ELSEVIER

Ecological Engineering 15 (2000) 365–372

ECOLOGICAL ENGINEERING

www.elsevier.com/locate/ecoleng

Adaptive management of coastal ecosystem restoration projects

Ronald M. Thom *

Battelle Marine Sciences Laboratory, 1529 West Sequim Bay Road, Sequim, WA 98382, USA

Accepted 10 March 2000

Abstract

There is a clear need to apply better and more effective management schemes to coastal ecosystem restoration projects. It is very common for aquatic ecosystem restoration projects not to meet their goals. Poor performance has led to a high degree of uncertainty about the potential success of any restoration effort. Under adaptive management, the knowledge gained through monitoring of the project and social policies is translated into restoration policy and program redesign. Planners and managers can utilize the information from the monitoring programs in an effective way to assure that project goals are met or that informed and objective decisions are made to address both ecological and societal needs. The three main ingredients of an effective adaptive management plan in a restoration project are: 1. a clear goal statement; 2. a conceptual model; and 3. a decision framework. The goal 'drives' the design of the project and helps guide the development of performance criteria. The goal statement and performance criteria provide the means by which the system can be judged. With the conceptual model, the knowledge base from the field of ecological science plays an active and critical role in designing the project to meet the goal. A system-development matrix provides a simple decision framework to view the alternative states for the system during development, incorporate knowledge gained through the monitoring program, and formulate a decision on actions to take if the system is not meeting its goal.

Keywords: Adaptive management; Coastal ecosystem restoration; Salt marsh; Seagrass

1. Introduction

1.1. Background

Confidence levels are low regarding predictions of specific outcomes of most restoration projects (NRC, 1992) because of uncertainty regarding spatial and temporal variability in natural conditions such as hydrology and weather, natural variation in growth and reproduction of plants and animals, errors in site preparation and in care and handling of transplant material, effects of natural predators on transplants, and unpredicted changes in the surrounding landscape due to human actions. During the development of a restoration site, our knowledge is often incomplete about the state of the system, the prognosis

---

* Tel.: + 1-360-6813657; fax: + 1-360-6813681.

PII: S0925-8574(00)00086-0

for further development, and the measures needed to correct problems. The evolving system is typically subjected to stresses that can significantly alter the progress and course of the project. In addition, attitudes (i.e. social values) can change.

It is not surprising that projects fail to meet goals. Although missing a goal may not be a major problem under some circumstances, it can be critical when restoration is conducted within a regulatory framework such as in compensatory mitigation projects. Here, projects are often carried out under major time and cost constraints, which can result in reduced planning time, poor site selection, and lack of understanding of conditions of the restoration site, causing further uncertainties about the performance of the project and ultimately reducing the success of the project. Failed restoration projects waste resources and lead to disillusionment among those trying to implement them (Hobbs and Norton, 1996). Disillusionment about our ability to restore ecosystems hinders restoration efforts and does not motivate funding of applied research needed to improve performance. In the end, the environment suffers and resource managers are left with a smaller range of options.

Vast sums of money now earmarked and allocated to restoration will be short-lived because of a potentially bad reputation of a mounting number of failed projects. In the United States alone, projects associated with regional or national programs easily total more than $100 million annually (Thom, 1997). Considering the potential for projects such as the Kissimee River-Everglades ecosystem restoration, this total could climb to more than several billion dollars. The net effect of failed restoration, especially at this scale of investment and visibility, could be the drying up of the project funds along with the will to restore.

Because of uncertainties in restoration and the experimental nature of many restoration projects, the principles of adaptive management are potentially useful in both planning and managing restoration projects toward a greater probability of success (Thom, 1997). This paper explains how adaptive management can be incorporated into coastal restoration projects. Detailed examples of how these principles can be applied are found in the two case studies by Marcus (2000) and Steyer and Llewellyn (2000).

1.2. Adaptive management

Adaptive management, which can loosely be defined as the learning by doing, relies on an accumulation of credible evidences to support a decision that demands action (Walters and Holling, 1990). If established early in the project planning phase and implemented during the monitoring and management phases, adaptive management can become a powerful method to systematically assess and improve the performance of restored systems as well as contribute to the technology of restoration.

An adaptive management program associated with a restoration project requires:

- measuring the condition of the system (using selected indicators);
- assessing progress toward goals and performance criteria (i.e. asking questions of the data); and
- making a decision on actions to take.

The three main actions are:

- doing nothing (i.e. waiting for conditions to improve);
- doing something (i.e. implementing corrective actions, based upon the data); and
- changing the goal (i.e. admitting that the project will likely never reach the original goal, and that an alternative system state is acceptable).

