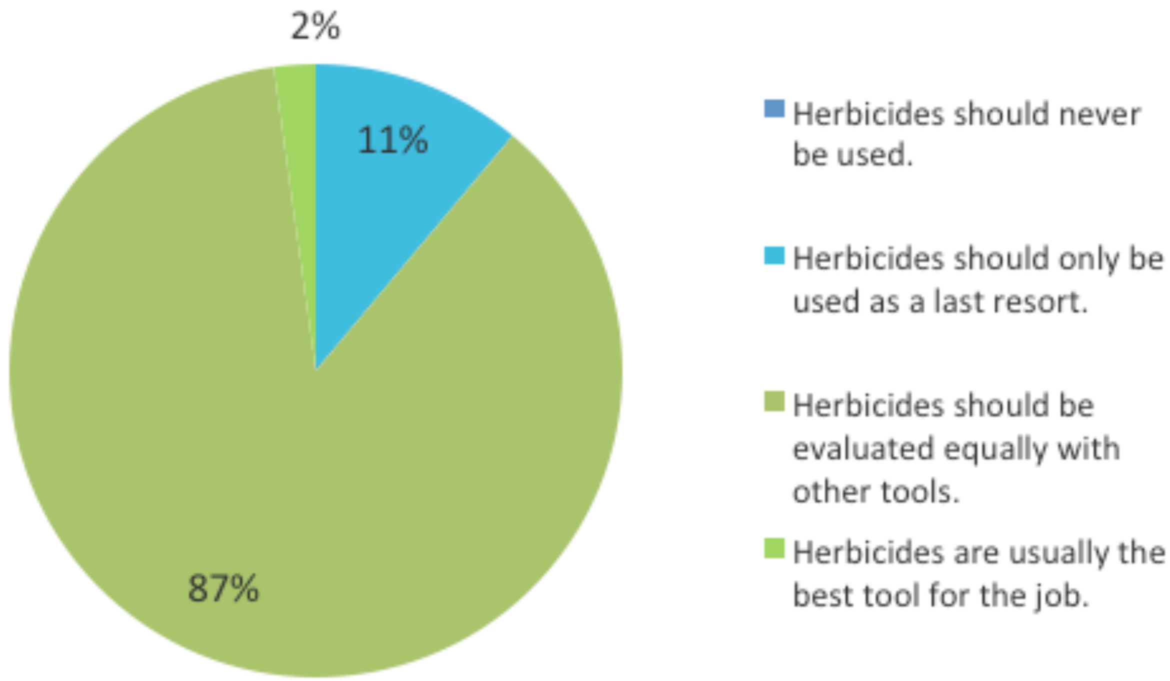
How often do you use the following non-herbicide control methods?



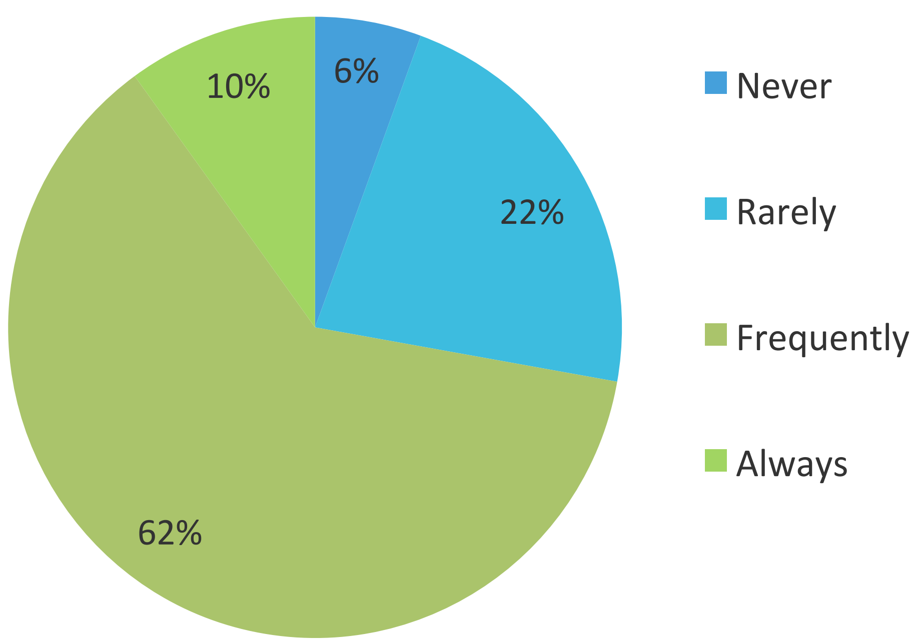
How often do you actively revegetate sites after herbicide application?



