9 Aspects of Adaptive Management of Coastal Wetlands: Case Studies of Processes, Conservation, Restoration, Impacts and Assessment

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9.1 Introduction

Coastal wetlands are dynamic and include the freshwater--intertidal interface. In many parts of the world such wetlands are under pressure from increasing human populations and from predicted sea-level rise. Their complexity and the limited knowledge of processes operating in these systems combine to make them a management challenge. Adaptive management is advocated for complex ecosystem management (Hackney 2000; Meretsky et al. 2000; Thom 2000; National Research Council 2003). Adaptive management identifies management aims, makes an inventory/environmental assessment, plans management actions, implements these, assesses outcomes, and provides feedback to iterate the process (Holling 1978; Walters and Holling 1990). This allows for a dynamic management system that is responsive to change.

In the area of wetland management recent adaptive approaches are exemplified by Natuhara et al. (2004) for wild bird management, Bunch and Dudycha (2004) for a river system, Thom (2000) for restoration, and Quinn and Hanna (2003) for seasonal wetlands in California. There are many wetland habitats for which we currently have only rudimentary knowledge (Hackney 2000), emphasizing the need for good information as a prerequisite for effective management. The management framework must also provide a way to incorporate the best available science into management decisions and to use management outcomes as opportunities to improve scientific understanding and provide feedback to the decision system. Figure 9.1 shows a model developed by Anorov (2004) based on the process--response model of Maltby et al. (1994) that forms a framework for the science that underlies an adaptive management system in the wetland context. The model indicates that 'Natural Environmental Characteristics' provide the environmental context in which coastal wetland processes operate, including, for example, estuarine geology and geomorphology, hydrological regime, climate, vegetation, and soils. The 'Natural Wetland Processes' lead to the development of a 'Natural Wetland Ecosystem'. The interactions of the natural wetland elements lead to a unique pattern of 'Natural Ecosystem Functioning'. Human actions, both direct and indirect, have the potential to alter the natural wetland processes and this results in altered ecosystems. Wetland management actions can restore the altered ecosystem towards a more natural level or may alter wetlands to provide for specific needs, such as pest management. The model is particularly suited to natural systems that are under pressure (such as coastal wetlands). It can lead to a greater understanding of the response of a coastal ecosystem to both anthropogenic and ongoing environmental changes; and sustainable management options may include wetland creation, restoration or maintenance of remnant wetlands.

This chapter provides case studies from the United States and Australia that exemplify the role science can play in informing the adaptive management process. The first case study (Section 9.2) demonstrates the application of a wide range of tools that can assist the understanding of long-term and recent processes, of both natural and anthropomorphic origin. The next case study (Section 9.3) shows how monitoring information can be used to inform management decisions to conserve wetlands. The use of adaptive management principles to review past management actions is demonstrated next, which focuses on aspects of restoration

**Fig.
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**Table
9.1**

(Section 9.4). Section 9.5 shows how adaptive management has refined the understanding of the impact of management actions on wetland process and suggests an extension to the application of the results. The last case study (Section 9.6) builds on the previous case study and integrates remote sensing into each part of the adaptive management framework. Each case study is related to the process model in Fig. 9.1 and to the adaptive management framework, as indicated in Table 9.1. The chapter concludes with an overview of how each approach is significant for the adaptive management of coastal wetlands.

9.2 Diverse Tools to Identify Processes and Long-Term Changes

Coastal wetlands are dynamic and geomorphologically complex ecosystems that are highly susceptible to change due to natural and human factors. In order to sustainably manage a wetland, as is required by state and commonwealth legislation in Australia, the natural behaviour of these ecosystems that operate over both long and short time-frames needs to be identified and understood. This case study illustrates a variety of tools to explore and explain processes along the freshwater--tidal interface in a subtropical environment in southeast Queensland, Australia. It addresses all components of Fig 9.1; and its role in an adaptive management framework is to provide an inventory of historic and recent processes and assess the impacts or outcomes of management actions in order to inform future planning and management.

The study area, located within a small sub-tropical coastal catchment that drains into the Logan River and Moreton Bay in southeast Queensland, Australia, is known as the Carbrook Wetlands, and comprises four remnant plant communities: intertidal mangroves fringing the tidal Logan River, a supra-tidal saltmarsh, inland a non-tidal slightly elevated rise supporting swamp she-oak (*Casuarina glauca*), and further inland a lower lying, flood-prone tea tree community (*Melaleuca quinquinervia*). A detailed history of environmental change is preserved within the estuarine sedimentary record of the study area and is a valuable indicator of natural environmental change. More recently, human-induced changes within the study area were superimposed on the natural process of environmental change, resulting in the wetlands suffering varying degrees of disturbance since European settlement in the late 1820s. The most significant changes occurred during European settlement, when vast areas of coastal lowlands were cleared for timber, sheep and cattle grazing, and for agricultural purposes, particularly sugar cane production. A second period of change occurred from 1989 to 1995, when the *Melaleuca* community suffered dieback in response to hydrological modifications to the coastal creek for the development of a golf course.

