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Doing adaptive management: improving the application of science to the restoration of a rare Lake Tahoe plant

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Adaptive management is probably the best available structure for linking science with decision-making when conserving biological resources. We have found that implementation of adaptive management requires: (1) modification of the conceptual model to include benefits to biological resources *in situ*; (2) upfront participation of all stakeholders in the conservation strategy and design of the adaptive management program with clear structuring of information flow and the sequence of project stages to facilitate stakeholder responses within a reasonable timeframe; and (3) use of key management questions to focus data collection and identify beneficial management actions. These guidelines are illustrated using our experience with Tahoe yellow cress (*Rorippa subumbellata* Rollins, Brassicaceae), a plant endemic to the shores of Lake Tahoe in California and Nevada and a candidate for protection under the Endangered Species Act. The project provides an operative example of science-driven decision-making that has been ongoing for over ten years. Several corollary ingredients are identified that have improved the chances of project success and helped to sustain the long-term effort.

Key words: adaptive management, Lake Tahoe, monitoring, plant conservation, *Rorippa subumbellata*, species restoration, Tahoe yellow cress,

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"The gap between theory and practice remains surprisingly wide in conservation biology."

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One of the greatest challenges in biological resource management is the development of an institutional structure that allows available scientific information to contribute to resource management and land-use decision-making. The structure must be strong enough to counteract political and economic influences that frequently lead to resource degradation. It must provide a transparent mechanism that directly links empirical information with alternative outcomes, and to implementation of the outcome that appears most beneficial to the target resource. And, most importantly, uncertainties and inevitable setbacks must be countermanded by long-term stakeholder commitment, attentive oversight, and stable financial support. Only then can a synergy between conservation theory and practice be realized, leading to significant improvement in the condition of species or ecosystems.

Adaptive management is probably the best available structure for linking science and decision-making and most government agencies have to some extent adopted its basic conceptual framework and rhetoric (Holling 1978, Walters 1986, Stankey et al. 2005, Gregory et al. 2006). It has been applied to efforts to conserve a wide variety of biological resources, including butterflies (Wisconsin Department of Natural Resources 1999, Lentz and Nogami 2007), fish (Walters 1992, Kareiva et al. 2000, Cinner et al. 2009), birds (Schmiegelow and Hannon 1993, Williams and Johnson 1995, Johnson et al. 1997, Dimond and Armstrong 2007), marsupials (Rout et al. 2009), terrestrial vegetation (Taylor et al. 1997, Gray 2000, Murray and Marmorek 2003, Haynes et al. 2006, Ascoli et al. 2009) and the biota of rivers (Walters et al. 2000, Levine 2004, Lovich and Melis 2007, King et al. 2010). Yet, despite its obvious strengths and intuitive simplicity, there are few examples of successful implementation of adaptive management (Stankey 2003, Stankey et al. 2005, Gregory et al. 2006), especially if the criterion for defining success is a demonstrated improvement in the condition of species or ecosystems.

Some argue that the failings of adaptive management are institutional, resulting from a conflict between the need for legal and political certainty within government agencies and the complexity and variability inherent to biological systems (Doremus 2001, Doremus and Tarlock 2005, Gregory et al. 2006). The necessary flexibility to experiment and freely adopt any one of several possible outcomes is at odds with typical regulatory procedures and administrative law (Ruhl 2005, Haynes et al. 2006). Others argue that adaptive management is itself complex and intimidating, requiring simplification in order to build programmatic momentum and participant enthusiasm (Morghan et al. 2006). Adding more scientific expertise, along with researcher-management dialogue to ensure better, more relevant studies is also recommended (Morghan et al. 2006).

We have found that implementation of adaptive management can be successful if: (1) the conceptual model of the process is modified to include direct benefits to target resources; (2) stakeholders are included early in the development of the conservation strategy and design of the adaptive management framework and information flow and the sequence of project stages are clearly structured to facilitate stakeholder responses within a reasonable timeframe; and (3) key management questions (KMQs) are used to focus science and realize a management vision. These facets of our adaptive management approach will be illustrated with the conservation of a single species, Tahoe yellow cress (*Rorippa subumbellata* Rollins, Brassicaceae), a rare plant endemic to the sandy shoreline of Lake Tahoe, California and Nevada.