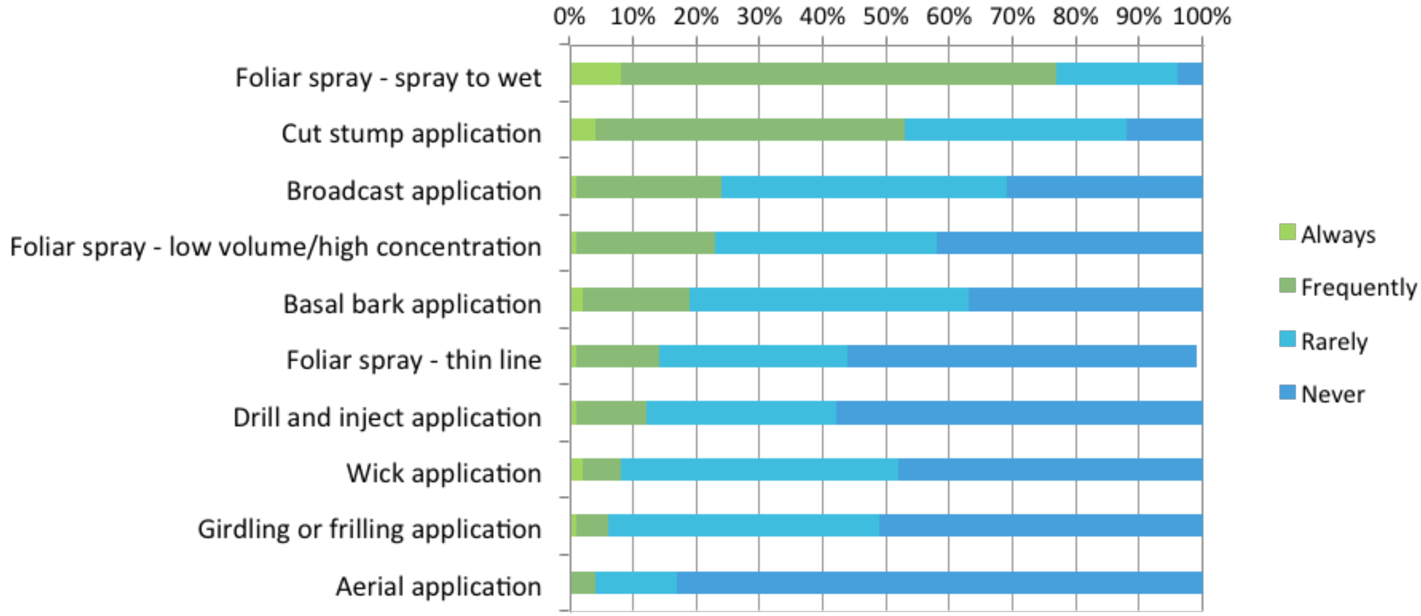
As related to the use of herbicides, for me IPM means:



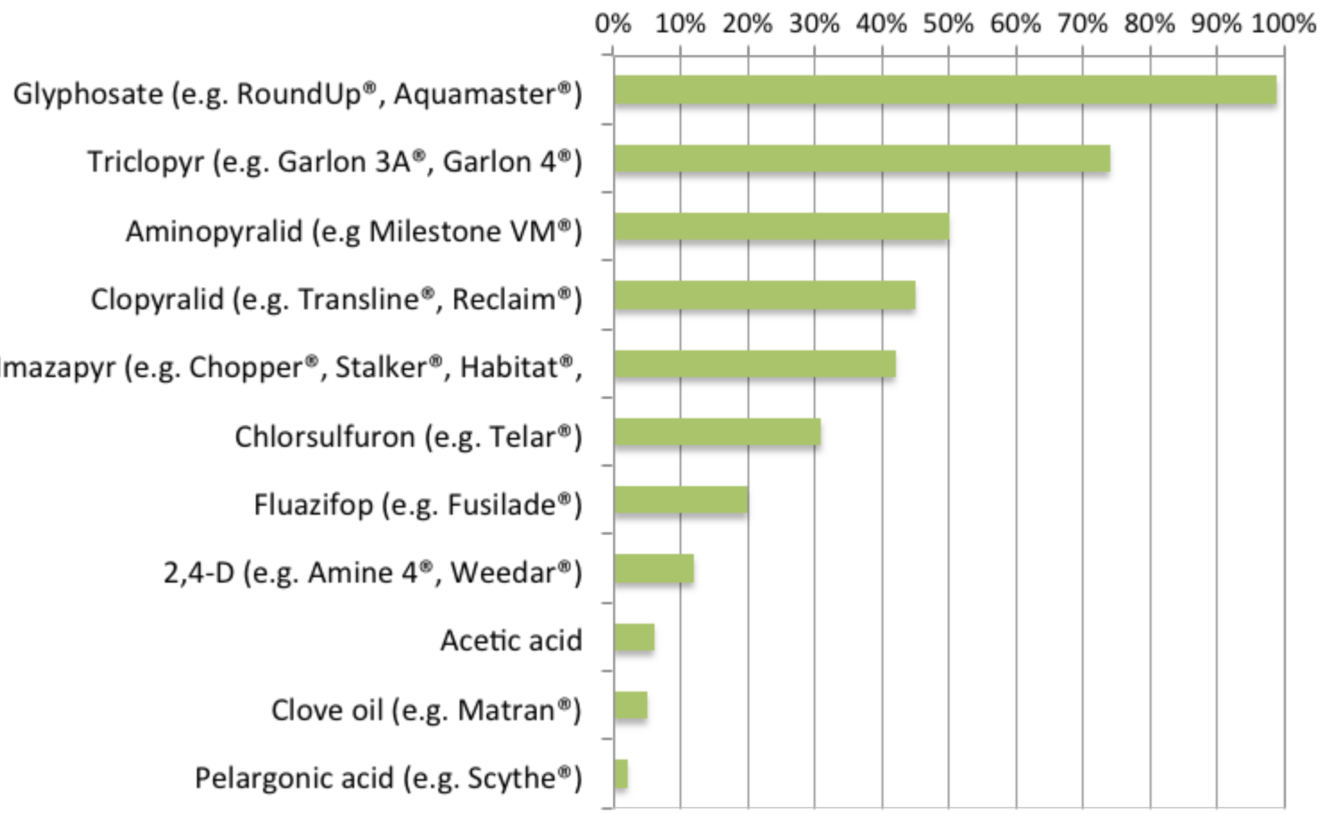
How often do you use herbicides for invasive plant control?



How often do you use the following herbicide control methods?



Which herbicidal active ingredients do you use for invasive plant control?
(percent of those respondents who use herbicides)



Appendix B: Risk Assessment Methodology

The methods used for estimating risk are based closely on USFS risk assessment methodology (link), in which three estimates are calculated for the exposure (dose) received as a result of various herbicide use scenarios. Each dose estimate is based on a set of best-case, most-probable, or worst-case assumptions based on exposure parameters appropriate to that scenario. The dose estimates are then compared to Toxicity Reference Values (shown in Appendix C) to assess risk if the scenario were to occur.

Exposure estimates were calculated using the risk assessment spreadsheets developed by Syracuse Environmental Research Associates (SERA) for the USFS and the Bureau of Land Management (BLM), published between 2007 and 2014. A full description is available in the report "Preparation of Environmental Documentation and Risk Assessments." Risk assessments for each of the herbicides discussed here are also downloadable from the USFS site. A detailed explanation of the methods used to estimate risk in this report is also available in Chapter 2 of the "2010 Marin Municipal Wastewater District (MMWD) Herbicide Risk Assessment." However, some parameter values and methods used for the risk estimates above differ from the *2010 MMWD Herbicide Risk Assessment*. Each of these changes is discussed below. Finally, the PRI website provides detailed information on how the risk charts were developed and allows users to modify application rates to assess changes in risk profiles.