The third action is controversial. However, projects that do not meet specific performance criteria but are ecologically viable are common (Simenstad and Thom, 1996). For example, a project may not produce the exact floral composition that was desired or predicted, but can still promote much-enhanced functions within the ecosystem. At the very least, the understanding gained with a project that ‘failed’ to meet performance criteria can be incorporated into planning the next project (NRC, 1992).

1.3. Adaptive management examples

Although there are numerous examples of very large (i.e. exceeding $50 million) restoration programs that recommend the use of adaptive management (Thom, 1997), there are a few published examples showing how adaptive management, was explicitly used to enhance the success of a coastal restoration project. A national review of aquatic restoration projects turned up no explicit examples among the 39 projects examined (Shreffler et al., 1995). However, every project reviewed had a restoration goal with associated performance criteria. Some projects had specific contingency plans if the project was not meeting performance criteria after a specified period of time. Monitoring, a key component of adaptive management, was specified in most projects. Contingency plans, within the context of adaptive management, represent a set of alternative actions if the 'experiment' indicates that a change is needed.

Zedler (1996) has provided examples of smaller tidal wetland restoration projects that evaluate restoration options on an experimental basis. The projects use a flow chart to show how experimental results fit in the decision process, and to make recommendations on full implementation of restoration actions (Fig. 1). The consistent element of the flow charts is the feedback loop from the assessment (i.e. monitoring) step to the decision step. This active adaptive approach is highly useful for testing options where uncertainty may be great, provided, there is time available for this evaluation step.

1.4. The problem with traditional goals for some restored systems

The reasons that restored systems do not meet intended performance criteria can be many. In

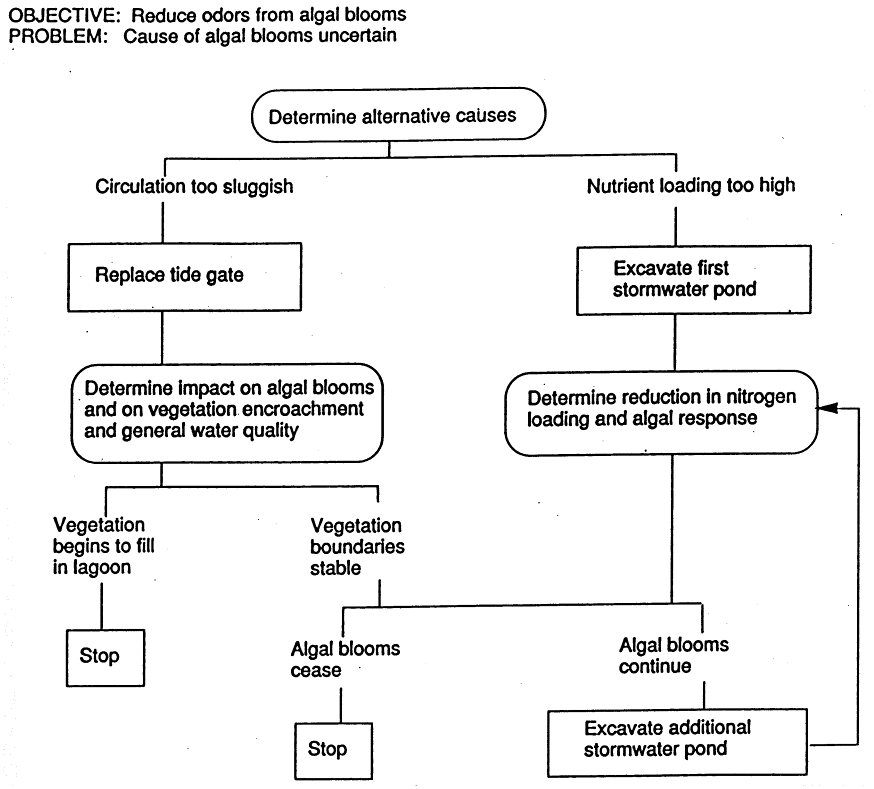

Fig. 1. Flow diagram for Formosa Slough, San Diego County, CA, USA (from Zedler, 1996).

some cases the oft-proposed performance criterion of 'matching conditions in a natural reference system' may not be realistic or appropriate. For example, diked tidal marshes subside substantially because of lack of sediment accretion coupled with oxidation of organic matter and dewatering (Josselyn et al., 1990). A performance criterion that states that following dike breaching, the *system will be statistically similar to a native tidal marsh after five years* sets the project up for failure. Subsidence may have reduced elevation a meter or more, preventing re-establishment of native vegetation in quantities similar to native reference marshes. Furthermore, at accretion rates of, for example, 5 mm per year, it would predictably take two centuries to build a meter in elevation and replace the native community. Hence, if after five years the system is moving from a non-tidal system *towards* a tidal marsh that is dissimilar but highly productive and diverse, the goals should be changed to reflect reality. Efforts to 'force,' via engineering, the restored system to match the reference system at any cost will be a waste of time and money.

