Adaptive management of alien invasive species: putting the theory into practice[1]

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ABSTRACT. Even though often based on scarce information, many actions due to conservation of biodiversity need to be carried out as matters of urgency. In the case of biological invasions, this is a common situation, as the real possibilities for controlling an invasive alien species are significantly reduced as it establishes and spreads over natural ecosystems. Adaptive management, that is, management practices planned on a solid experimental basis, allows managers to tackle urgent problems at the same time they generate essential information to test the effectiveness of control practices and the precision of assessments of the impacts of invasive species over natural ecosystems or of the need to carry out complementary restoration practices. The basic principles of adaptive management are presented in this paper with examples of its application in the control of invasive alien species in the pampas of Argentina.

Keywords: adaptive management, invasive alien species, invasive non-native species, biological invasions

LACK OF INFORMATION: A CONSTANT IN CONSERVATIONIST MANAGEMENT

One of Conservation Biology's main concerns is to minimize the impact of human activities on the structure and composition of ecosystems and to seek more harmonious forms of interaction between the human species and biological diversity (Primack et al., 2001). Since its origin it has been defined as a crisis discipline, referring to the fact that it requires urgent action, and in most cases it includes high amounts of uncertainty (Soulé, 1985). Biodiversity conservation actions cannot wait until full knowledge of all factors involved in each situation is available, nor their necessary relationships. This fact goes against traditional scientific formation that drives natural science professionals to seek increasingly more information before they can feel comfortable in making decisions. Although it may still be risky to adopt management measures without precise information, it is unrealistic to think that generic scientific studies can contribute decisively to an improvement in decision making, or that

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qualitative studies such as lists of species or soil maps are indispensable prior steps for making any decision. In the current environmental degradation scenario, decisions generally need to be taken as matters of urgency. To abstain from carrying out a management action is a decision whose consequences can be as or more serious than doing something mistakenly (Zalba, 2005a).

The management of biological invasions is a particularly clear example of this type of situation: invasive alien species are one of the main agents for environmental degradation and it has been proven that as the invasion process advances, the possibilities for limiting their impact on natural ecosystems is significantly reduced. Thus, immediate action and early control are actions of maximum priority and economy (Baskin, 2002, Mack et al 2000, Wittenberg and Cock, 2001). The Convention on Biological Diversity recommends confronting the problem of alien invasive species based on the precaution principle: the lack of scientific certainty should not be used as justification to postpone or not implement eradication, contention or control actions. Likewise, rapid action to prevent the introduction, establishment or expansion of an invasive alien species is recommended even if there is uncertainty about its impacts in the long term (IUCN, 2000).

The precaution principle offers a foundation for a management policy that prefers “prevention over cure”, a strategy that is definitely the most appropriate to confront a problem with such serious consequences and such difficult or complex management. This principle is no doubt insufficient to solve all the limitations related to the control of invasive species. For example, the number of invasive species that are able to establish themselves and advance on natural or semi-natural ecosystems in a focus area frequently exceeds the real capacity for management, making it impossible to act on all species at the same time. On the other hand, part of these species may not represent significant threats, at least at the outset. It thus becomes necessary to establish priorities by virtue of the criteria for current or potential impacts and the greater or lesser feasibility for control (Hiebert and Stubbendieck, 1993, Parker et al., 1999).

The impact of invasive alien species on biodiversity is frequently conspicuous, as occurs in the case of rat that prey on island birds, large herbivores and their effects on natural fields or species of invasive bushes or trees that completely cover an environment, suffocating native vegetation (GISP, 2005). In other cases, the effects of invasive alien species on the environment are more difficult to define. Among other reasons, the presence of these species coincides in time and place with other agents of environmental transformation with advancing agricultural production, the expansion of urban environments as the fragmentation of natural ecosystems. So how do we know whether the invasive alien species is responsible for a specific environmental change or for the retraction of one or a group of native species? As previously mentioned we cannot wait for solid proof of the impact and only then begin control actions because this delay can make it too late to solve the problem. Nor can we simply act without observing how the environment responds when a problem is perceived to exist because this can lead to poor investments in terms of time and resources. In a worst case scenario, if the initial perception is wrong and the cause of environmental degradation is not the invasive alien species, you can lose the environmental values that were being threatened regardless of the success of control or eradication actions. Therefore, the key to this issue is to organize the management strategy in a way to confront the problem while simultaneously increasing the scientific knowledge required to solve it.