Conceptual Models Must Include Target Resource Improvement

Resources and land management agencies have widely embraced adaptive management as their approach to improving the condition of species and ecosystems (Walters 1986, Nudds 1999, Smit 2003, Pavlik and Espeland 2005). Adaptive management recognizes inherent complexity and uncertainty by using "learning by doing" as its operational definition (Taylor et al. 1997, Stankey et al. 2005, Gregory et al. 2006). The process is iterative, usually portrayed as a cycle of strategy, design, implementation, monitoring, evaluation, and adjusting management (Figure 1; based on Sit and Taylor 1998). Decisions or actions are evaluated using carefully designed monitoring, and modifications to management actions are in turn tested with updated monitoring protocols. With each turn of the cycle, active learning through monitoring and evaluation reduces management uncertainties by developing tools that prove beneficial to the resource. Adaptive management is logical, can deal with uncertainty and data gaps, and is similar to the scientific process of hypothesis testing (Haynes et al. 2006).

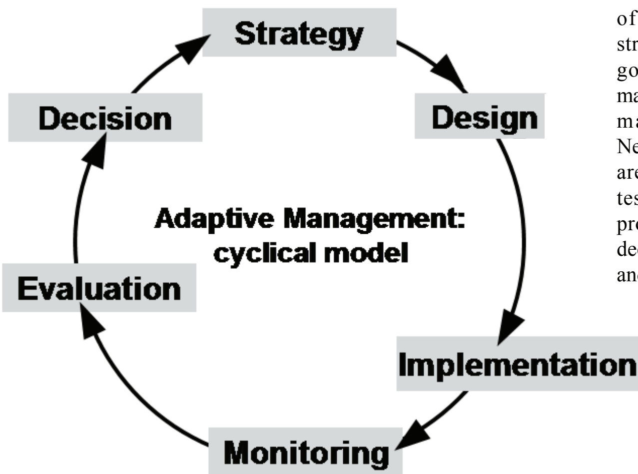

Figure 1.—The cyclical model of adaptive management. The strategy includes the assembly of goals, objectives, tools and key management questions by an adaptive management working group. Necessary research and monitoring are designed and implemented to test a novel management action, providing data for evaluation and decision-making. Modified from Sit and Taylor (1998).

A weakness in the classical model of adaptive management is that benefits to the target resources are not always readily apparent. Although learning and communication are key outputs of the process (Stankey et al. 2005), there must be a strong connection to decision-making that leads to resource improvement. File cabinets across the country are filled with monitoring data that have never been used to make a critical decision, much less make a difference in the condition of a targeted resource. Ultimate success is not found in the turning of the cycle — that is, the endless accumulation of data or continual amendments to monitoring design (Walters 1997). Strategic elements, such as developing objectives or key management questions, should not necessarily be constantly revised as the cycle implies. Instead, monitoring should be explicitly linked to tests of specific management actions (Macnab 1983, Pavlik 1996, Morghan et al. 2006). Success can only be found in using monitoring data to improve stakeholder understanding and management effectiveness to improve the condition of a target resource.

We propose a small but significant modification of the *de rigueur* conceptual model of adaptive management. We envision adaptive management not as a circle, but as a helix composed of cycles linked by prudent, "best-available" actions sustained over time (Figure 2). The incline of the helix is determined by resource response, which is the real measure of worth for any conservation action (Palmer et al. 2005). The response metric is any measurable attribute deemed critical to the quality of the target resource. It is best defined by the strategy of goals and objectives developed by stakeholder participants on an Adaptive Management Working Group (AMWG). The time scale of the metric depends on the targeted resource; twists of the adaptive management helix could take years for single species and decades for ecosystems (see Haynes et al. 2006, Lovich and Melis 2007).

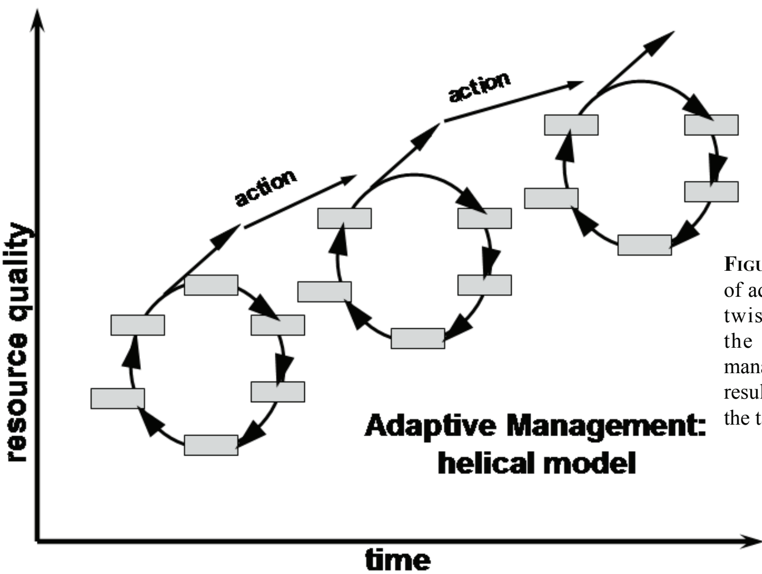

FIGURE 2.—The helical model of adaptive management. Each twist of the helix results in the application of a proven management action, in this case resulting in improved quality of the target resource.