Modifications to USFS Risk Estimation Methods

Several modifications to USFS/SERA default values were made for this report:

TRVs: Toxicity Reference Values (TRVs) based on LD_{50} or LC_{50} values were transformed to "No Effect" levels by incorporating an additional uncertainty factor of 20, the methodology used by US EPA to adjust TRVs for assessment of effects to endangered species. This transformation ensures that all TRVs are based on "No Effect" levels, and allows direct comparison of herbicides. This change has been incorporated into the more recent USFS herbicide risk assessments, and PRI updated the older risk assessments to include this change.

Percent of diet contaminated: In more recent versions of the USFS/SERA herbicide risk assessments, the percentage of an animal's diet assumed to be contaminated was modified to 10% (best-case), 30% (most-probable) or 100% (worst-case). PRI applied the same change to herbicides not yet adopted by USFS, to ensure an "apples to apples" comparison between herbicides. Residue rates assumed for herbicides on food (fruit, vegetation and prey) were based on the most up-to-date values from USFS/SERA (WorksheetMaker 6.0). The caloric error factor, which was introduced in recent versions of USFS/SERA worksheets, was not utilized here.

Herbicide Residue Rates: USFS changed the residue rates used in the latest version of their risk calculation spreadsheets for estimating exposures from consumption of contaminated fruit, insects and vegetation. This change lowers the best-case predicted dose for wildlife from consumption of contaminated food. In the new versions of the spreadsheets, a new lower residue rate was introduced that is equivalent to the following:

Best-case residue rate = Most-probable rate x (Most-probable rate ÷ Worst-case rate)

For example, for consumption of short grass, the values changed from 85, 85, and 240 mg of pesticide ingested/kg of body weight per lb of pesticide applied/acre to 30, 85, and 240 mg/kg per lb/acre.

These values were incorporated into the calculations for all of the herbicides to ensure comparison of equivalent values.

Insect Contamination Rate: The USFS changed the mass of a honey bee from 93 mg to 116 mg and the surface area from 2.66 cm^2 to 1.42 cm^2 in the more recent herbicide reviews. The net effect is to reduce the estimated dose received by the honey bee. These values were incorporated into the calculations for all of the herbicides to ensure comparison of equivalent values.

Appendix C. Toxicity Reference Values Used to Estimate Risk

Toxicity Reference Values (TRVs) are given in terms of mg of acid equivalent (AE) or active ingredient (AI) . NOAEL is the No-Observed-Adverse-Effect Level.

Receptor (units)	Herbicide	TRV Used	USFS TRV	Endpoint
Honeybees (mg/bee)	2,4-D Acid	1075	1075	NOAEL
	Aminopyralid	1075	1075	NOAEL
	Chlorsulfuron	25	25	NOAEL
	Clopyralid	909	909	NOAEL
	Glyphosate	860	860	NOEC
	Imazapyr	860	860	NOAEL
	Triclopyr BEE	620	620	NOAEL[b]
	Triclopyr TEA	620	620	NOAEL[b]
Birds, acute (mg/kg body weight)	2,4-D Acid	415	415	NOAEL
	Aminopyralid	14	14	NOAEL
	Chlorsulfuron	1686	1686	NOAEL
	Clopyralid	670	670	NOAEL
	Glyphosate	1500	1500	NOAEL
	Imazapyr	2510	2510	NOAEL
	Triclopyr BEE	126	126	NOAEL[b]
	Triclopyr TEA	126	126	NOAEL[b]
Birds, chronic (mg/kg body weight)	2,4-D Acid	76	76	NOAEL
	Aminopyralid	184	184	NOAEL
	Chlorsulfuron	140	140	NOAEL
	Clopyralid	15	15	NOAEL
	Glyphosate (no surfactants)	58	58	NOAEL
	Glyphosate (with POEA)	43	43	NOAEL
	Imazapyr	610	610	NOAEL
	TCP[c]	116	116	NOAEL[b]
	Triclopyr BEE	7.5	7.5	NOAEL[b]
	Triclopyr TEA	7.5	7.5	NOAEL[b]
Mammals, small (mg/kg body weight)	2,4-D Acid	25	25	NOAEL
	Aminopyralid	104	104	NOAEL
	Chlorsulfuron	75	75	NOAEL
	Clopyralid	75	75	NOAEL
	Glyphosate	500	500	NOAEL
	Imazapyr	738	738	NOAEL
	Triclopyr BEE	440	440	NOAEL[b]
	Triclopyr TEA	440	440	NOAEL[b]

