Controlling invasive species

Management

Biological diversity is built on biological diversity. Where there are plant communities with large numbers of native species, there are healthy and diverse populations of animals and insects; and having a diversity of native animal and insect species in turn helps maintain a diverse plant community. Plants support animals; at the same time herbivorous animals help keep dominant plants in check, thus providing a measure of stability to ecosystems. Indigenous species are much more likely than exotic species to have evolved mutual ecological relationships with predators and competitors that sustain this coexistence. Exotics, released from their specialized natural enemies, have fewer restraints. However, exotic species are not inherently a problem for land management: only a small number of those that are introduced ever become "naturalized," or free-living outside of cultivation. Of these, only a fraction spread to become dominant members of the ecosystem. While it would be unrealistic to assume that we can or should restore the Laguna to a community of entirely native species, the best way to protect biodiversity is to manage the populations of invasively-spreading plants and animals, whether these species are native or introduced, and to work toward restoring healthy, resilient ecosystems.

Indigenous species have mutual ecological relationships

Exotics have fewer restraints

The term *invasive* is generally used to describe plants and animals that have the capacity for explosive population growth, becoming widespread and eventually dominating ecosystems. State and federal law reserve the term for exotic species, but elsewhere "invasiveness" is used broadly to describe characteristic patterns of population growth, rather than nativity. In many situations it is difficult to draw firm lines. Should natural range expansions be considered exotic invasions? Should we consider geographic or legal boundaries, when determining whether a species is native or non-native? For example, botanists believe that the bush lupine, *Lupinus arboreus*, has recently invaded the northern California coast from its historic range south of Monterey. While fertile philosophical discussions

Invasive or invasiveness

have emerged around these issues, management decisions must be made on a pragmatic basis, case by case, weighing environmental impacts.

The worst invasives are those that overtake and displace sensitive native species, or that are "ecosystem engineers"—that is, they have very broad ecosystem-level effects (Crooks 2002). For example, in riparian areas the giant reed, *Arundo donax*, can displace native woody trees like willows. As *Arundo* provides little shade and requires large amounts of water, streams become warm and shallow, with low dissolved oxygen and poor habitat value. *Arundo*, French broom and a number of other invasive species can also increase the risk of wild fires. A number of aquatic invasive plants are believed to accumulate sediment, and alter flood capacity. With accelerated international movement of goods and materials, the global exchange of non-native plants and animals has also accelerated, increasing the risk of introducing invasive species. Global climate change can stimulate invasiveness and range expansion in both introduced and native species.

Ecosystem engineers

Most natural areas of the Laguna have been colonized by non-natives—some introduced by the earliest Spanish explorers and Mexican settlers, while others are more recent arrivals. Many species came accidentally, as weed-seeds in grain; large numbers were also intentionally introduced—as forage crops, game animals and garden plants. Most of California's invasive species are from other countries with similar Mediterranean climates, like Australia, Argentina, or South Africa; and these regions have been reciprocally invaded by some of our own endemic species, like the California poppy.

Accidental and intentional introductions

Besides increasing the rate of species introduction, human activities have made the Laguna more susceptible to invasion. Many invasive organisms are good colonizers, which easily become established following environmental disturbance; for example, spreading along road-cuts. Other invasives are superior competitors in high-nutrient conditions, and urban and agricultural runoff and wastewater discharges have contributed to elevated nitrogen and phosphorus levels in the Laguna's floodplain and seasonal wetlands. Atmospheric nitrogen deposition from automobiles and industry has been shown to contribute to the spread of invasive species elsewhere in California, and may be a factor in the Laguna as well. Removing native riparian forests has created sunny conditions that favor the spread of aggressively growing aquatic plants. However, many human-induced contributions to the spread of invasive species can be ameliorated through environmental restoration and land management, and a combined program of research, management, restoration, and source control (reduc-

Superior competitors

ing the influx of new species) is likely to be the most effective means of preserving the Laguna's biodiversity.