Shreffler et al. (1995) found that the primary goals of the projects they reviewed were re-establishing historical vegetation, restoring or enhancing habitat for wildlife and fish species, stabilizing shorelines, controlling mosquitoes, treating wastewater, and restoring hydrology. Thom and Wellman (1996) recommend that if goals can be stated in a clear manner and can be reworded as a set of testable hypotheses, performance criteria can be developed. Further, the task of developing the criteria involves linking criteria to the goals of the project, linking criteria to the actual measurement parameters, and specifying the bounds or limit values for the criteria. They concluded, based on a review of aquatic restoration monitoring programs, that it is not necessary to develop a large number of complex measures if a small, simple set of measures will suffice. NRC (1992) recommended that at least three parameters should be selected and that they included physical, hydrological, and ecological measures. The most efficient parameters are those that are easy to carry out, are strong indicators of controlling factors and ecological goals, are repeatable and are scientifically-defensible (Thom and Wellman, 1996).

1.5. Duration of monitoring

The duration of a monitoring and management program for a restoration project is controversial, and a growing body of evidence on restored and constructed systems shows that most aquatic systems do not reach stability in less than five years (Thom and Wellman, 1996). Cairns (1989) stated that if the system is essentially 'new', and contains no vegetation and for which hydrology must be established, development will take a very long time. In contrast, systems requiring only minor adjustments of existing conditions will require less time. The system should be monitored long enough to provide reasonable assurances that the system has either met its performance criteria or that it will not likely to meet the criteria. The program should extend to a point somewhere after the period of most rapid change and into the period of stabilization of the system. In the procedure developed earlier (Thom, 1997), predictions of time to reach each development stage are made prior to initiation of the restoration action. These predictions then dictate the duration of the monitoring program.

2. Incorporating adaptive management into coastal restoration projects

2.1. Main components

The three main components of an effective adaptive management plan for a restoration project are:

1. a clear goal statement;
2. a conceptual model; and
3. a decision framework.

Along with these, the responsible party must have the will to implement and manage the project through its 'lifetime,' and there must be positive interaction between technical advisors and the project management team (Zedler, 1996). Moni-

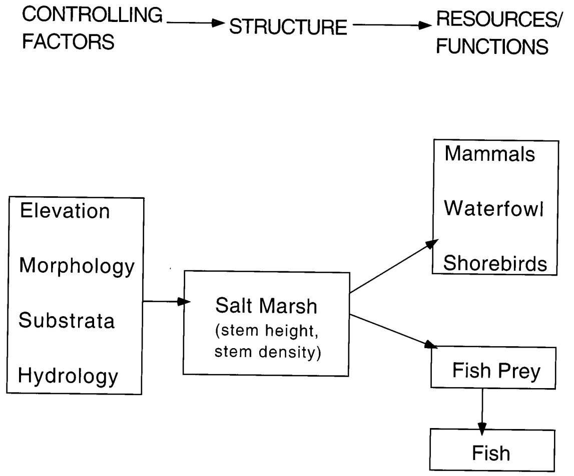

Fig. 2. Conceptual model of a salt marsh restoration design for Manchester, Washington, USA, showing controlling factors, and structural and functional characteristics.

toring is an integral part of the evaluation framework.

2.1.1. Goal statement

The most commonly stated paradigm in restoration ecology is 'establishing a goal for a restoration project is critical' (NRC, 1992). The goal 'drives' the design of the project, and helps guide the development of performance criteria. The goal statement and performance criteria provide the means by which the system can be judged. Monitoring provides the tools, and a systematically applied adaptive management plan provides the framework. In the planning phase, the management team (i.e. the managers and advisors) decides that the system shall be in a specific target state after a certain number of years. The team should also predict potential alternative states or conditions of the system on its way to meeting the final target conditions defined by the goal. Finally, the team needs to determine the procedures to follow if the system is in these alternative states.

2.1.2. Conceptual model

With the conceptual model, the knowledge base from the field of ecological science plays an active and critical role. The process of writing down *controlling* factors along with the desired system structure and function is a useful exercise for providing the basis for the design of the project. Ecological structure must be established in order for the desired ecological function (goal) to occur. In order to achieve the structure and function, physical, chemical, and biological controlling factors must be correct at the site.