Receptor (units)	Herbicide	TRV Used	USFS TRV	Endpoint
Mammals, large (mg/kg body weight)	2,4-D Acid	5	5	NOAEL
	Aminopyralid	50	50	NOAEL
	Chlorsulfuron	5	5	NOAEL
	Clopyralid	15	15	NOAEL
	Glyphosate	500	500	NOAEL
	Imazapyr	738	738	NOAEL
	TCP[c]	12	12	NOAEL[b]
	Triclopyr BEE	0.4	0.4	NOAEL[b]
	Triclopyr TEA	0.4	0.4	NOAEL[b]
Fish (mg/liter of water)	2,4-D Acid	4.8	95.6	$LC_{50} \div 20$
	Aminopyralid	50	50	NOEC
	Chlorsulfuron	30	30	NOEC
	Clopyralid	5[a]	103	$LC_{50} \div 20$
	Glyphosate (no surfactants)	0.5	0.5	NOAEC
	Glyphosate (with POEA)	0.048	0.048	NOAEC
	Imazapyr	10.4	10.4	NOAEC
	TCP[c]	0.18	0.18	NOAEC[b]
	Triclopyr BEE	0.091	0.091	NOAEC[b]
	Triclopyr TEA	20	20	NOAEC[b]
Aquatic Invertebrates (mg/liter of water)	2,4-D Acid	1.25[a]	25	$LC_{50} \div 20$
	Aminopyralid	89	89	NOEC
	Chlorsulfuron	10	10	NOEC
	Clopyralid	23.1	23.1	NOEC
	Glyphosate (no surfactants)	2.7	2.7	NOAEC
	Glyphosate (with POEA)	0.075	0.075	NOAEC
	Imazapyr	41	41	NOAEC
	TCP[c]	0.55	0.55	NOAEC[b]
	Triclopyr BEE	0.045	0.045	NOAEC[b]
	Triclopyr TEA	25	25	NOAEC[b]

[a] *To ensure comparison of equivalent endpoints between herbicides, all TRVs expressed as LC_{50} or LD_{50} values were translated by either USFS or PRI to "No Effect" levels by incorporation of an uncertainty factor of 20, similar to that used by US EPA to protect endangered species. This practice was only recently incorporated into the USFS methodology, so PRI implemented these changes for the herbicides reviewed by USFS prior to the change.*

[b] *For triclopyr and TCP toxicity to mammals, USFS used allometric parameters that correct the NOAEL for the amount of food and water consumed, based on body weight and size, to adjust for differences between the test species and the taxa to which the TRV is applied.*

[c] *TCP is the primary degradation product of triclopyr. Because triclopyr must degrade before any TCP is produced, only the chronic scenarios of large mammals and birds eating vegetation involve potential exposure to TCP. The other scenarios are acute events, where triclopyr has not yet degraded to form TCP. Chronic exposure to treated vegetation will result in exposure to a combination of the parent compound and TCP, which degrade at similar rates. The risk bars are based on the TRV for the more toxic (lower value) of the two to produce a more protective risk estimate. For both mammals and birds, the risk charts are based on the TRV for triclopyr acid, since it has the lower value.*

