Chapter 8

If You Can't Measure It, You Can't Manage It: An Ecological Approach to Weed Management

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We are often given the impression that all weeds are bad. Dandelions in our lawn, bindweeds in our veggie patch, and spotted knapweed along our roadsides all need to be removed. But, is that true? And even it is it, can we realistically control all of them - particularly if our backyard is hundreds of thousands of acres of public land? This is the nature of the problem facing most public land managers in the West, and the Greater Yellowstone Ecosystem is no exception.

Virtually all public lands and national parks contain populations of non-native and invasive plants. For a multitude of reasons such species are considered undesirable and the general mandate is to remove them when they are found; a strategy known as early detection, rapid response. However, finding and controlling these species is difficult and expensive, particularly over large and rugged landscapes.

Bruce Maxwell and Lisa Rew were asked to develop and perform a survey of non-native plants in the Northern Range of the Park and develop a strategy for controlling non-native plant populations that occur over such a huge area. Is early detection and rapid response the most efficient and effective use of limited resources? Or might it be best to leave some of these populations alone?

Rew and Maxwell are not newcomers to these types of applied questions. Both have worked on weed management strategies for many years in agricultural and natural settings. They are also modelers. This means they use various statistical methods to build simulations of the real world. In turn, the simulations are used to develop a better understanding of the complexities of an invasion as well as the most efficient way to control them.

Here we see the approaches they have taken. Resource managers have used their probability models to search for previously undetected non-native plant populations, and to evaluate how changes in land-use may alter the presence of invasive species. Their most recent work evaluating when to manage suggests that sometimes, early detection and a passive response is the most logical management option.

J. Johnson



Lost in Montana (Trey Ratcliff)

Chapter 8

If You Can't Measure It, You Can't Manage It: An Ecological Approach to Weed Management

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The overarching question we apply to our research work is: Can ecological information improve the ability of land agencies to manage the non-native plant species in their area? Stated another way: Will it pay off both economically and ecologically to spend some amount of time and money on understanding the ecology of these species in order to better target and prioritize their management?

Or, is it better to try to eradicate new arrivals when and where they can be found (early detection, rapid response - EDRR), and simply control more established species where they are known but not worry about looking for more of them?

To answer these overarching land management questions we need to address a series of questions relevant to plant ecology:

- How does one detect a plant population, particularly one in the early stages of invasion, i.e. when it is very rare?
- Is the population having a negative impact on the surrounding community, e.g. reducing the number, abundance, biomass and/or reproductive output of other species, or altering the amount of available water?
- If a population has established where is it likely to go next and how rapidly?
- How early in the invasion is early enough to make EDRR (i.e. eradication) work?
- When is it too late to stop the invasion because we cannot possibly target all the patches of the weed?

We will describe the approaches we used to answer these questions for the Northern Range of Yellowstone National Park.

The Problem with Non-Native Plant Species

Most of the plant species that have invaded Yellowstone National Park (YNP) are herbaceous flowering species that can be broadly divided into "monocots" (short for monocotyledons or one seed leaf) which are mainly grass species, and "dicots" (short for dicotyledons or two seed leaves; also called broadleafs or forbs). These species stop growing aboveground during the colder months, generally dying back to the ground each year but maintaining a root system from which they resprout the next year. Most of these non-native species occur in meadows mixed with native plants of similar size and general appearance, making them difficult to identify



▲ PHOTO 8.1 Public land managers fear non-indigenous plant species will drive out native species and replace them with a less healthy ecosystem. In fact, some non-native species are beneficial to native systems. (Jerry Johnson)

Non-Native Plants: Terms and Assumptions

The terms invasive, alien, exotic, non-native, non-indigenous and to a lesser extent weed are often used synonymously to refer to plant species not present at some previous point in history: pre-Columbian or pre-European human immigration. In reality there is little information on plant species occurrence prior to European settlement in the Greater Yellowstone Ecosystem. The first plant collections made in the Park were in 1871 by Robert Adams, a member of the Hayden Expedition. Frank Tweedy published the first flora list for the park in 1886. We tend not to use the term invasive species unless its invasiveness has been quantified, but use all the other terms interchangeably.

Management of non-indigenous plant species (NIS) within a rangeland or wildland ecosystem is typically based on the premise that they are invasive and therefore, must be managed. Noxious weeds are a subset of NIS legally designated by federal and individual state governments as having negative impacts upon crops, livestock, and native plant communities. However, the selection criteria are not consistent nor generally quantitative.