The salt marsh conceptual model in Fig. 2 shows controlling factors (i.e. elevation, slope, soil type, and hydrology) that are critical for the desired ecological structure and function. If the project does not meet its structural or functional goals, the project manager can go back to the conceptual model to understand what went wrong. In some cases, this process may show that either the conceptual model or the values (e.g. elevation range) for the controlling factors were incorrect. Based on this knowledge, corrections can be recommended.

In the example in Fig. 2, the planner would write down the actual values for the controlling factors, for example, elevation range (+1 to 1.3 m relative to mean sea level), morphology (slope between 1:30 and 1:200), substrata (fine sand to silt) and hydrology (mixed semidiurnal tides; salinity 15–30 ppt; waves no greater than 1 m; and current velocities less than 0.5 m s^{-1}). Structural parameters could include stem density and stem height that would promote waterfowl and shorebird use as well as fish prey production. These data would be gathered from the literature and/or from sampling of natural systems nearby the site to be restored. If, for example, the target stem density or height is not attained, then the planner can consult the monitoring information and compare that with what was thought to be the appropriate ranges for controlling factors. It may be that wave energies were greater than predicted, or that salinity was lower than predicted, resulting in stressful conditions for the plants. From this analysis, a revised prediction of the ultimate vegetation structure and decisions regarding actions to improve conditions for the plants can be evaluated.

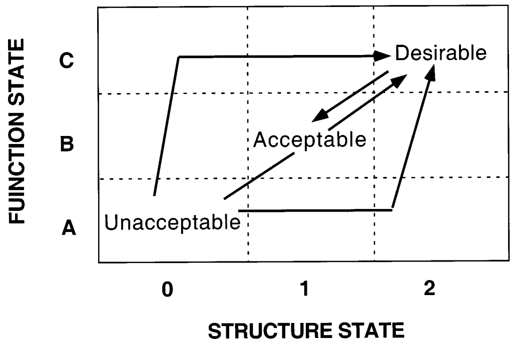

Fig. 3. Generalized model of system development showing pathways of development from initial undesirable state to the desirable (target) state for both structural and functional conditions.

2.1.3. Decision framework

As a new system develops to the desired (target) structure and functions through time, it may follow several developmental pathways (Fig. 3; Bradshaw, 1987). It may also oscillate between two or more system states depending on the factors such as disturbance regimes and climate. A system-development matrix is proposed as one simple way to view the alternative system states (Fig. 4; Thom, 1997). Here, knowledge of the system gained through the monitoring program can help explain why a system may be in an alternative state. For example, a system that has a low density of a selected plant species (structural state) but a high density of animals (functional state) may be due either to unusually high survival of young-of-the-year animals or low predation pressure (upper left box in Fig. 4). Alternatively, the information used to develop the matrix may have been insufficient or incorrect. Upon seeing this result early in the monitoring phase, the management team may decide on one of the three options listed in Section 1.2. They may conclude, based on the data, that the event is unusual due to anomalously favorable conditions for the animals and that the abundances are not sustainable. In this case, the decision by the committee may be to wait (i.e. do nothing).

	STRUCTURE		
FUNCTION	**Rudimentary**	**Intermediate**	**Climax**
Optimal	•functions are independent of structure •functions are best at early stage of development •anomalous condition	•functions are best at intermediate stage of development	•function and structure are fully developed •stable ecosystem •self-maintaining •resilient
Intermediate	•functions are intermediate at early stage •early stage of development •moderate disturbance/disruption	•functions are intermediate at intermediate stage •intermediate stage of development •moderate disturbance/disruption	•moderate function at full structural development •moderate correlation of function with structure •moderate disturbance/disruption
None - Low	•early in development •failed structure •high disturbance/disruption	•functions are low at intermediate stage •incorrect community •moderate disturbance/disruption	•low function at full structural development •incorrect community •anomalous condition

Fig. 4. Generalized system-development matrix showing the 9 states a restored system can occupy during development (redrawn from Thom, 1997).

The range of values for functional and structural performance criteria results from dividing the x and y-axes into three (i.e. low, medium, and high) or more levels (Fig. 4). This approach recognizes that, owing to uncertainties due to natural variability, influences from the surrounding landscape, and frail predictive capabilities, we can reliably only get *close* to the target (Shreffler and Thom, 1993; Hobbs and Norton, 1996).