Appendix D: Factors Affecting Herbicide Runoff to Surface Waters

Herbicide Half-Life

Herbicide half-life is a measure of persistence in the environment. Herbicides that are persistent in the soil environment continue to have herbicidal activity and cause adverse effects on the ecosystem until the concentration drops below a level that is toxic to plants. The range of half-lives for the herbicides in soil under aerobic conditions—in the presence of oxygen and microbes—can vary by a factor of ten or more for each herbicide. Exposure to sunlight can accelerate decomposition of some herbicides. The longest half-lives are typically relevant under arid conditions where microbial degradation rates are low. Anaerobic degradation is usually slower than aerobic degradation. In general, glyphosate is expected to be less persistent than other herbicides considered in this assessment, while imazapyr and aminopyralid are among the most persistent. Triclopyr BEE and TEA rapidly degrade or dissociate to triclopyr acid, so the persistence of triclopyr degradates—triclopyr acid and TCP— is most relevant to triclopyr applications. Organic herbicides such as clove oil, pelargonic acid, and limonene have very short half-lives (a few days to a week), which limits their potential for exposure.

Figure D-1 shows the range of half-lives for the herbicides in soil under aerobic conditions. In the plot, herbicides are arranged in order of the Central value of their measured half-life. The Upper, Lower and Central values on Figure D-1 are based on a review of the academic literature and the values used by government agencies, including US EPA, USFS, California Department of Pesticide Regulation (DPR), and the Oregon Department of Environmental Quality (ODEQ) (see PRI website for more information). The Central values for the herbicides used in the plots (except for 2,4-D and aminopyralid) in Figure D-1 are the half-life values used by USFS in its risk assessments as the Central half-life estimate in soil, with the values for 2,4-D from DPR's environmental fate review and for aminopyralid from US EPA's risk assessment. Lower and Upper values used in the figure are taken from US EPA's risk assessments or from DPR's or ODEQ's environmental fate documents summarizing the available literature studies. Half-lives vary depending on test conditions, and comparable studies conducted under the same test conditions were not always available for every herbicide. When soil values were unavailable, the half-life on fruit was used.

Figure D-1 is intended to provide as much as possible an "apples-to-apples" comparison of aerobic soil half-lives. However, imazapyr does not degrade in soil under aerobic conditions, so a field dissipation half-life (5.9 years) is used, in order to provide a numerical point of comparison to other herbicides. Note that half-lives of herbicides in water or in anaerobic sediments (such as wetlands) may be different than the aerobic soil half-lives presented in Figure D-1. For most pesticides, the anaerobic half-life (in the absence of oxygen) is longer than the aerobic half-life. Sunlight and processes that dissipate herbicides in the environment like rainfall runoff, absorption by plants, or irreversible binding to soils can also alter the persistence of a chemical in the treated area.

Figure D-1 shows the total range of half-lives observed for the different chemicals. Half-life values used by the USFS in their worksheets are those used to produce the charts and are more narrowly constrained to reflect half-lives under the most common conditions.