It is important to note that not all resource management requires a rigorous, science-driven adaptive management framework (Lee 1993, Gregory et al. 2006). Where there is minimal uncertainty as to the outcome of an action, and the overall effect on resource quality of existing tools is well known, common practices management can be applied with a high probability of success. Circumstances with greater uncertainty, but combined with reliable, previously developed tools, justify use of a less intense and presumably less costly form of adaptive management, referred to here as adaptive management with best available technology. In the past, this type was unfortunately labeled "passive" (Walters and Holling 1990) even though it requires a formal, structured approach, including strategic planning, design, monitoring, etc., along with stakeholder participation on an AMWG. When using best available technology, the focus is on implementation, and monitoring data are used to confirm that actions are producing the desired trajectory for the resource. But, when there is little or no available technology with known effects and therefore a high degree of uncertainty regarding the outcome of an action, a fully developed program of adaptive management with hypothesis testing should be employed. This is the most costly form of management ("active"), in which each action is treated as a test of an individual management-oriented hypothesis (Walters and Holling 1990, Pavlik 1996, Gregory et al. 2006). Adaptive management with hypothesis testing requires an experimental design with randomization, replication, and adequate statistical power to develop reliable tools that can be applied to the target resource. Correctly assessing the degree of uncertainty and choosing the appropriate form of management for a target resource can greatly simplify the institutional requirements and greatly lower the costs associated with a given project.

Stakeholders Participate in the Development of the Conservation Strategy and Design of the Adaptive Management Framework

Initiating adaptive management requires a structured, cooperative approach to developing a conservation strategy. The strategy sets the vision for the species or ecosystem and articulates the goals and objectives for the target resource within a defined, realistic timeline. The objectives for each resource element need to be measurable so that they can be used as yardsticks for measuring success (Walters 1986; Pavlik 1994, 1996; Elzinga et al. 2001). The conservation strategy is not simply a laundry list of recommended studies or knowledge gaps that should be filled before any action is taken or decision is made — a major failing of most recovery plans (Schemske et al. 1994).

The vision as conveyed in the goals and objectives of the conservation strategy is best achieved through the consensus of affected stakeholders. Typically, a panel of land managers, government regulators, and scientists forms an AMWG, but representatives of private landowners, affected industries and the public at large should also be encouraged to bring their concerns or objections to the table. In exchange for access, AWMG members must be cooperative and committed to the conservation of the target resource; each stakeholder brings a distinct perspective to the process, but all must focus on improving resource quality by cooperating in an open, non-adversarial forum. Utilizing a structured, cooperative approach to developing the conservation strategy allows the AMWG to address all members' concerns or objections directly and build trust through straightforward communication (Fule 2003, Stankey et al. 2005). Without broad stakeholder support, opposition or apathy can halt both the development and implementation of the conservation strategy.

Once the conservation strategy is agreed upon and finalized, the integrity and effectiveness of the decision-making process in an adaptive management framework depends on a structured and timely flow of data so that stakeholders will be able to anticipate and respond to their own, institutional constraints (e.g., permits, public notice, funding, hiring) with minimal difficulty. Within this framework, the decision-making entities have clearly defined positions in the flow of information (Figure 3).

The AMWG is the workhorse of the process as it provides the direct communication conduit for all affected agencies, local governments, and private entities. It is through the AMWG that adaptive management becomes a community learning process, imbedded within a regulatory and bureaucratic environment with its logistical, economic, and political constraints (Haynes et al. 2006). It is a major responsibility of the AMWG to address these constraints as it prioritizes research and monitoring tasks and carries out the duties of budgeting and long-term planning. The AMWG may solicit outside scientific review and public comment and brings forth funding needs to an executive committee, comprised of agency decision makers, and executive directors. It is the role of the executive officers to