> *The Nature Conservancy's weed management information and planning tools have been invaluable for developing the following recommendations.*

Management priorities

The primary focus for restoration and management in the Laguna is to enhance populations of desirable plant and animal species, in order to maintain or restore ecosystem processes, such as water recharge and purification, soil retention, and biological diversity. Controlling weedy plants and animals is a necessary part of land management in the Laguna, but the fundamental goal is to increase the self-sustaining ability of the Laguna's ecosystems to resist invasion by weedy species, and to prevent the introduction of new weeds. Prioritization for weed control activities is based on actual and potential impacts to native species and communities, especially when weeds threaten species at risk of extinction. Studies have shown that the cost of controlling invasive species increases exponentially as with the size of the infestation, and the likelihood of successful control declines (Rejmanek and Pitcairn 2002). Therefore, it is best to take a precautionary approach, placing the highest priority on controlling small populations of aggressive species, even before their impacts become apparent.

Enhance populations of desirable species

Place highest priority on small populations of aggressive species

Site-specific planning and adaptive management

Although ecologists, weed scientists and restoration practitioners continue to improve weed management techniques, each ecosystem is different. There are important biological distinctions between invasive species, differences in the sensitive resources being protected, differences in site accessibility, annual variations in weather, and gradual environmental shifts related to long-term climate change. Consequently, there is no absolute recipe for invasive species control, and restoration plans have to be developed on a site-by-site basis, following the principles of adaptive management. Although specific plans must be developed for each site, projects have to be evaluated in a watershed context; for example, management priorities at a particular site depend, in part, on the risk of invasive species spreading to and from nearby properties, and on sensitive species present at those sites. For this reason, it will often be necessary to form collaborative management agreements for invasive species control. Vegetation management often requires permitting from the CDFG, the County's Permit and Resource Management Department, and possibly

No absolute recipe for invasive species control other agencies. This permitting can take substantial time, and must be incorporated into the planning process.

Prevention

The best way to control invasive species is through prevention. Many of the worst invasive species, like water hyacinth and pampas grass, are readily available for sale to gardeners and landscaping companies. California Partnership for the Prevention of Invasive Plant Introductions through Horticulture (Cal PPIPIH) is a collaborative effort between weed scientists and the nursery industry to reduce this type of new weed introduction. The group is coordinated by Sustainable Conservation, an environmental non-profit, and they have developed a list of plants to be voluntarily phased-out of retail distribution (see links in appendix A). This list was compiled by identifying which common species in the nursery trade had the greatest negative impacts, and although not exhaustive (certain troublesome species, such as *Ludwigia*, were not included) is a very promising first step toward reducing source populations. Habitattitude™ is a similar public education campaign, developed as a collaborative effort between the pet trade, the US Fish and Wildlife Service, and NOAA. Rather than focusing on particular problem species, Habitattitude emphasizes the importance of not releasing any aquatic plants or animals into the wild. The Marin/Sonoma Weed Management Area, a consortium of local agencies and organizations, has developed a *Don't Plant a Pest* brochure, highlighting problem species for our area. Other proposed education campaigns for Sonoma County include working with local nursery owners, and having displays and educational materials available at farmer's markets, perhaps in partnership with the Master Gardener's program.

California Partnership for the Prevention of Invasive Plant Introductions through Horticulture

Habitattitude

Don't Plant a Pest

Accidental introductions are more difficult to prevent. For example, many weed seeds are transported in hay bales grown in other parts of California; or in the gut of grazing animals moved between pastures. The California Dept. of Food and Agriculture, the U.C. Extension Service, and the Resource Conservation Districts provide education and outreach programs for farmers, who are generally very concerned about weed prevention. Invasive species are often dispersed along frequently disturbed roadsides (Gelbard and Belnap 2003), and Caltrans has its own programs for integrated vegetation management (see links in appendix A). Seeds on the shoes of hikers are a source of invasive species infestation in public parklands, taking root in the disturbed soil along trails; and hikers and bikers are also a suspected source of contagion for pathogens like Sudden Oak Death. Restricting access to pristine or biologically sensitive areas as

Seeds on hiking shoes

well as public education about specific problem species and the importance of clean shoes can help contain new and re-introductions.