In reality any plant species that persists in a community, either native or non-native, has the potential to be invasive given optimum environmental condition. The key here is 'optimal' conditions: population growth rates may vary due to habitat suitability and can vary across time as resource availability fluctuates. Invasiveness can be defined as a population increasing in density and/or spatial extent.

The result of the assumption of invasiveness for all non-native species is that the same level of management effort is usually applied to all populations of the species, regardless of the environments in which they grow, even though population growth rates (i.e., the level of invasiveness) vary across the landscape. In addition, the impacts that a species' population is having on the environment surrounding them will also vary. Impacts include diminished native plant diversity, alteration of community structure and composition, threats to rare and endangered species, reduction in wildlife habitat and forage, alteration of disturbance regimes, depletion of soil moisture, changes in nutrient dynamics, and changes in the structure and function of belowground communities. However, few studies have evaluated populations in a range of different environments.

It seems intuitively unlikely that the same species has the same impact under all conditions when we know that the degree of invasiveness varies. The invasiveness and impact of a non-native population is not merely a function of it's presence. It is also the species' biological attributes, site-specific environmental conditions, and the composition of the surrounding plant community. To assume that all populations are capable of the same degree of invasion and impact, and that the impact is consistent across a varied landscape, may result in a misdiagnosis of the invasion and impact potential of the species. This mistake may result in inappropriate or inefficient management.

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without a trained eye and often a taxonomic key. A total of 187 non-native plant species have been recorded within the Park, which comprises 15% of the total plant species. Many of these species have very pretty flowers and one may argue, add to the aesthetic value of the ecosystem. It is also the case that some of them, such as timothy grass (*Phleum pratense*), can have higher levels of nutrients in them than the native grasses and therefore are useful as a food source for elk, bison, and other grazing animals.

As with most issues there is a whole gamut of views. At one end are those that argue that all ecosystems or habitats change over time so the presence of non-native plant species is not a problem. Others would argue that these species have the potential to destroy the ecosystem by displacing native plants that support the food web that connects everything from bacteria to grizzly bears. At the extreme end of the range are those who consider the sheer presence of a non-native plant to be an unacceptable impact. Rather than just choose where to stand along this "no-problem to big-problem" continuum we are collecting data and have developed a framework to help us and land managers determine how to address this problem in a more rational way.

Quantitative information collected to determine the impact of non-native plant species indicates that there is great variation in the impacts caused by invasive species and even between different patches of the same species. That is, in one patch a species might have a negative impact by displacing native species. In another, the impact may be negligible or non-existent. Ecologists and land managers almost always default to the *precautionary principle* and so would rather assume that the introduced species is likely to have some detrimental impact and thus would recommend removal just to be safe.

This reasoning seems logical from a conservation point of view, but two points make the issue more



▲ PHOTO 8.2 Elk grazing in an area of the Northern Range of Yellowstone National Park that is highly infested with the non-native grass timothy (***Phleum pratense***) and other nutritious "weeds". The grass was introduced by the National Park Service as forage for bison and elk. Today, it is found throughout public and private lands in the region and is an important food source across the Greater Yellowstone. (U. S. Fish and Wildlife Service)