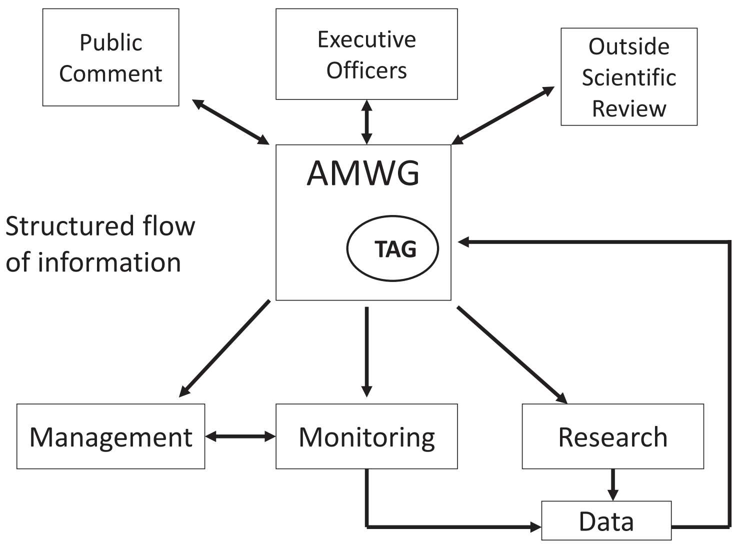

FIGURE 3.—The structured flow of information between participants and activities of the adaptive management program for Tahoe yellow cress. Members of the Technical Advisory Group also sit on the Adaptive Management Working Group, but convene separately to solve technical problems and oversee management actions, monitoring, and research. Modified from Pavlik et al. (2002).

identify and generate funding opportunities and integrate the resource-specific focus of the particular conservation strategy into other local or regional planning.

The more technical aspects of implementing research are best addressed by a subset of members that form a Technical Advisory Group (TAG). The TAG is given direction by the AMWG, but they are insulated from the politics of the AMWG because they are only charged with providing a robust mechanism for evaluating management actions and adding to the knowledge base. If there are 12 members of the AMWG, then two to four with research experience serve on the TAG. The TAG translates management objectives into monitoring objectives with precise definitions of what will be measured, and with what degree of statistical certainty (Elzinga et al. 2001). The TAG then selects study sites, determines experimental design, and analyzes the data in order to make technical recommendations that inform the decision-making process within the AMWG.

Key Management Questions Focus Science to Realize a Management Vision

The function of Key Management Questions (KMQs) is to focus science on the specific management issues and data gaps that, once resolved, will assist in realizing the goals and objectives set forth in the management vision (Figure 4). A well-constructed KMQ narrows an otherwise broad base of scientific inquiry (represented by the lower triangle in Figure 4) to a more finely resolved endeavor directly pertinent to future management. Similarly, the broad base of management vision (the upper triangle in Figure 4) is narrowed to another fine point by the same KMQ. Thus, a good KMQ directly links the management vision to the science and all research is then designed to inform the specific goals and objectives of the conservation strategy. In this way, a monitoring program is directly linked with an objective, and there is no *post hoc* as to the utility and application of monitoring data that are generated (Lee 1993, Pavlik 1996, Gregory et al. 2006).

The ultimate test of a good KMQ, however, is that its answer provides concrete guidance to the AMWG. In evaluating a particular question, each stakeholder should be

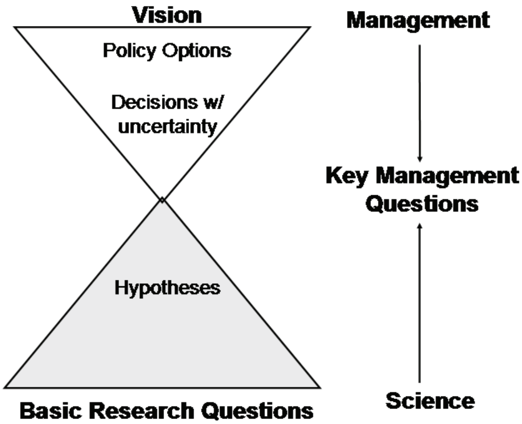

FIGURE 4.—Key management questions narrow the focus of basic research by limiting hypotheses to those that test a resource management action. Such actions, when implemented, narrow the alternative policies that affect a management vision for the target resource. Modified from Pavlik and Espeland (2005).

able to work backwards from a major decision (e.g., "Do we need to protect every patch of occupied habitat currently supporting a population?") and deduce the KMQ (e.g., "Are all suitable habitat patches occupied by an existing population?"). From there it is not difficult to envision the basic design of an appropriate study that provides the answer (e.g., through an experimental reintroduction) and to reject others that do not link into the conservation strategy. Key management questions also have the effect of focusing agency effort and leadership. The process of developing good KMQs helps agency leadership and staff to understand and support needed research as a critical part of conservation and shrinks the domain of possible issues and concerns to a manageable number.

PRACTICING ADAPTIVE MANAGEMENT ON TAHOE YELLOW CRESS

Although simplification of the adaptive management process has been urged (Morghan et al. 2006), the lack of concrete, operating examples often is a significant impediment to its success (Doremus 2001). The conservation of Tahoe yellow cress (*Rorippa subumbellata* Rollins, Brassicaceae) provides an ongoing, operative application of science-driven decision-making to the conservation and restoration of an imperiled biological resource.