Uncertainty becomes questions and answers that guide management strategies

A critical step to efficiently managing an invasion process is to detect the key uncertainties, or the gaps in information, which if solved, would significantly improve the capacity to solve the problem. These gaps in information can be made into questions, and these in turn will guide the formulation of hypotheses that are tested by the management strategy. It is not necessary to wait for all the answers to start the action. To the contrary, begin the control and take advantage of the opportunity to get to better understand the problem. This is the basis for adaptive management (Nyberg, 1999), a continuous cycle of actions, monitoring, learning and adjustment of new actions that permits increasing the efficiency of control practices for invasive alien species. In adaptive management, control actions are organized as experiments that clearly lay out the expected consequences of interventions should the problem's initial diagnosis and the premises about the ecosystem's functioning be correct. As an example, let's suppose there is a study in a protected area where the management goals aim to conserve the communities of wild birds. Several years of studies show that some species of wild birds saw a reduction in their populations whereas others had much greater current densities than in the past. It is suspected that this change has to do with the invasion of an alien tree species whose fruits are consumed by birds, favoring some trophic groups and giving them advantages over others as the invasion density increased. Based on this, a decision is made to begin control action of alien plants in order to reduce their numbers in the bird communities. **FIGURE 1** shows a management plan where:

- The goal is to conserve bird communities, the diagnosis deals with changes in the relative abundance of different trophic groups by virtue of the availability of the alien species' fruits;

- The objective represents the specific expected result based on the management actions taken (for example, reduce the area covered by the invasive species by half within one year);

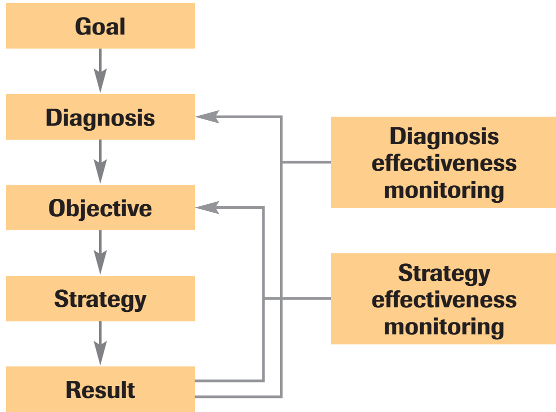

Figure 1. Adaptive management sketch

- The strategy refers to actions that will be taken to achieve this objective (for example, the use of herbicides applied on the girdling base of tree trunks);

- The result of the strategy is expressed by the boxes to the right of the plan, which represent the two levels of action monitoring.

On one hand, it is possible to test the effectiveness of the implemented action (did the herbicide reduce the presence of the invading species in the area?), and on the other hand, this plan allows us to judge the precision of the initial diagnosis (did the changes in bird species composition effectively responded to the presence of the invasive alien species?)

FIGURE 2 shows the possible monitoring results. If the results are negative (species abundance did not decrease), the strategy must be reevaluated (rather than applying herbicides to the trunk, begin to cut the trees and apply the chemical product in the stumps to prevent resprouting). If the results are positive, the management goal must be reevaluated: is it possible to observe any change in the composition of the bird community? If yes, continue the monitoring actions underway. If not, it is necessary to consider the initial diagnosis as mistaken or incomplete: despite the reduction in invasive alien species abundance, the bird communities did not recover their previous characteris-

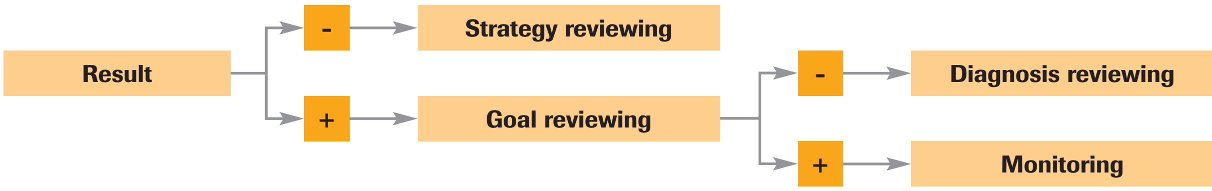

Figure 2: An adaptive management strategy results evaluation sequence

tics. In this case, it is important to take into account that the natural systems generally present significant degrees of inertia whereby the expected answers are not manifested immediately after the control action (Steedman, 1994). Furthermore, in situations of intense degradation, it is necessary to apply complementary practices to restore the environment's resilience and accelerate its recovery.

Other issues related to control actions, such as the impact from herbicide use, can also be evaluated in the process. The answers to this question have shown that the problem is absolutely not in using chemical products *per se*, but in how these are applied. If herbicide use is carried out in a topical and local manner, it can generate benefits to conservation by virtue of eliminating the problem of invasion and to the natural environment restoration. Punctual impacts on the environment are frequently tolerated in the control of invading species based on the perspective of mid-term restoration, which does not happen if the invasion prospers indefinitely. The decision to not carry out the control is not neutral when dealing with invasive alien species. Time tends to act in favor of the invasion until its advance may no longer be reversible because of the environmental impact it has already caused or other factors, such as higher costs to eliminate them.