A characteristic feature of the study area, and of almost all of Australia's coastal embayments and wetlands, is the presence of sediments and soils rich in iron sulfides (acid sulfate soils; ASS). Since the last glacial period, ASS formed as a result of estuaries infilling with marine and fluvial sediments. These sediments are a natural part of the terrestrial sulfur cycle in which dissolved, oxidized forms of sulfur from estuarine or marine waters are reduced to sulfides by anaerobic bacteria (Van Breeman 1982). The sulfides then combine with the iron from terrigenous sediments to form iron sulfides, the most common form being pyrite (FeS_2). The subtropical climate of southeast Queensland plays an important role in the geochemical behaviour of these soils. The variable rainfall, together with its duration, intensity, and seasonal distribution significantly influence the physical and chemical properties of the ASS that occupy the coastal wetland environments in southeast Queensland. The substrate is prone to sulfuric acidification if the

water table is lowered either naturally through evapo-transpiration or artificially drained.

Approach: an Inventory of the Past to Explain the Present

The research examined the evolution and connectivity of four coastal wetland community types by integrating the results from three discrete studies that focused on:

- the geomorphic evolution and vegetation history, providing an understanding of how the wetlands evolved during the Holocene and rates of natural ecological change;
- the connection between estuarine deposits (ASS) and their inherent chemical attributes;
- the land-use history of the area, providing a context from which to assess the impact of disturbing ASS.

9.2.1 Geomorphic Evolution and Vegetation History

In order to examine the geomorphological evolution and vegetation history of the floodplain, undisturbed samples were obtained using continuous augering from a transect of six boreholes that extended from the *Melaleuca* backswamp to the banks of the Logan River, encompassing the entire study area. The soil was sampled for pollen and soil analysis, soil morphological data and ASS, pH tests were recorded in the field, and detailed stratigraphic logs were prepared.

Radiocarbon dating was carried out on six intact shells extracted from boreholes in the *Melaleuca* backswamp and in the *Casuarina* forest. The stratigraphy indicated that the floodplain evolved from an infilling estuary since the peak of the Holocene transgression 6500 BP. Pollen records from the four representative wetland communities (previously mentioned) were examined and compared to the stratigraphy to reconstruct the evolution of Holocene coastal wetland vegetation during the marine transgression and subsequent shoreline progradation (Fig. 9.2). The pollen spectra of the lower Zone 1 generally reflected the estuarine depositional environment that existed throughout the study area during the mid to late Holocene. The partitioning of Zone 2, between the *Casuarina* and saltmarsh sites, was influenced by the lateral extension of down-catchment freshwater deposits and by sub-tidal deposits from the Logan River.

The mid--late Holocene vegetation history was controlled by natural damming associated with meandering and levee building by the creek that influenced freshwater input, drainage, and salinity. When the stratigraphy and the pollen zones of the *Melaleuca* and *Casuarina* sites are compared, there is a 100 cm lag between the stratigraphic and pollen zone boundaries. Based on an extrapolation of radiocarbon dates from further down the profile at one site, the results suggest that it took 800 years during the late Holocene for a significant change to occur from estuarine- to freshwater-dominated vegetation at both sites. Thus, pollen analysis, when used in combination with stratigraphic modelling, provided an important point of reference for rates of natural ecological change in response to evolutionary changes to the physical environment. More recent changes related to human occupation are considered next.

9.2.2 Human Modification of Carbrook Wetlands

In order to examine possible explanations for ecosystem changes in the Carbrook Wetlands, information drawn from field observations during 2000--2003 and a field investigation (2002) were combined with evidence obtained from historical records, using a series of aerial photographs from 1934--1995, analysing historical records, maps, survey plans, and photos. Based on the analysis of aerial photos, the development of a golf course in 1989 led to the incursion of saline water into

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the freshwater wetlands. By 1990 the local creek was shortened by more than half its original length. Field observations during 2000--2003 noted that dead *Melaleuca* were unstable and haphazardly falling to the ground. The change in hydrological conditions from freshwater to saline conditions resulted in the progressive decline in health and destruction of the *Melaleuca* wetlands.

The purpose of the geochemical field investigation was to determine the status of the underlying ASS layers of each of the wetland plant communities (previously mentioned). Soil samples for upper and lower soil horizons were subjected to X-ray diffraction (XRD) for mineral composition. Redox status and soil pore water quality were also measured and the data fed into the MINEQL (ver. 4.2) model (Westall et al. 1976) for an assessment of geochemical equilibrium. In particular, the focus was on examining the conditions conducive to iron sulfide formation or breakdown and possible impacts for coastal wetland vegetation and receiving waters.

Soil pore-water results (Table 9.2) show that all the soils had relatively high levels of soluble iron, except for the deep subsoil (at 1 m) at the mangrove site.