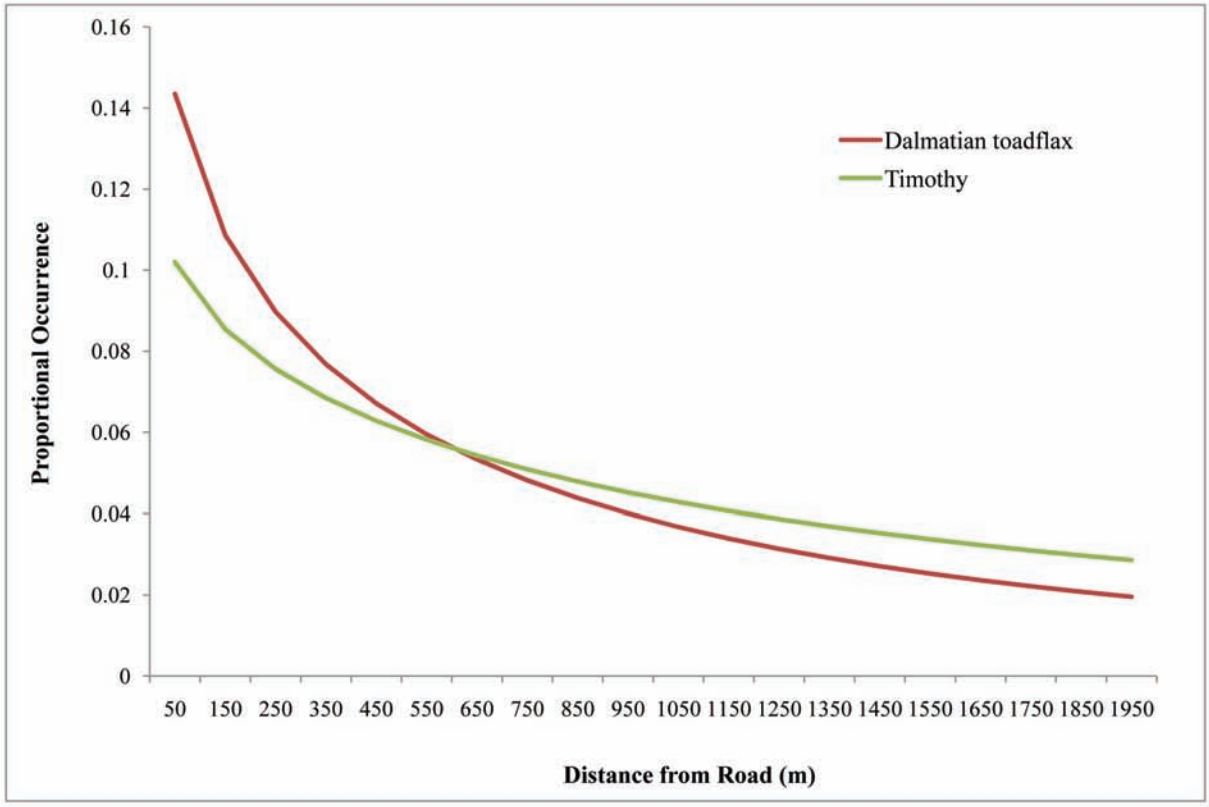
questionable. First, it is costly to detect and remove non-native plant species. Second, the methods used to remove these species, primarily herbicides, can have extensive off-target effects – often killing the native plants that may offer the greatest competition to the invaders. The reason for these off-target effects is that most herbicides, especially those used for general weed management in range and wildland areas are not selective to a specific species. A particular herbicide targets either grasses or broadleaf species. If one applies a broadleaf herbicide to control, for instance, spotted knapweed (*Centaurea stoebe*, formerly *C. maculosa*) it will also kill the native broadleaf species present in the same area such as sticky geranium (*Geranium viscosissimum*), larkspur (*Delphinium spp*.), etc. The result of killing off the native species along with the non-natives is that there will be bare ground left behind. As non-native species tend to be adapted to disturbed environments, it is more likely that the same or other non-native species will re-establish in these areas, at least initially. Another consideration is that unless the herbicides are applied at an optimal time - when the plants are actively growing and with all the water and nutrients they need - the success of the herbicide is far from 100%. In fact, under many field conditions killing 80% of the target plants would be considered a success. This represents an economic waste as well as an inefficient control method. Although it must be said that the timing of other control methods, such as pulling by hand, is even more time critical and often less effective and, biological control methods take a longer time to reduce the target population. Herbicides are a useful tool but due to the inherent problems mentioned above they should be used to target the most rapidly increasing populations. This includes those acting as sources (i.e. sending out seeds to start new populations across the landscape) and those having the most negative impact on the surrounding community.

Field Detection and Predictive Maps

Detecting invasive plant populations is difficult and tedious because in areas such as the Greater Yellowstone Ecosystem they are essentially rare, even though they can be locally abundant. Someday it may be possible to reliably detect non-native invading plant species with remote sensing, but for now it is of limited help in the detection process due mainly to the scale of the imagery, the size of plant patches, and cost. Instead, we rely on ground based field methods to maximize the efficiency of the search for the metaphorical needle in the haystack. Sampling methods have been designed which capitalize on our knowledge of how species were introduced to an area and how they disperse.

The occurrence of non-native plant species in Yellowstone, like other places, is associated with humans. Some species have been introduced as flowers to decorate the lodges and their dining rooms (e.g. Dalmatian toadflax, *Linaria dalmatica*) and for other ornamental purposes such as lawns (e.g. Kentucky bluegrass, *Poa pratensis*). Others, such as timothy grass, were introduced to increase the forage for wildlife and domestic stock animals back in a time when Park management was dictated more by utility than conservation. A third type of introduction is more accidental and is along roadways where the sand, gravel, and rock material used to build the roads or provide for increased traction on ice in the winter, comes from stockpiles outside of the Park that are infested with non-native plant seeds. The Park Service along with other agencies recently introduced a weed-free certification for gravel pits to reduce this introduction vector. Other roadside introduction is related to vehicles themselves, with seeds and other plant parts being moved around on vehicles. This third type of introduction relates to large areas of the Park and should be considered when identifying the likely places to find new populations.