The recognition of uncertainties is the basis of adaptive management. The diagnoses must always be placed as hypotheses and management actions designed so they can be tested. To test the precision of a diagnosis, it is necessary to establish explicit projections founded on the hypotheses formulated on the relationship between the presence of the invasive alien species and the detected symptom of environmental change (in the previous example, the changes in the bird communities). Applying a "ready-to-use" solution without criteria makes us miss the chance to learn about the system in question. No tool can replace the knowledge generated at a specific location by virtue of management practices, not even knowledge of ecology and natural history.

The control of invasive alien species involves complex systems and the results of management actions could be a consequence of the action itself, of disregarded external factors, or a combination of both. For example, in the previous case, a restoration process of the bird community structure could respond to another concurrent environmental factor in the region, regardless of control actions, thus generating confusion. A reduction in herbicide use in the fields around the reserve in question can result in the recovery of affected bird populations. In this case, it would be possible to commit the mistake of attributing a cause and effect relationship between management action and the observed response in the bird population. To reduce the probability for this type of error, it is necessary to organize management actions in a flexible plan, such as: a) carefully select the system's response indicators; b) include control areas where management actions are not carried out; c) consider the possibility of replication and attribute the treatments to chance; and d) control or measure eventual confusion factors (Feisinger, 2003).

Another important advantage of adaptive management is that it permits developing large scale experiments: ecological assays are frequently limited to small parcels with few square meters of surface, which are not very representative and insignificant from a statistical point of view. It is well-known that many biological phenomena operate on large scales. Adaptive management can operate in water basins that cover an entire natural protected area or region, which permits obtaining knowledge on a real scale (Sit and Taylor, 1998).

INCREASING MANAGEMENT EFFICIENCY

Monitoring not only permits adjusting the diagnosis, but it also helps select the most appropriate control methods for each species in each situation, as well as the most efficient manner to apply these methods. The control strategies for invasive alien species used in the natural fields of Argentina involve control actions organized to respond to critical questions and increase control efficiency. A strategy for restoring natural fields affected by ligneous invasive alien species at the Ernesto Tornquist State Park in Sierra de la Ventana, Argentina has been in place since 1999. This project is founded on the application of adaptive management and basically consists of cutting alien trees and bushes off that spontaneously advance on one of the last remaining ecosystems in a good state of conservation, locally called the Pastizal Pampeano (Zalba and Villamil, 2002). The invasive alien species produce dramatic reductions in the region's native wild animal and plant diversity and are associated with severe erosion problems that fundamentally result from natural fires. The success of the control action in the area is not measured by the number of cut trees, but by the changes associated with the vegetal community, since there is no avail to eliminate alien species if they are replaced by other alien species, or if the cutting itself causes erosion problems that aggravate the degradation of natural systems. Data are collected together with the cutting actions that permit adjusting management and the chance to better understand the invasion process (Zalba et al 2000, Zalba 2005b). Reproductive aspects are being studied to determine at what age the invading trees begin to produce seeds, what happens to the seeds that are stuck in cut trees which are not removed, what impacts a fallen tree has on subjacent vegetation and the effect herbivores and fire have on the advance of alien trees, among others. The answers to these questions are then used to decide which areas are priorities for control, when it is most convenient to cut the trees or with what frequency it is necessary to return to each control area and repeat the actions until the seed bank or sprouting process is eliminated (Cuevas, 2005).

The tests carried out thus far indicate that the seeds retained in the cones of cut *Pinus halepensis* trees are released in the summer after the trees were cut, regardless of when they were cut. No doubt, the percentage of viable seeds released from the cones of trees cut in the beginning of summer is significantly greater than from those cut in the autumn or winter. This information helps distribute control efforts throughout the year in order to minimize seed dispersion from cut trees. Other tests showed that the pines begin to release seeds at the age of seven and that the seeds that fall to the ground only remain viable for one year. This means that if there are no new external contributions of seeds, an area where the *Pinus halepensis* has been removed only needs to be rechecked once, between two and six years after the cutting. In the meantime, the seeds that have fallen to the soil will have lost all feasibility or have germinated, and the repetition of the management action will occur before the new plants have reached reproductive maturity (Cuevas et al., 2006). In Brazil, the most commonly used pine species reach maturity at between four and five years of age, depending on the environment in which they are located. In other words, control actions must be repeated in shorter periods of time, between three and four years, to guarantee that the seed bank has not been reestablished (Ziller, 2000).

In short, the organization of management actions using a flexible and consistent design permits the optimal destination of resources and increases the chances to control invasive alien species in an efficient manner. Adaptive management represents the opportunity to increase objectivity and prove whether the control of an invasion effectively contributes to the conservation objectives of native biological diversity or if complementary restoration practices are necessary for the affected environment to get back its resilience. The lessons learned from the management processes organized on a solid experimental base can serve to confront similar situations with any invasive alien species.

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