Early detection / rapid response

After prevention, the most effective management for invasive species are programs focused on early detection and rapid response. If infestations are found while they are still small, they can often be removed and eradicated with minimal use of chemicals, by hand pulling, tarping, or some other low-impact control method. This is by far the most successful and cost-effective intervention, and can many times avoid controversial treatments such as pesticide applications or lethal removals of invasive animals. Where pesticide is the only feasible control method, catching infestations at an early stage will require less chemicals than if the invader is allowed to spread to large areas.

Low-impact control methods

The biggest obstacle to early detection/rapid response programs is getting financial and institutional support for control activities when the invader has not yet had noticeable local impacts. Several purple loosestrife plants growing next to a creek may seem harmless, and even a desirable addition to the local flora. However, the best way to judge if a new species is likely to spread aggressively, is by evaluating how it behaves in similar ecosystems. The California Invasive Plant Council, a statewide organization, has targeted their efforts on tracking and ranking non-native species that are known to be invasive in wildlands. The California Dept. of Food and Agriculture has undertaken similar work, focused mainly on halting the spread of agricultural weeds and insect crop pests. Both organizations give top priority to the control of new introductions. Early detection/rapid response is also a central recommendation of the Ecological Society of America's draft position paper on invasive species management (Lodge 2006).

California Invasive Plant Council

California Dept. of Food and Agriculture

Ecological Society of America

Managing large infestations

Remote or neglected areas can sometimes develop huge infestations of invasive species, as demonstrated by the Laguna's *Ludwigia* invasion. The prioritization for managing or controlling plants in these areas depends on the impacts of the invasion, and the availability of practical control methods. Many times such an invasion is a symptom of other environmental problems, like nutrient enrichment, hydrologic modification, or a change in fire regime; and in these cases, restoration of natural processes is a critical part of long-term control planning. Ideally, we would manage

Restoration of natural processes

these large infestations by addressing underlying factors that have allowed these species to become dominant (Sheley and Krueger-Mangold 2003). However, restoration takes considerable time and planning. Invasions are by definition, novel events, and it is sometimes difficult to know, without extensive research, what kinds of restoration projects will make the ecosystem resistant to any new species (D'Antonio 2004; Lodge 2006). The most successful invasive species are opportunists, with broad habitat tolerances. Without predators or pathogens, such species can potentially out-compete natives even in pristine, healthy ecosystems. Consequently, restoring to a particular historical condition may not be sufficient to discourage the invader. Also, the Laguna watershed has been profoundly altered by generations of human settlement; and it may not be possible to attain a functional historic state. Instead, the "restoration" needs to be defined as restoration of ecosystem function, which as much as possible accommodates anthropogenic changes, while bringing back the most desirable habitat attributes.

Restoration of ecosystem function

Restoration practices that are most likely to support invasive species control include nutrient reductions, restoration of hydrologic conditions (for example, not irrigating in vernal pools), and restoration of healthy riparian corridors. Reducing soil disturbances can reduce the ability of invasive species to colonize new territory, but in many parts of the Laguna, soil disturbance or movement is a natural process. Restoring native perennial bunch grasses can crowd out exotic annual grasses, and has been quite successful in parts of the Central Valley. Restoration of grazing regimes is also likely to be a key component of grassland restoration.

Given the time and uncertainty associated with ecosystem restoration, if a particular invasion has profound environmental impacts, it will be necessary to move forward with an interim control program.

Introducing specialized biological controls

Biological control—introducing specialized herbivores, predators or pathogens—can be a very effective management solution, bringing populations of the invader to low, sustainable levels. St John's Wort *(Hypericum perforatum)* was once considered the worst invasive in the western United States, until three leaf-beetles were introduced from Europe as biological control agents, beginning in the 1940s. Within five years the weed was reduced to less than 1% of its previous range (Holloway and Huffaker 1951). Now, St John's Wort is only a problem in areas that are too damp or shady for the beetles to thrive. Although biological control has much promise as an ecological solution, it is not trouble-free. There have been a number of cases where biological control organisms have become invasive species in their own right, and have driven desirable native species (non-target hosts) to the brink of extinction (Louda 1997). A rigorous biological control program requires many years of testing before a control organism can be released, and sometimes several different control organisms (for example, a seed predator and a plant pathogen) may be required to slow the invasion. Other biological control techniques may also be effective, for example, rearing up large numbers of native insect herbivores to decimate invasive plants in problem sites, or releasing sterile male Mediterranean fruit flies to interfere with med fly reproduction in newly-infested areas. All biological control programs require extensive research and long-term funding.