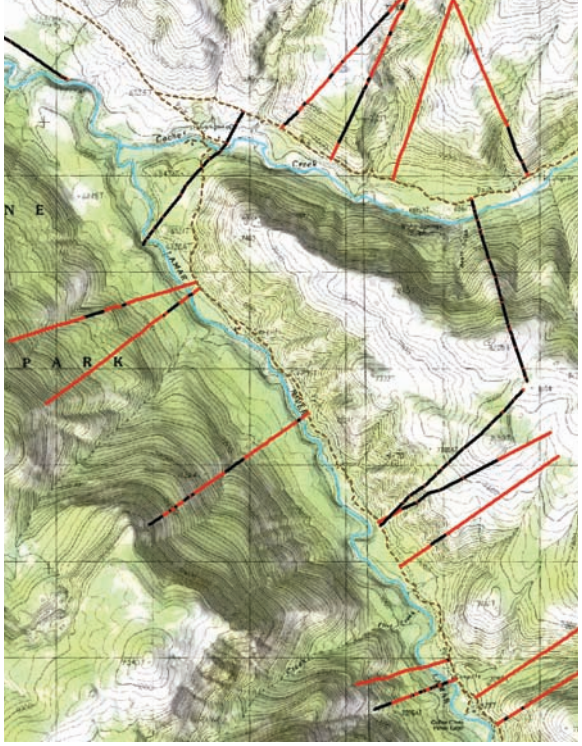
During 2000 our team of plant ecology scientists at Montana State University was asked by the Park Service to create an inventory of the non-native plant species and their distribution in the Northern Range of the Greater Yellowstone Ecosystem. Given that the area of the Northern Range is so large, 152,785 ha, and the initial budget was small and finite, it was abundantly clear that we could not sample the entire area. We used the knowledge that non-native plants tend to be associated with roads and other rights of way and decided to start sampling from those areas and move along a perpendicular transect away from them. In this way, we



▲ FIGURE 8.1 The declining distribution or proportional occurrence of Dalmatian toadflax (*Linaria dalmatica*) and timothy (*Phleum pratense*) with increased distance from roads in the Northern Range of Yellowstone National Park. Roads act as vectors for non-indigenous plant species with plants propagules being spread by such things as construction activity, winter road safety materials as well on vehicles. (Invasive Weed Ecology Lab, MSU)

could determine if there was a pattern of species spread from roads and other places with human disturbance into the surrounding wild areas. After one year of preliminary data collection, we found that for non-native species, the frequency of occurrence measured as the number of times we found the particular species divided by the number of times we looked for it, decreased with increased distance from roads and trails. This verified that the primary modes of introduction for most of these species were factors associated with the roads.

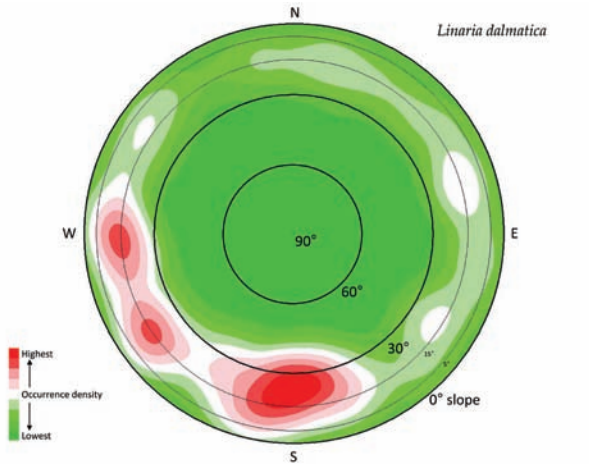
From the preliminary data we concluded that the roads and trails represented source habitat for these species, and so we refined our design and sampled extensively during the following three summers (2002-2004). We designed two kilometer long transacts that started on roads or trails and extended into the backcountry perpendicular to the road or trail but not re-crossing them. Two field technicians would walk along the transect and carefully look for non-native plant species recording the presence of each with a global positioning system (GPS) in a ten meter wide swath. The crew generally used compasses to maintain their bearings from the start to the end of each transect, as GPS work less reliably under dense tree cover, in steep ravines, etc. Performing these transects is easy and fun for those with slight masochistic tendencies; much of the Park has very rugged terrain and slopes above 40 degrees are not uncommon. Forests of deadfall from the 1988 fires left trees lying like pick-up sticks across the landscape. Progress can be very slow. Often, the length of our two kilometer transects was truncated by terrain (cliffs) or animals, most often bears but sometimes bison, in our intended path! In general, two transects were completed per day and these days would vary from the shortest at around four hours to the longest at 12 hours