Tahoe yellow cress (TYC) is a rare plant endemic to the sandy shoreline of Lake Tahoe in California and Nevada. This low-growing perennial mustard has small yellow flowers, fleshy leaves, and exhibits vigorous clonal growth by spreading rootstocks. Since first described in 1941, TYC has been collected or observed at over 60 locations around Lake Tahoe. The total number of TYC occurrences and the locations of those occupied sites have fluctuated through time, largely in response to the level of Lake Tahoe. Lake level is regulated through the operation of the Truckee River dam, which adds an additional six feet storage capacity above the natural rim of Lake Tahoe. Lower lake levels expose a greater amount of sandy habitat and TYC has been documented at as many as 48 locations in one survey period. When the lake is near its legal capacity, as few as nine sites have been occupied.

In response to ongoing threats from recreation, development, and lake-level management, the species was listed as endangered by the State of California in 1982 and state-listed as critically endangered in Nevada the following year. In 1986, the U.S. Fish and Wildlife Service identified Tahoe yellow cress as a candidate species for protection under the Endangered Species Act. Near extinction of the species between 1995 and 1999 prompted an upgrade in the priority status for federal listing in 1999.

The threat of listing TYC under the federal Endangered Species Act brought together a myriad of interests among personnel representing issues related to lake-level management, habitat preservation, recreational development, and private property rights. Federal protection would immediately affect about 70% of the shoreline around the Lake, inhibiting dam operations and reducing recreational access for millions of beach visitors a year. Virtually every pier renovation, storm drain replacement, and erosion control project that required a federal permit would become much more complicated and costly. In 2000, the affected stakeholders formed an AMWG to develop and implement a conservation strategy for the species.

The overarching goal of the AMWG was to produce a voluntary conservation strategy that would preclude listing of TYC under the federal Endangered Species Act and eventually provide grounds for down-listing under state laws in California and Nevada. The development of the Conservation Strategy for Tahoe yellow cress (Conservation Strategy) (Pavlik et al. 2002) was the first stage of the Tahoe yellow cress AM program (Figure 5). One year was required to synthesize 22-years of survey data collected by various agency personnel and to clarify stressors to the species and to the Lake Tahoe nearshore ecosystem.

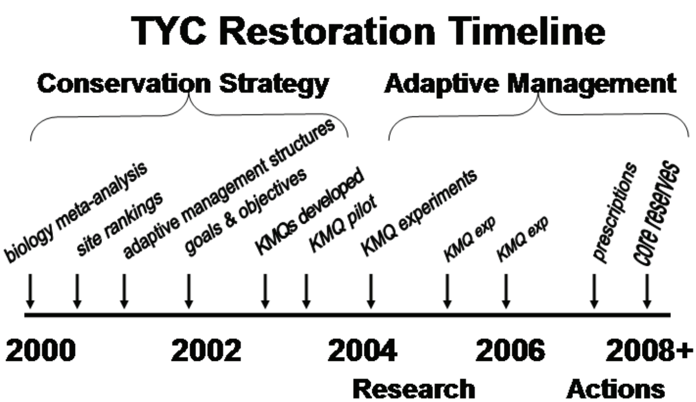

FIGURE 5.—Timeline of major events for restoring Tahoe yellow cress, including the Conservation Strategy and adaptive management.

As a result of this biological meta-analysis, the Conservation Strategy proposed a mainland-island metapopulation model for TYC. This model of metapopulation dynamics refers to spatio-temporal changes in distribution and abundance where "mainland" subpopulations persist over long periods of time while other "island" subpopulations come and go through the processes of local colonization and extirpation. Thus, the species can persist in sandy beach habitat around Lake Tahoe despite periodic high water levels and human-related impacts (Pavlik et al. 2002). Consequently, restoration and maintenance of the metapopulation dynamic became the major focus for devising KMQs and testing management actions

Existing populations were then prioritized for conservation with a quantitative ranking system based on the abundance, persistence, and variability of each subpopulation. The site rankings formed the foundation for the specific measurable objectives of the Conservation Strategy. Next, the AMWG came to an agreement about an initial adaptive management framework for structuring information flow and making management decisions (see Figure 3). An "Imminent Extinction Contingency Plan" was devised defining the types and degree of actions to be taken when the number of populations or the sizes of populations become critically low. This kind of pre-planning for future action is necessary because: (1) there may be insufficient time between the identification of an imperiled population and need to take action; (2) the description of possible actions to be taken to save the species will be known to all stakeholders in advance; and (3) the level of effort and resource commitment is acknowledged by all agencies and stakeholders. Addition of an "Imminent Extinction Contingency Plan" to a conservation strategy strengthens the often weak link, where monitoring and research fail to lead to any change in management.