Grazing as another form of biological control

Controlling weeds with grazing animals is another form of biological control, and has many advantages. Unlike releases of specialized insects or pathogens, grazing animals are relatively easy to manage, and there is little risk that they will become invasive. Goats have been successfully used in the Berkeley and Oakland hills for brush control to reduce fire danger; and a number of private companies now offer commercial services for invasive species management with sheep and goats. However, grazers are not effective in every situation. Aquatic plant invasions cannot usually be managed with conventional grazing animals, because of the risk to water quality, and because most common domestic animals do not do well under wet conditions for extended time periods. Grazing animals can also be a vector of invasive species, spreading seeds in fur, hoofs and feces; lands that have already been disturbed by overgrazing are particularly vulnerable to these introductions. For appropriate vegetation management, it is critically important to first develop a grazing plan, targeting invasive species at the optimal time of year, and bringing in the proper number of animals to maximize environmental benefits without environmental degradation. See Chapter Four for a discussion of using grazing animals to control invasive species.

Environmental restoration and grazing management are the most desirable control methods because both approaches rely on reestablishing ecological processes. However, there are numerous other methods for managing or eradicating invasive plant and animal species. Techniques for controlling invasive plant populations range from burning, flooding, tarping, and handpulling to herbicide applications. Invasive animals are often controlled by hunting and trapping; or sometimes using biological control, as for example, when the virus *myxomatosis* was introduced to control rabbit populations in Australia. Every technique has an environmental impact, and land managers must balance non-target impacts, costs, and effectiveness, when planning each project. Large-scale control

Burning, flooding, tarping, handpulling and herbicides efforts usually require extensive permitting and can be very expensive. As a consequence, action should be taken only when careful evaluation indicates that allowing the invader to spread unchecked will result in more environmental damage than controlling it with available methods.

Integrated pest management

Integrated pest management (IPM) incorporates a combination of control methods, which complement one another to increase the overall effectiveness of the program. For example, an IPM program for invasive grasses may bring together classic biological control, livestock grazing and controlled burns, carefully timed for maximum benefit. Pesticides are incorporated into IPM programs, but used in a targeted way, only where necessary. Long-term IPM approaches focus on improving the overall health of the ecosystem, and establishing desirable native species. They require sustained monitoring and research, and adaptive management. The University of California, Davis, houses a statewide integrated pest management program, and provides information on controlling many household, agricultural, and wildland pests.

Finding pesticides with low environmental impacts

Where pesticides are necessary to control particularly virulent invasives, care must be taken to find formulations with low environmental impacts. Many pesticides must be applied with adjuvants or surfactants, products that allow the active ingredient to stick to or penetrate the plant's waxy outer cuticle, flow smoothly through spray equipment, or otherwise improve its application or effectiveness. In some cases, these additives are more toxic than the pesticide itself, and the entire formulation should be considered during the planning process. Recent studies on frogs found that the surfactants in RoundUp, a glyphosate-based herbicide, caused very high mortality, while glyphosate alone was shown in other studies to be relatively benign (Relyea 2005). RoundUp is a terrestrial herbicide and is not approved for use around wetlands, but the researcher, Rick Relyea of the University of Pittsburg, conducted this research because RoundUp is one of the most widely used herbicide products in the world, and is often used for aquatic weed control in other countries. Because of the risks to the environment, and the potential health effects to the applicator, pesticides should only be applied by experienced, licensed professionals, in consultation with knowledgeable biologists familiar with local vegetation.