▲ FIGURE 8.2 We walked 375 10 m wide transects, shown here as solid black lines, perpendicular to roads or trails and generally 2 km long. Red portions represent the location of a target invasive plant observed along transects. The area shown is a 10-km by 10-km sample of our study area in the Northern Range of Yellowstone National Park. (Invasive Weed Ecology Lab, MSU)



▲ PHOTO 8.3 Survey crews traveled in teams of two – one to use a compass to stay on the transect, the other recorded the presence and absence of non-indigenous plant species. (Lisa Rew)

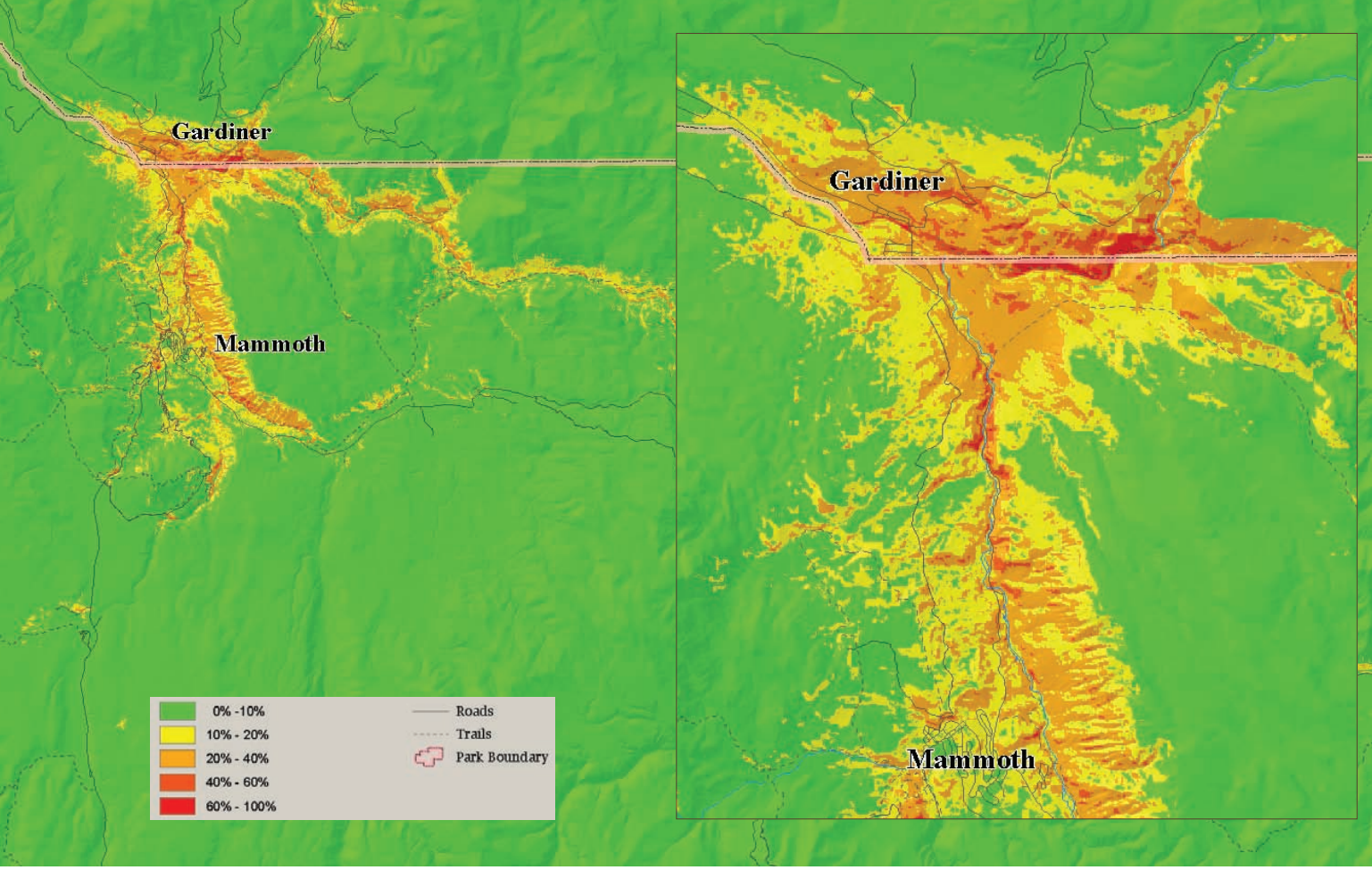


▲ FIGURE 8.3 This rose diagram shows the frequency of occurrence of Dalmatian toadflax (*Linaria dalmatica*) on the landscape with respect to slope and aspect. The annuli (target circle lines) represent the angle of the slope with the outside of circle being flat and the center a 90-degree cliff. The aspects are labeled like a compass with N at the top. Red demonstrates the highest frequency of occurrences through pink, white, light green and finally dark green where no patches were found. The diagram shows that toadflax favors relatively flat slopes with a south to southwest aspect. (Invasive Weed Ecology Lab, MSU)

excluding travel time. Over the four summers (2001-2004) with between one to four crews working each week, we collected data along 375 transects, or 611 km throughout the Northern Range of YNP. Despite this effort we still only sampled about one percent of the Northern Range.

Back in the lab we analyzed our data to try to understand the underlying patterns in species presence. Using digital elevation (topography) maps, the frequency of occurrence (presence/absence) of each non-native species could be associated with an elevation, aspect, slope, and calculated solar energy input. We could also associate presence with fire history and distance from road, trail, etc. The data was then used to predict where each species is likely to occur within the Park regardless of whether we visited the area or not – we refer to these predictions as Probability of Occurrence or PO maps. All of this is achieved using a geographic information system (GIS) and additional statistical analysis.

The PO maps for each non-native plant species allow managers to narrow their search when attempting to find and/or control them. We hope this is useful in



▲ FIGURE 8.4 Probability of Occurrence maps for Dalmatian toadflax *(Linaria dalmatica)* in the Northern Range of Yellowstone National Park. The decline in toadflax occurrence with distance from roads and trails, the preference for south and southwestern aspects, slopes between 15 and 30 degrees and other environmental variables are demonstrated by these map. The maps are useful tools for the park service to use to target the likelihood of future infestations. (Invasive Weed Ecology Lab, MSU)