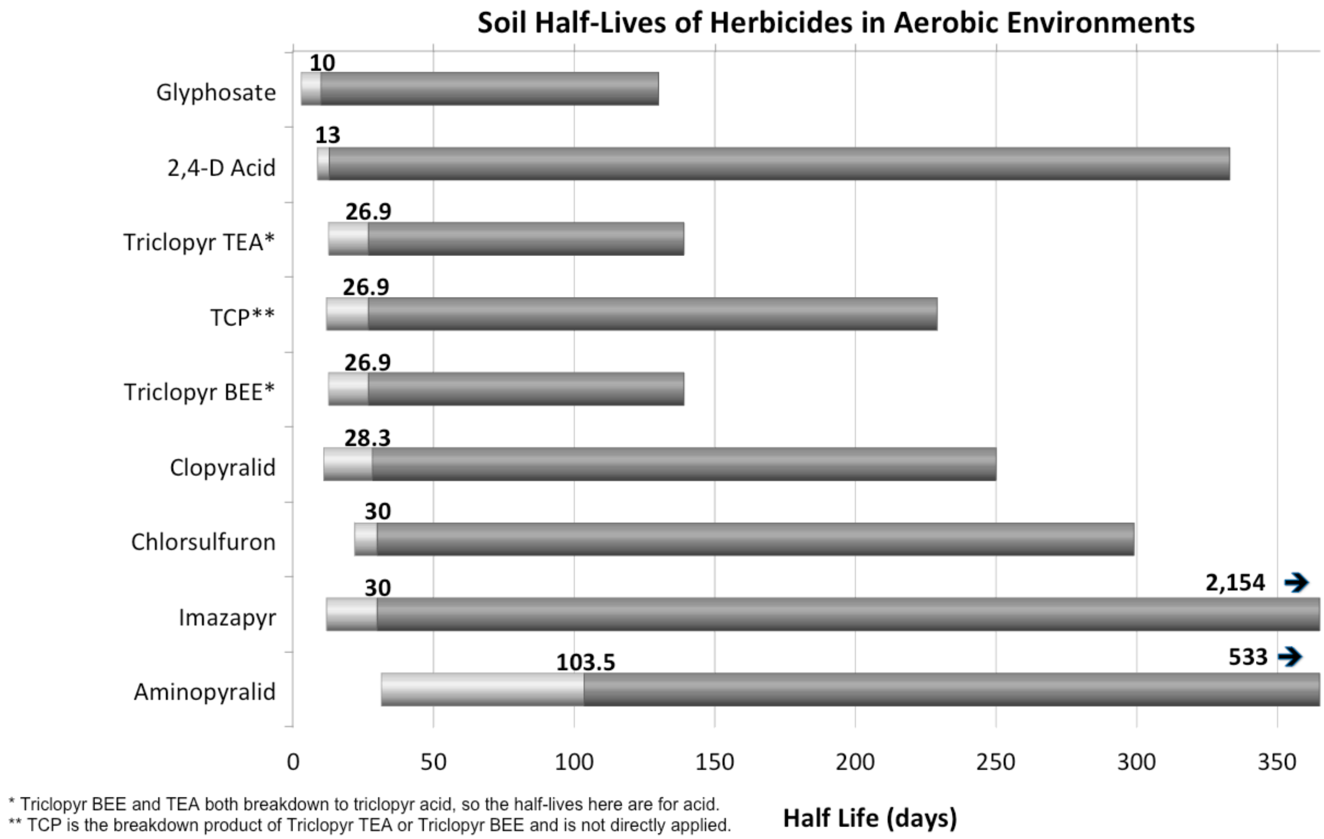


Figure D-1: Comparison of the range of herbicide half-lives under aerobic conditions in soil. The high end of the range is typically under arid conditions where microbial degradation rates are low. Exposure to sunlight can accelerate decomposition and shorten the half-life of some herbicides. Sources are described in Appendix C above. For aminopyralid, see EPA Fact Sheet 2005. For imazapyr, see EPA 2007 Appendix A Imazapyr Effects Determination for the CA Red-legged frog.

Water Contamination Rates

Water contamination rates are a measure of how much of an applied herbicide will run off of the treated area into nearby water bodies. Maximum or peak concentrations of herbicides in water bodies receiving runoff are typically observed when rainfall or irrigation occurs soon after treatment, before the herbicide has degraded substantially. The concentration of herbicide in this “first-flush” runoff may potentially impact aquatic organisms and terrestrial animals that make contact with or drink contaminated water. The potential of herbicides to move off-site in runoff water depends on water solubility, half-life, and the ability of the herbicide to bind to soil. The site characteristics are relevant too, as different soil types bind to herbicides differently. Bare or impermeable soils are much more prone to runoff than vegetated areas; sandy soils are susceptible to leaching that may result in groundwater contamination.

The risk charts use the USFS method (based on the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model) to estimate the concentration of each herbicide in water for an application to 10 acres, no buffers along the edge of the treated area, and rainfall after the application based on averages for a variety of sites. The range of water contamination rates is based on the range of site variables such as soil type and chemical properties. Use of buffer zones around water bodies will reduce water contamination.