Extension Toxicology Network

Pesticide Action Network

In planning pesticide control programs, it is very important to have good information about the products. The Extension Toxicology Network has an excellent website on the environmental toxicology of pesticides, produced through collaborative effort by five different universities. The Pesticide Action Network's Pesticide Database also has a useful site, with well-organized information on pesticide risks compiled from a variety of different sources. The California Dept. of Pesticide Regulation website has a searchable database documenting commercial pesticide applications by year, product and county. This site also contains information on long-term groundwater monitoring for pesticide residues, and information on pesticide risk assessments.

California Dept. of Pesticide

Using herbicides to control weeds

Once a decision has been made to control an unwanted plant, another decision has to be made regarding the most appropriate method to use. One of the possible methods is the application of herbicides. Sometimes this option can be chosen in tandem with other methods, a strategy which often results in greater long-term effectiveness.

When applied according to recommended concentrations herbicide can be applied safely and without detriment to both humans and wildlife. Treated areas can heal quickly, and when coordinated with an active re-planting program, can result in a healthier and more diverse biology than untreated weed infestations.

Part of the evaluation for whether or not to use herbicides includes a careful study of the reproductive strategy of the plant to be controlled. For example, plants that reproduce vegetatively through underground rhizomes may be impossible to control through burning, disking or grazing. In fact, pulling or digging up plants with large underground systems can disturb the site leading to a second wave of exotic plant invasion. Similarly, using livestock to browse or graze unwanted plants can heavily impact an area, especially when native plants are more "tasty" and livestock move on to the weed species only after the desirable ones are depleted.

Careful study of the reproductive cycle

Another practical consideration is cost. Labor, material, and tools involved in disking or pulling or tarping can be greater than the cost associated with applying herbicides. Although cost is seldom the only important variable in choosing herbicides, factors such as timeliness and efficacy can contribute to a more compelling cost/benefit justification.

Making the decision to use herbicides can sometimes be as simple as eliminating all other choices. Tarping may not be possible if the infestation is large or if the plant is tall or woody. Burning may not be possible because of the concern for the safety of nearby structures or because strictures on air quality prohibit it. Disking may not be feasible simply because it is ineffective. Grazing may not be feasible due to the intermixed presence of endangered species, or due to the lack of adequate containment fencing, or because trampling would be excessive and damaging. When all other options have been eliminated, the final remaining choice may be herbicides.

Once a decision has been made to use an herbicide, a careful evaluation of biological uptake is critical. Is the chemical broadleaf-specific or does it also kill grasses? Does the chemical kill the underground structures or is it only effective on the plant's above-ground structures? Is the chemical persistent in the environment and does it have pre-emergent qualities that continue to be effective long after application? How does soil affect the efficacy, persistence and mobility of the chemical? Is the chemical water soluble, and is it permissible to use in waterways and nearby areas? Many of these questions can be answered through careful reading of the herbicide's label and Material Safety Data Sheet (MSDS). Numerous other non-biased and peer reviewed sources of information are also available on the worldwide web (e.g. http://extoxnet.orst.edu/).

A careful evaluation of biological uptake is critical

The use of herbicides is regulated by law and each chemical is approved for use on certain types of plants and under certain types of conditions. These factors narrow the choice of which herbicides can be used. Many wildland weeds have been the subject of field research. A particularly good source of information derived from these studies is The Nature Conservancy's Global Invasive Species Initiative (http://tncweeds.ucdavis.edu/) The California Department of Pesticide Regulation, together with specialists at the California Department of Fish and Game can also assist in the selection of safe and effective herbicides.