any large area because any way to help land resource managers prioritize which areas to search for new weed populations will increase the efficiency and effectiveness of management.

Once species have been found or their location predicted with PO maps the next stage is monitoring for invasiveness and impact of populations. We have found that the PO values are a reliable surrogate of habitat suitability for a species. As the habitat becomes more suitable, the plant is more invasive. For example, Dalmatian toadflax prefers a more southerly aspect on a 15-30 degree slope. In these locations, it will tend to be increasing in density and area and therefore is likely to produce more seeds. If those seeds fall in a more suitable habitat, they have the potential to produce more new populations. Using the PO values, the manager responsible for controlling non-native species can prioritize species and patches for management based on whether or not they are in areas of high or low PO. High PO would receive management first.

Determining the Rate of Spread

In 2007 and 2008 we began to retrace some transects from 2001-2004 to determine what changes occurred to the populations of non-native plant species. Using the GPS, we were able to retrace our tracks along each transect to determine if there were any new patches, if any patches had gone extinct, if they had grown or, if the populations are unchanged.

Using the presence and absence data from the same transects observed in two different years we are able to estimate the probabilities of colonization and extinction

as well those areas remaining unoccupied or occupied. The probabilities of changes in a population over time are called Markov transitions. We found, once again, that PO values, as a surrogate for habitat suitability, was a significant covariate or driver of these transitions. That is, PO value is a good positive predictor of where new patches are likely to occur; the higher the PO value, the higher the probability of seeing a new patch of the target species. Similarly, low PO value is a good predictor of where patches are likely to go extinct without intervention. We also found that distance to the nearest existing patch along a transect was a robust predictor of new colonization, this phenomena also increased along the PO gradient. Equipped with these different transition probabilities we can develop new maps detailing different rates of spread over the landscape, and over time. This ability to simulate an invasion of a non-native plant species also allows for the simulation and evaluation of different management strategies for curtailing the invasion.