Another year was spent reviewing, discussing and revising the draft strategy by all potential stakeholders, including the general public. After external review, the Conservation Strategy (Pavlik et al. 2002) was formally adopted by federal, state, and local governments with lakeshore management responsibilities, as well as the primary lakefront homeowner's association.

While the development of the Conservation Strategy did not result in an immediate direct benefit to TYC populations, the process of identifying and ranking external stressors that degraded the population and the Lake Tahoe system made it apparent that the best available technology to mount a restoration effort was quite limited, and adaptive management with hypothesis testing and a KMQ framework would be required.

The Conservation Strategy for TYC identified two main stressors: (1) artificially high lake levels imposed by dam operations, and (2) trampling from recreational beach use. A strong, negative correlation (r^2=0.71, P<0.001) was established between lake levels and the number of populations found around the lake in a given year. This stressor is compounded by the fact that annual visitor density increases exponentially as rising waters submerge available beach habitat. While TYC response to both external stressors is simple and obvious — population distribution is restricted in wet years with high lake levels, and trampling reduces local abundance — the resulting management actions are not. Given the political realities of water and power, those actions must compensate for artificial fluctuations in the lake without requiring changes in the operation of the dam.

To focus the research phase of the Tahoe yellow cress adaptive management program, five KMQs were derived (Pavlik and O'Leary 2002) that addressed knowledge gaps for decision-making (Table 1). KMQs were shaped first by a written survey of AMWG members, who identified more than 60 variables they believed were relevant to TYC conservation. Many of these variables and the questions they evoked were academic, lacking a direct connection to realistic management options (e.g., pollen flow, pollinator availability) or they were components of larger questions that could be subsumed and thus simplified. Having fewer, more general KMQs helped AMWG members: (1) fully envision the range of relevant research that would be done; (2) see linkages between specific research projects and specific decisions they would be facing; (3) decide which research to fund and which to reject or forestall; and (4) understand that the costs and timeframe for research would be finite.

Table 1.—Key management questions for focusing on science and management of Tahoe yellow cress.

(1) Can TYC populations occupy any site around the lake margin that has sandy beach habitat?
(2) Are there ecosystem factors that can affect TYC performance within an occupied site or microhabitat?
(3) Can TYC populations be created or enlarged in order to restore the self-sustaining dynamics of the species?
(4) Can any TYC genotype or gene pool perform equally well at any appropriate site?
(5) Can TYC microhabitats or places be found or created that are less likely to be adversely disturbed despite high visitor use or intense shoreline activity?

The first twist of the hypothesis-driven AM helix for TYC began with a pilot study in 2003. The one-year pilot demonstrated that TYC was a "cooperative" species: easily grown in a greenhouse, amenable to *in situ* experimentation, and responsive to critical variables that could be manipulated by management actions (e.g., planting distance from the shore, recreational impacts). Replicated experiments using over 10,000 container-grown plants were subsequently designed and installed at multiple locations around Lake Tahoe from 2004 to 2010 (Pavlik and Stanton 2005, 2007; Stanton and Pavlik 2010). During this period, the level of Lake Tahoe fluctuated from the natural rim to the highest level allowed by federal regulations. Experimental reintroductions in different microhabitats and in years with different lake levels allowed us to evaluate the role of source population genetics, planting distance above the water table, and inundation in the growth and persistence of experimental populations of container-grown plants. Importantly, we learned that the clonal growth form and prolific seed production of TYC make it amenable to effective translocation within or among beaches around Lake Tahoe (Stanton and Pavlik 2010). Experimental plants in suitable habitats produced more than 1.5 million seeds and nearly 10,000 asexual plantlets. Such tangible benefit to the species prompted the U.S. Fish and Wildlife Service to downgrade the priority status for federal listing of TYC in 2005 because of "continued commitments to conservation demonstrated by regulatory and land management agencies participating in the Conservation Strategy." This first twist of the helix took eight years.

While the first twist of the AM helix focused on implementing the research agenda developing propagation, outplanting, and restoration tools, the second twist of the AM helix represents a transition to implementing appropriate management actions at a wide diversity of sites around Lake Tahoe. Newly developed available actions are composed of complimentary, research-vetted actions formulated into two ends of a management spectrum: (1) protecting habitat quality at core "mainland" and high-priority "island" sites; and (2) enhancing the size and extent of core and high-priority populations with outplanting of container-grown TYC.