Professional applicators are licensed. In Sonoma County, pesticide applicators are regulated by the Agricultural Commissioner's office. After safety and legal training an individual who applies for a license may take an exam and, if passed, becomes a certified pesticide applicator (CPA). A professional who has studied a broad range of pesticide products may make recommendations to other CPAs on the choice of products for a particular project. This recommendation will usually be made after examining the relevant project variables including plant species to be controlled, soil pH, proximity to open water, presence or absence of nearby agricultural activities, etc. A Pesticide Control Recommendation (PCR) is a written recommendation that prescribes the use of a particular herbicide on a particular plant species. A PCR will also recommend a surfactant to be used in the mixture. Surfactants are additional compounds that enhance the ability of a plant to absorb the chemical, or enable it to adhere to the plant, or make it more or less water-soluble, or allow it to be applied more uniformly, or add other physical or chemical properties that increase

Certified Pesticide Applicator

Pest Control Recommendation

the effectiveness of its application. PCRs also prescribe concentrations for both the active compound and any recommended surfactants. When reviewing the PCR, land managers should pay particularly close attention to the side effects known to occur from surfactants—they are not as tightly regulated as active compound, and have been implicated in some studies as having unwanted effects on amphibians.

When applying herbicides, strict monitoring of wind conditions are important and adherence to drift standards are critical—this is especially important in wildland areas that are adjacent to agricultural row crops. PCRs often set the upper limit for wind speed at 10 MPH.

Application techniques vary based on the species being controlled, the herbicide being used, and the extent of the infestation. Stem-tip painting of concentrated herbicide, applied immediately after cutting a tree limb or plant stalk, can effectively be used on a wide variety of plants—from large-trunked arroyo willows to small-stemmed blackberries. Spraying diluted concentrations of leaf-absorbing herbicide via handheld applicators can be efficient when the plant to be controlled is found in small isolated patches, or when threaten or endangered species are in the nearby vicinity. Backpack sprayers are essentially the same technology as handheld sprayers and can be used for similar purposes. Motorized spray-rigs, which varying in size and sophistication, are often the most suitable technology for large infestations; spray-rigs are less precise and should only be used when indiscriminate application is called for—typically large monocultures.

Overall, using herbicides to control weeds is a short term intervention, not a long term solution. Good restoration ecology seeks to bring natural balance to an area. When successful, this means that chemical interventions are no longer needed. By learning from the successes and failures of other restoration ecologists, land managers should thoughtfully evaluate invasive plant threats and should confidently use herbicides when appropriate.

Commercial use of invasive species

Many invasive species, including *Arundo*, water hyacinth and *Ludwigia*, have been studied for their potential commercial benefits, beyond horticultural uses. For example, researchers in the southeastern U.S. are investigating *Arundo*'s potential as a biofuel, to be farmed in large commercial plantations. Water hyacinth and *Ludwigia*, as well as a number of other aquatic plants, have been tested for use in constructed wetlands to remove aqueous nutrients and heavy metals. Perennial pepperweed is thought by some

Invasive speices as biofuel, medicines, and foods to have medicinal and culinary uses. Rather than trying to eradicate these species, it is sometimes suggested that we find ways to harvest them, to provide an economic benefit for Sonoma County.

The difficulty with this approach is that long-term commercial objectives conflict directly with the goal of managing natural areas to protect native biodiversity. If, rather than removing *Arundo*, we instituted a regular harvesting operation, there would be no restoration of habitat values in these riparian areas. Rather than becoming wild, stream channels would become agriculturalized and further degraded from the continued disturbance of harvesting operations. Creating an industry around by-products of invasive species creates a demand to maintain those species in the environment. Similarly, *Ludwigia* could be cultivated in constructed wetlands, and used to remove nutrients from the water column. For this operation to be effective, the plants would have to be harvested on a regular schedule, but this would preclude the possibility for managing the wetlands as wildlife areas. While this is a potentially feasible scenario in some farm ponds, researchers believe that *Ludwigia* seeds and reproductive fragments are, to a certain extent, spread by birds. As a consequence, it would be impossible to contain these plants, and there would always be a risk of introduction to natural areas. If we want to have wild places in our watershed, where native plants and animals grow in abundance, we have to restrict the introduction and control the spread of non-native species throughout the region.

Wild lands or agricultural operations?

Monitoring and research

Weed monitoring

Mapping infestations

Weed mapping and monitoring programs are essential for early detection and rapid response to initial infestations, and are a central component of adaptive management planning for large-scale invasive species control. These data should be gathered into the Laguna Ecosystem Database, along with notes and information about control methods. Ideally, data will be collected using protocols that integrate with national and international weed monitoring information systems.