Simulation of the Manage or Not Manage Dilemma

Based on the ecological knowledge that we have gained about how plant invasions proceed including the variability among species, and populations within each species, we can return to our question: Is the scientific information valuable enough to improve the management of these invasions or would it be better to just put all of the effort into eradicating or controlling populations when found? Ideally, we would have ten or more seasons of data to track changes in the populations on the ground before making such recommendations; during that time some patches would spread and give rise to new patches. However, public land managers rarely have the time to wait so long to make a decision. As an alternative to long term field monitoring we created two theoretical simulation models based on the transition data we had already collected.

When using theoretical models it is considered good technique to use competing models to ask the same question; that is, models with difference in their structure



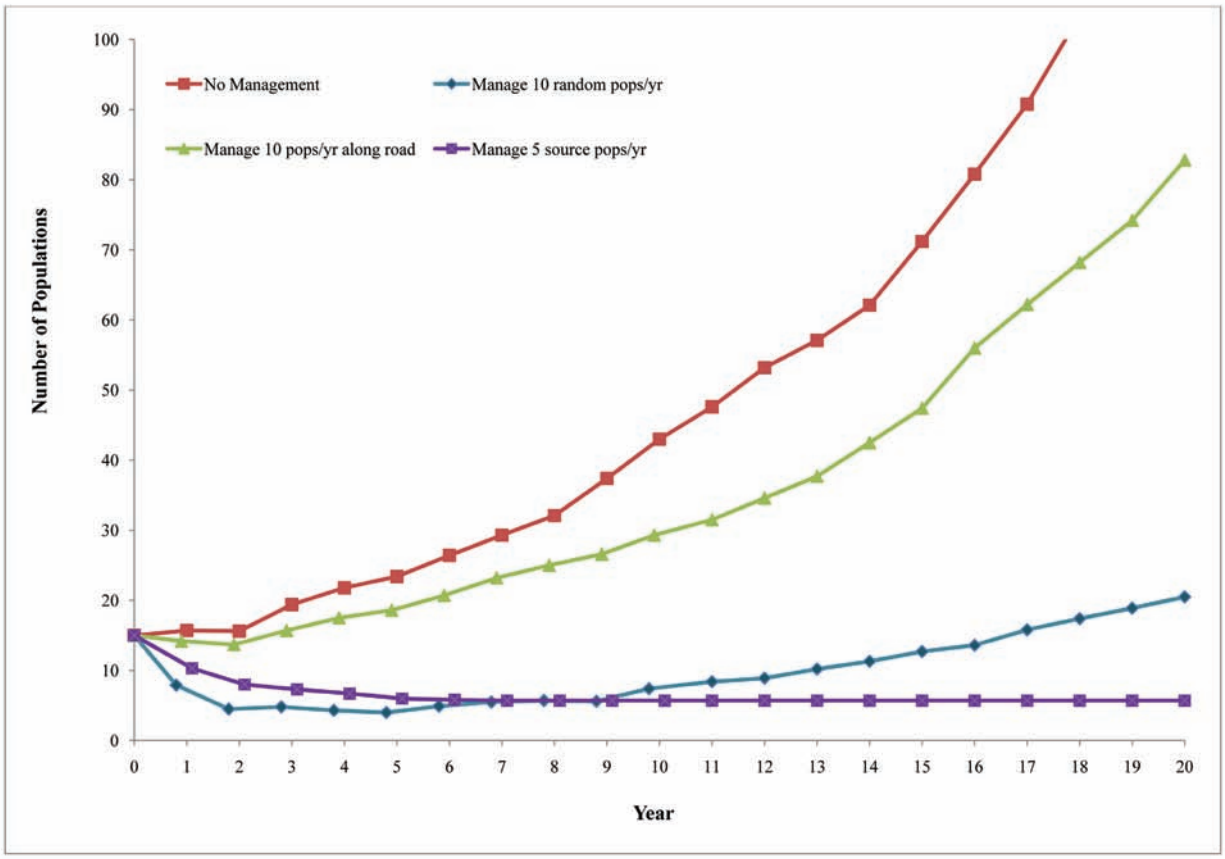
▲ PHOTO 8.4 Management of non-indigenous plant species with herbicides is the most common form of management and is typically conducted close to roads. Unfortunately, unless the chemical treatment is applied at the correct time and in the correct way, it can be relatively ineffective. Our models show that sometimes such treatment is not warranted because the infestations are so pervasive; however, given early detection of new outbreaks herbicide application may be cost effective. (Erik Lehnhoff)

for simulating the same phenomena. If both produce the same response/results one has greater confidence in the results. Our first model assumed a highly simplified landscape with no variability in habitat quality but three classes of populations: extinction, equilibrium and source class, and four management strategies. The second model assumed a more variable background that provided a range of habitat suitabilities similar to the PO gradient for establishment and invasion potential.