Implementation of these management actions on public lands has already led to intra-agency conflicts between resource and recreation interests, as well as regulatory issues. These need to be acknowledged and addressed in identifying new planning strategies for establishing core population reserves. On private properties, the AMWG is in the process of developing innovative community engagement strategies that increase the role of landowners in Tahoe yellow cress protection and restoration through a Stewardship Program. The resolution of such institutional and public outreach matters may rely on the science developed during the first helical twist, but will also require new approaches that evolve out of personal communications and commitment. It is this translation of knowledge into beneficial actions that is the crux of the second helical twist. We expect the next phase to take several years, after which modifications and improvements can be made and the degree of project success (i.e., the achievement of pre-defined objectives) can be ascertained.

Ingredients for Successful Adaptive Management

Not all biological resources are equally amenable to conservation through adaptive management. Adaptive management projects that involve large, complex systems with many target species and a very large number of stakeholders pose many challenges. Although these are the exact situations that seem to warrant a highly structured approach to applying science in a decision-making framework, they may not be the best situations for teaching us how to do it. Institutions that want to apply adaptive management, that is, learn to alter their policies and procedures using focused hypothesis testing, should start by evaluating a pool of fewer, more “cooperative” targets in order to select a species or ecosystem that is amenable to actions and monitoring, and that is likely to respond (positively or negatively) over short periods of time (e.g.,from one to five years). In that way, the AMWG, the TAG, and the stakeholders have an opportunity to turn the helix and become engaged in the learning process. Intractable political situations are not the best place to start, but the right amount of conflict, consequence, and stakeholder commitment are necessary elements that can make success a near-term possibility.

Our project with TYC provides an example of the helix of adaptive management that has been operating for 12 years. During that time we have identified several ingredients that have helped generate a near-term sense of success among stakeholders.

The right amount of conflict and consequence.—Conflict is often a motivating force in convincing stakeholders to participate in a conservation strategy (Haynes et al. 2006). The threat of federal listing of TYC was the original consequence that led to the development of the Conservation Strategy and formation of the AMWG, and it continues to bring stakeholders to quarterly AMWG meetings. This looming consequence has moved the adaptive management process forward and reduced the amount of conflict among stakeholders. Once the AMWG was united in this cause, the first twist of the AM helix produced a wealth of knowledge useful to managers, and it also directly benefitted the species with the release of new seeds and plantlets into appropriate habitats around Lake Tahoe. Such tangible benefit to the species prompted the Fish and Wildlife Service to downgrade the priority status of the species under the ESA, highlighting how the continued commitments to conservation demonstrated by regulatory and land management agencies participating in the Conservation Strategy can lead to positive regulatory outcomes. The second twist of the helix, involving the translation of acquired knowledge into management prescriptions and restoration actions, is establishing new reserves for core populations and enhancing each to exceed an empirically derived minimum viable population size. Such improvements to the resource, along with a systematic approach to learning and cooperation, are the principal benefits that can be achieved from adaptive management.

Cooperative species and ecosystems with strong identifiable stressors.—Many rare species tend to be idiosyncratic (Fiedler et al. 1997). Genetic aberrations (Nickrent and Weins 1989, Korbecka et al. 2002), complex breeding systems (DeMauro 1993, 1994; Scobie and Wilcock 2009), susceptibility to microbial and insect interactions (Ledig 1996, Klironomos 2002) and other, less-than-robust life history traits, offer significant impediments to both research and restoration (Guerrant and Pavlik 1997). Small and few populations also constrain efforts to manipulate and expend this kind of biological material. Therefore, the rarest species under the most urgent circumstances might not be the best candidate for learning to do adaptive management. Although there may not be a choice as threats build, regulations are invoked, and politics drive conflicting agendas, choosing a "cooperative" species, with few internal or cryptic constraints, would vastly increase the chances of sustaining a productive and potentially successful program. And the axiom follows, that "success breeds success."

Tahoe yellow cress is a cooperative species that responds primarily to fluctuations in the level of Lake Tahoe and to recreational pressures. It is a short-lived herbaceous perennial that produces copious seed and is capable of robust vegetative growth. Flowering and fruiting occur during the earliest stages of establishment, and self-compatibility reduces the importance of pollinator availability. It is readily propagated under greenhouse or lab conditions from seed or rootstock with ordinary potting mix, and seed viability is high and germination exceeds 80%. Compared to other plants that have been inventoried by starch gel electrophoresis, TYC has very low levels of isozyme variation (Bair 1997; Saich and Hipkins 2000; DeWoody and Hipkins 2004, 2006). We were able to confirm this lack of genetic differentiation using common garden techniques. This minimizes the need for mixing plants from different source populations during restoration, although the existence of locally unique alleles still justifies a broadly stratified approach.