Data collection protocols

A number of agencies and organizations have been developing GIS databases for weed monitoring, and over the next several years we will likely see the emergence of a national weed database. For example, The Nature Conservancy and the US Fish and Wildlife Service have collaboratively developed WIMS, the Weed Information Management System. This is an integrated hardware and software application, which seeks to standardize monitoring protocols and data collection and storage. WIMS tracks weed occurrences, assessments on the size and status of infestations; it also keeps records on treatments that have occurred in order to measure their success. Having standardized protocols allows different land managers to share meaningful information, and allows researchers to analyze the pattern of invasions over large regions. As local data are collected, they can be stored in the Laguna database, and simultaneously uploaded to the national database.

Weed Information Management System

Invasive species research

Invasive species research is one of the fastest-growing study areas in the ecological sciences, barely keeping pace with invasive species' environmental and economic impacts. A wide variety of research is needed to understand the dynamics of invasions, and to develop successful management techniques (D'Antonio et al. 2004). Overall, improving our understanding of invasive species in the watershed will depend on improving our understanding of the physical and biological processes as a whole. In many ways, invasions are controlled by the hydrology, geology, water chemistry, and ecology of other Laguna plants and animals. Research on the baseline characteristics of the Laguna must move forward in parallel with research on invasion biology.

Hydrology, geology, water chemistry, and ecology

There is always a tension between the need for management action and the ability for science to provide rapid answers. D'Antonio and colleagues (2004; see also Larson 2005) drew parallels between invasive species research and disease research, and in fact some diseases, like West Nile virus and Sudden Oak Death, are considered to be invasive species. For both diseases and invasions we need a wide diversity of research. Some scientists must study the origin and genetic basis of the organism, other researchers must study its impacts on other species, and others are needed to work toward finding a cure. As an analogy, if a patient begins to go into crisis from a terminal disease, the medical researcher may feel pressured to try risky experimental treatments: but the doctor (or in our case, the land manager) has to work closely with the researcher to weigh risks and benefits before proceeding.

Experimental treatments and research

One of the first steps for an invasive species program is to have good taxonomic information, including keys for field identification. The best indication of invasiveness is how a species behaves in other areas; and the effectiveness of control techniques can vary between closely related species. The exact identity of a species is also usually necessary for receiving state or federal funding for control programs. Easily accessed internet-based information systems, such as WIMS, with physical descriptions, geographic information, management recommendations, and references for relevant ecological studies, will be a powerful new tool for increasing the efficiency of control efforts.

Understanding reproduction

One of the most important factors to understand about a particular invasive species is how it reproduces and spreads. For example, *Arundo* spreads solely by vegetative reproduction, when fragments of roots or rhizomes are transported by floodwaters. Without deliberate introductions by human gardeners, it is therefore possible to eradicate if control efforts begin at the top of the watershed and work down. Purple loosestrife produces up to 100,000 tiny seeds per plant, which can be spread by wind, water, or animals. Because it is a perennial, it is important to both keep seed from maturing, and to kill mature plants and their roots. Yellow starthistle, a prolific invader of California grasslands, is an annual with a short-lived seedbank and can be effectively controlled with carefully timed mowing, grazing, or herbicide applications. It takes careful research to understand which life-stage is most important to target for maximum control.

Targeting life-stage for maximum control

Ecological studies, evaluating the interactions between invasives and other species or physical processes are very important for determining control priorities. Some non-native species, such as dandelions, are widespread, but are not considered to have big impacts on sensitive plants and animals in the Laguna. Other species, like the Louisiana swamp crayfish living throughout the Laguna, are likely to have drastically altered the wetland ecology, but these effects have never been measured. Researchers are only beginning to understand the ecological effects of *Ludwigia* invasions, and this work will take many years to complete.

Research on control techniques is also extremely important. Although it is sometimes necessary to move forward with incomplete information, whenever possible control projects should include a research component to evaluate the success of management actions and fine-tune techniques to site-specific conditions as part of the adaptive management plan. Funding for research and monitoring should be built into grant applications.

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