The simulation experiments conducted with the first model (constant habitat suitability) revealed some interesting outcomes. First, the Early Detection Rapid Response (EDRR) management approach was more

successful than the other management strategies at reducing the number of populations in the first seven years. The constraints of this approach were that detection and control had to successfully remove more than 67% of the populations and, the managers had to randomly choose the populations to manage regardless of their location relative to the road. These requirements for success with the EDRR strategy are stringent and may be very difficult to achieve. A detection and removal rate of 67% of all populations would be very optimistic for most of the species that have invaded YNP and the GYE. Further, eradication far from existing roads or trails is time consuming and expensive.

Monitoring to identify source populations, followed by their management (Monitor 50% and Manage 50% time), became the best management approach for reducing the rate of invasion after approximately nine years. This is true even when only five populations could be managed in any given year. Thus, this model suggests that ecological information that can help identify source populations is of value and may be the best approach for managing invading populations. The long and short of it is, *if* detection and control rates are high and imposed as soon as a species arrives in the area, EDRR can work well, *but*, as soon as a species has been present for around ten or more years there are too many populations for chemical control to work if it is just applied to random populations or those near roads. After around ten years, knowing which populations are being invasive and



▲ FIGURE 8.5 Based on our simulations and incidence of non-indigenous plant population, we developed responses to different management strategies over a 20-year period. We determined that managing new source populations is the best management approach. If new infestations are eradicated early then control is effective. This approach depends on early detection in remote locations using models based on field data and real world observations. (Invasive Weed Ecology Lab, MSU)

spreading seeds to other areas will provide better overall reduction in the number of populations. For most non-native species in YNP and the GYE, this latter scenario is the most realistic.

The second simulation model – with variable background environment –shows a similar pattern. EDRR will work if it can be implemented early enough in the invasion process so that a large proportion of populations can be detected and eradicated without regard for a population's potential for being a source for new patches. However, if one is slower to locate new species and their populations, gaining ecological information about the species (monitoring) and using that information to target (kill) source populations will be the superior management approach.

These are results from theoretical simulation models, albeit they are based on some field data. Theoretical models still make many people nervous, as all models are based on assumptions that cannot reflect the full complexity of the natural world. Models have the advantage of helping us test assumptions and determine driving processes that would take decades of fieldwork to ascertain. Therefore, we will continue to collect data for the next few years using the same transects and will continue to improve and modify the second model with more empirically based information. Over time, we will be able to suggest best management strategies with more certainty.

Conclusion

Returning to the original and overarching question: *Can ecological information improve the ability of the land agencies to manage the non-native plant species in their area?* The answer from our fieldwork and modeling is "yes". The occurrence of non-native plant species varies over the landscape and there is no evidence that any of these species will "take over" and form a monoculture over the entire area. There are parts of the landscape that are more or less suitable for a particular species due to differences in environmental variables such as aspect, slope, soils and other vegetation. There is also a trend of more non-native plant species being present in disturbed areas; this is demonstrated by higher frequencies of non-native species close to roads and trails in our example. The correlation with disturbance is very important, whether the disturbance is more anthropogenic such as road maintenance or the addition of gravel, or natural as in the case of wildfires and floods. As a general rule, an area will be more susceptible to invasion by non-native plants if it is disturbed. This needs to be considered when thinking about the likely benefits of control. Our sampling and simulation models demonstrate that most non-native species in the GYE are already too frequent for Early Detection and Rapid Response to have a positive effect of reducing population numbers. It may be possible to use EDRR to reduce numbers in a specific small area such as 10 ha but likely, there are so many populations in the surrounding area that new populations would easily reinvade.

There is a bright side to this dark cloud for public lands managers: *if* we spend some time detecting and monitoring (i.e. measuring) a small number of weed populations, *then* we can extend this information to an entire area of interest. We can prioritize the species and populations to manage and can thereby reduce the total number of source populations within an area such as the GYE. As non-native plant species are present on most public lands and national parks, this prioritization approach will work there too. In addition, park and resource managers have many demands on their time and budget and no state or federal agencies have enough money to manage all noxious weeds in their area, let alone all the non-native species. Using the information described would change the way non-native species are currently managed and could prove to be an effective economical and ecological way forward.

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