Are there such things as cooperative ecosystems that would be as amenable to learning AM with hypothesis testing? This we cannot say for sure. Tidal marshes readily form wherever restoration establishes the requisite regime of inundation, sedimentation, and propagule arrival (Zedler et al. 1982, Breaux et al. 2005). Mid-elevation ponderosa pine forests respond well to low-intensity groundfires (Korb and Springer 2003, Zimmerman 2003). And dammed riverine systems can be manipulated to affect fisheries and sand bar deposition (Kareiva et al. 2000, GCDAMP 2007), but biological benefits have been mixed. Perennial grasslands, however, are very difficult to wrestle from the clutches of invasive species (Carlsen et al. 2000), and desert scrub is subject to the long-term vagaries of climatic stochasticity (Lovich and Bainbridge 1999, Bainbridge 2007). Again, the choice may be an early determinant of the prospects of successful adaptive management.

Potential for long-term funding.—Long-term funding is usually a major factor that limits effective adaptive management (Levine 2004, Haynes et al. 2006). The obvious advantage of having so many dedicated stakeholders on the AMWG is that the probability of obtaining long-term funding is increased. Of the 13 signatories to the TYC Conservation Strategy, six agencies have provided money during the first six years, and six others have provided in-kind contributions of labor and materials. In addition, we have had support from two outside sources that have been administered through local agencies. The budget for adaptive management has averaged $72,000 per year, including the costs of the Conservation Strategy, running the AMWG and the TAG, conducting pilot studies, surveys and research projects, and production of all reports (two per year). The total amount of contracted grant money for running the AMWG and conducting research has been over $500,000.

Continuity and communication to counteract turnover.—During long-term projects, it is inevitable that representatives serving on the AMWG will come and go. New members join, bringing with them a set of experiences and philosophies that differ from those who began the process. They will not have the benefit of knowing exactly what decisions were made and why, nor will they have the time to read and digest the volumes of minutes, progress reports, and annual summaries that rapidly accumulate after a few years. They may start to question why certain designs or analyses were employed, as well as the collective wisdom of what colleagues have previously decided to do. A certain amount of such scrutiny and re-evaluation is absolutely necessary to ensure quality, but too much can bring forward progress to a grinding halt. Therefore, it is essential that complete turnover of AMWG personnel be avoided by designating an "anchor" agency or consulting firm that remains committed to the project for its duration. The anchor does not have to lead the AMWG, but it does have to serve as an archive, communications hub, and steady presence to insure continuity. When necessary, it must also provide workshops for new AMWG members to help them understand the backlog of decisions and information generated by the project and where the uncertainties, gaps, and conflicts now stand. Ultimately, the contributions of these new members should come from focusing on current problems that affect their stakeholder constituency.

Discussion

Despite its obvious strengths and intuitive simplicity, examples of successful implementation of adaptive management are lacking, especially if the criterion for defining success is a demonstrated improvement in the condition of species or ecosystems. Our project with TYC provides an example of an adaptive management program that has been operating successfully for 12 years. From its inception in 2002, stakeholders have been united in the common cause to prevent the federal listing of the species and kept the program focused on improving the TYC population as a direct outcome of the adaptive management process. The science-driven approach to recovery, guided by a KMQ framework, has led to direct benefits to the population through experimental outplantings and subsequent seed production. This success and the continued threat of federal listing have propelled the adaptive management process forward. We have learned that having an anchoring entity for the AMWG is critically important to maintaining continuity and keeping momentum. Long-term funding made it possible to keep independent consultants as part of the AMWG to conduct research, facilitate the group, and be an anchoring entity. Tahoe yellow cress proved to be a very cooperative species that exists in a system with clearly identifiable stressors, and we recommend taking great care to select an amenable target species or system for those who want to learn to do adaptive management.

One of the key lessons learned from our project is about how to better apply science in an adaptive management program. Recently, Murphy and Weiland (2014) outlined a framework that identifies five essential points where science guides adaptive management: (1) developing conceptual models; (2) confronting management prescriptions with available data; (3) building quantitative models; (4) designing monitoring schemes; and (5) interpreting returns from monitoring. The process of developing the Conservation Strategy for TYC brought science into the adaptive management program at the beginning and provided the initial point of engagement. It brought 22 years of survey data out of the darkness of file cabinets and resulted in a biological conceptual model for recovery and a quantitative model for prioritizing sites. The annual monitoring scheme subsequently has been revised several times until the AMWG came to the conclusion that the monitoring could not tell them anything new and a more adaptive, less intensive approach was adopted to simply meet regulatory requirements. The next turn of our adaptive management helix will focus on confronting management prescriptions with the knowledge we have gained through the intensive research program. Even with the many successes of the program, it has been difficult to get managers to change their on-the-ground operations and integrate newly developed management tools into the complex regulatory environment at Lake Tahoe. The AMWG continues to struggle with this, and the ultimate confirmation of our project success will be removal of TYC from the candidate list under the ESA.

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