2.2. Role of the management team

The group of individuals assigned to managing the project can use credible evidence to help formulate decisions systematically. If explanations and alternative actions are defined up front while planning the project, and if written down in a simple form that can be revised annually, decisions on actions will be easily made. The matrix or flow chart provides a framework for actively using the monitoring data, and ultimately provides a mechanism for learning from the project.

A simple matrix and accurate conceptual model, established in the planning phase of a restoration project and implemented through the monitoring phase, can provide a useful tool for managing projects to their maximum expected performance. The adaptive approach strives to minimize conflict while maximizing use of available data and knowledge for learning from the developing system and making educated decisions in a cost-effective way. If designed and implemented appropriately, the decisions that will be made will be scientifically defensible, will be sensitive to new information on the project, will provide a logical link to goals through the conceptual model, clearly guide adjustments in the system, and will be generally the most cost-effective.

2.3. Cost

Because adaptive management programs require some level of monitoring, they can potentially become expensive. Thom and Wellman (1996) found that monitoring costs averaged 13%, and ranged from 3 to 62%, of the total cost of aquatic restoration projects. Adaptive management involves some up-front costs associated with planning the projects, and some post-construction costs. There are no data that I have found regarding these costs, but I believe that a half-day meeting each year where the monitoring data are reviewed relative to the goals and where actions are prescribed would not increase project costs substantially.

Acknowledgements

This manuscript was prepared for the National Conference on Goal Setting and Success Criteria for Coastal Habitat Restoration, 13–15 January 1998, Charleston, SC. The Conference was hosted by the National Marine Fisheries Service Restoration Center and NOAA Coastal Services Center. I thank P. Wilber and G. Thayer of NOAA for the opportunity to participate in the Conference. I sincerely appreciate the support of the Institute for Water Resources (IWR) of the US Army Corps of Engineers and the Waterways Experiment Station (WES) for support in developing this concept. J. Munce (IWR), J. Titre and D. Yozzo (WES) were instrumental in developing the concept. Comments by S.G. Leibowitz and one anonymous reviewer significantly improved the manuscript.

References

Bradshaw, A.D., 1987. The reclamation of derelict land and the ecology of ecosystems. In: Jordan, W.R. III, Gilpin, M.E., Aber, J.D. Jr (Eds.), Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, London, pp. 53–74.

Cairns, J. Jr, 1989. Restoring damaged ecosystems: is predisturbance condition a viable option? Environ. Prof. 11, 152.

Hobbs, R.J., Norton, D.A., 1996. Towards a conceptual framework for restoration ecology. Restor. Ecol. 4, 93–110.

Josselyn, M., Zedler, J., Griswold, T., 1990. Wetland mitigation along the Pacific Coast of the United States. In: Kusler, J.A., Kentula, M.E. (Eds.), Wetland Creation and Restoration, the Status of the Sciences. Island Press, pp. 3–36.

Marcus L., 2000. Restoring tidal wetlands at Sonoma Baylands, San Francisco Bay, California. Ecol. Eng. 15, 373–383.

National Research Council Academy of Sciences, 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, DC, p. 552.

Shreffler, D.K., Thom, R.M., 1993. Restoration of urban estuaries: new approaches for site location and design. Prepared by Battelle Pacific Northwest Laboratories for Washington Department of Natural Resources, Olympia, Washington.

Shreffler, D.K., Thom, R.M., Scott, M.J., Wellman, K.F., Walters, M.A., Curran, M., 1995. National review of non-Corps environmental restoration projects. Pacific Northwest National Laboratory, Richland, Washington; final report prepared for US Army Corps of Engineers, Institute for Water Resources, Alexandria, VA, IWR Report 95-R-12.

Simenstad, C.A., Thom, R.M., 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol. Appl. 6, 38–56.

Steyer, G.D., Llewellyn, D.W., 2000. Coastal Wetlands, Planning Protection, and Restoration Act: a programmatic application of adaptive management. Ecol. Eng. 15, 385–395.

Thom, R.M., 1997. System-development matrix for adaptive management of coastal ecosystem restoration projects. Ecol. Eng. 8, 219–232.

Thom, R.M., Wellman, K.F., 1996. Planning aquatic ecosystem restoration monitoring programs. Pacific Northwest National Laboratory, Richland, Washington; final report prepared for US Army Corps of Engineers, Institute for Water Resources, Alexandria, VA, IWR Report 96-R-23.

Walters, C.J., Holling, C.S., 1990. Large-scale management experiments and learning by doing. Ecology 71, 2060–2068.

Zedler, J.B. (Ed.), 1996. Tidal Wetland Restoration: a Scientific Perspective and Southern California Focus. California Sea Grant College System, University of California, La Jolla, CA.