Water contamination rates are measured in units of milligrams of herbicide per liter per pound of herbicide applied per acre (mg/L per lb/acre). Actual herbicide concentrations in the receiving water body will depend how many pounds of active ingredient are applied to land that drains to the water body. Use of herbicides with application rates of fractions of a pound per acre (see Table 4-1) will generally result in lower concentrations than herbicides with higher application rates. Predicted concentrations in the receiving water bodies for the half-maximum application rates for each active ingredient are shown in Figure D-2. These concentrations were used to estimate the risks displayed in the charts for aquatic species and for animals drinking the water.

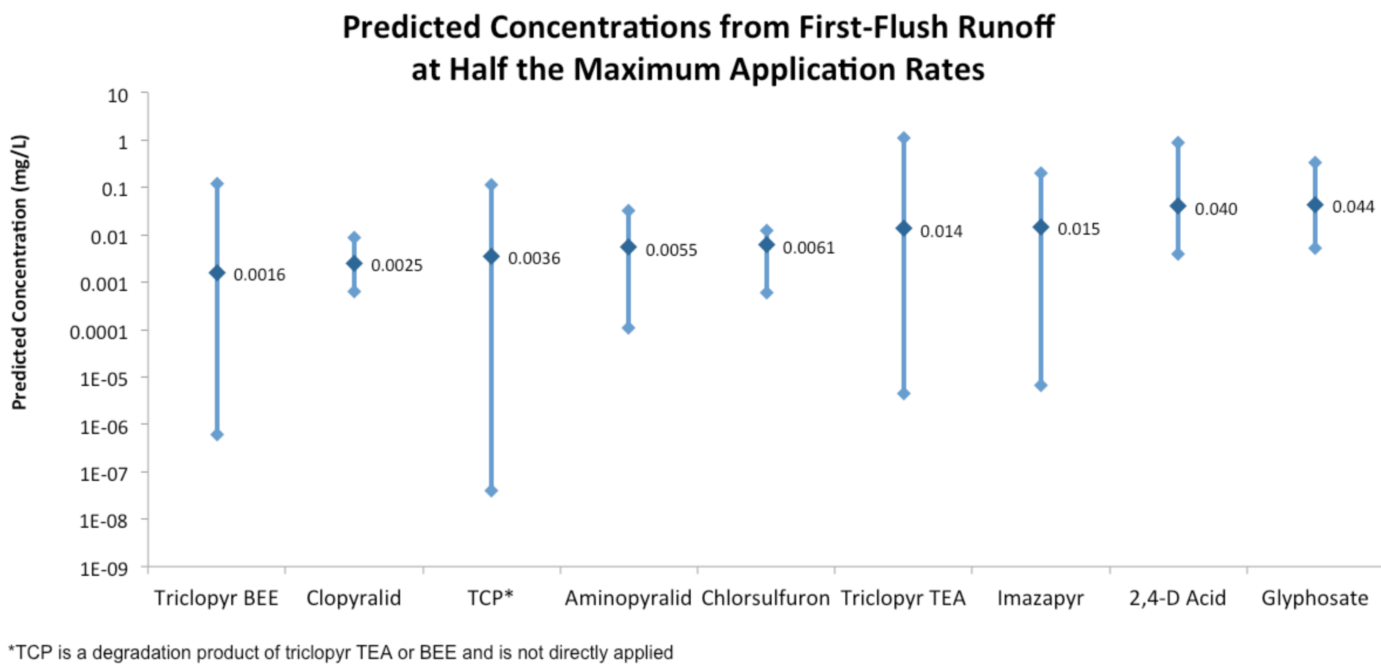


Figure D-2: Comparison of the range of predicted concentrations in peak runoff after terrestrial application at half-maximum application rate. Factors affecting predicted concentrations include application rate, water solubility, half-life, and the ability of the herbicide to bind to soil (Koc). Use of buffer zones near surface waters will help to reduce water contamination. Source: "Estimated Water Contamination Rates" in USFS risk assessment worksheets at www.fs.fed.us/foresthealth/pesticide/worksheets.shtml.

Resources

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General Resources

California Invasive Plant Council: www.cal-ipc.org

Center for Invasive Species Management at Montana State University: www.weedcenter.org

United States Department of Agriculture, National Invasive Species Information Center: www.invasivespeciesinfo.gov

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