However, for all samples extracted from the mangrove and saltmarsh sites, soluble aluminum levels were low, pH conditions weakly acid to neutral, and Cl:SO₄ ratios greater than 7.2, indicating that minor iron sulfide oxidation

(possibly acid volatile sulfides) may be occurring, but that seawater was buffering any acidity produced. Inland, soluble aluminium levels were extremely high in the shallow aerated subsoils under *Casuarina* and *Melaleuca* communities. This, together with the strongly acid pH conditions and Cl:SO₄ ratios of 2.2 to 5.5 in all samples, is consistent evidence of significant and accelerated oxidation of iron sulfides in the *Casuarina* and *Melaleuca* wetlands, caused by artificial landscape drainage. At Carbrook, these changes have impacted differently on the various wetland communities present. Even though the surface elevation between wetland soil sampling sites varied by no more than 0.25 m, the depths to watertable at time of sampling were much more variable (0.5--3.0 m).

In similar low-lying coastal wetlands elsewhere in east coast Australia, channel-shortening and the excavation of drainage networks for the rapid removal of floodwaters led to a reduced hydroperiod and accelerated oxidation of iron sulfides. After a long dry period, oxidation by-products (iron, sulfuric acid, aluminum) are released into drains and receiving waters (White et al. 1996; Johnston et al. 2003). The legacy of over-drainage has been the change in wetland vegetation, salinization, acid scalding, soil acidity, and poor water quality linked to fish kills and loss of aquatic habitat. A common method to ameliorate ASS conditions is to re-instate and mimic a more natural hydrologic regime whilst modifying current land practices. This can be achieved by maintaining higher water levels in drains in order to reduce ground water gradients to the drains, and/or to contain water over ASS landscapes in order to reduce the wetting--drying cycle.

9.2.3 Conclusion

Recognition of the nexus between the geomorphic evolution of an area, the distribution of existing and potential acidity (ASS), and the interaction of climate, hydrology, and artificial drainage are critical for the effective management and sustainability of coastal ecosystems. This research provides a greater understanding of the response of a coastal ecosystem to both anthropogenic and ongoing environmental changes -- a key consideration when devising sustainable management strategies. In order to devise ecologically sustainable management options for highly vulnerable coastal ecosystems such as the Carbrook Wetlands,

the adaptive management approach must rely on sound scientific understanding of the processes operating in the national coastal wetland ecosystem. This will help to assess the consequences of various management options so that ecosystem values can be maintained.

The next section explores the monitoring needed to conserve wetlands affected by environmental change.

9.3 Managing for Conservation: Monitoring Ecological Changes in Coastal Wetlands in Northeast Florida, USA

Considering the model presented in Fig. 9.1, natural wetland processes may be modified through environmental change, as well as by human activities, resulting in altered wetland ecosystems. In an adaptive management framework, assessing change is a monitoring activity but can also be used to revise the inventory and provide feedback to future planning and actions.

Environmental change in natural areas of Florida happens frequently when the incidence of fire is reduced, causing woody plants to increase and herbaceous plants to decrease. Human-induced impacts to natural systems also occur at many scales and magnitudes from sea-level rise due to global warming (Williams et al. 1999) to land development, pollution, invasion by exotic species, and hydrologic change caused by drainage canals or groundwater withdrawals for public supply and agriculture. Monitoring not only provides empirical measures of ecosystem change, but also supplies environmental data to support the development and calibration of models that can be used to better manage conservation lands.

Adaptive management of conservation lands is the best approach to maintaining natural areas and their biodiversity.

9.3.1 Approach

Stokes Landing Conservation Area (SLCA) is a 111-ha preserve located just north of the City of St. Augustine in St. Johns County, Florida. This natural area lies along the west bank of an Tolomato River estuary and has a variety of upland natural communities (scrub, pine flatwoods, hammocks) and wetlands (salt and freshwater marshes, swamps, bogs). In order to better understand the processes affecting SLCA and how to manage the natural resources, five wetland and five upland sites were selected for monitoring. At each monitoring site soils and vegetation were characterized over four years and water levels in shallow wells and rainfall were collected weekly, providing a baseline record of the system. Sites were selected based upon plant community type, access, and security from vandalism. Water table characteristics were monitored in 3-m wells similar to those described by Miner and Simon (1997). Depth to water from ground surface was recorded weekly from January 1995 through December 1999. A bucket-type soil auger was used to sample the soil at each site. Color, texture, and hydrologic indicators (Hurt et al. 1998) were noted for each horizon encountered. Soils were classified to series (Soil Conservation Service 1999). Plant species richness was determined by delineating a plot (20×20 m) adjacent to each well. The plant species growing within each plot were recorded. A rain gauge was installed next to well 9 in the saltmarsh and rainfall amounts were recorded weekly.

9.3.2 Environmental Characteristics

Rainfall at SLCA varied greatly from month to month and between years. Typically, January through May were the driest months in northern Florida. During this study, 1997 was a very wet year (ca. 153 cm of rain) and 1999 was an extremely dry year (ca. 105 cm of rain).

**Fig.
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Comparing wetland and upland soil characteristics, the wetland sites generally had higher organic content (muck) at the surface (A horizon). Most sites had sandy soils with well developed elluvial zones (E horizons) where iron, aluminum, and other materials had been leached lower, and spodic horizons (Bh) where these materials and organic compounds accumulated, indicating a fluctuating water table (Fig. 9.3).

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Sites with the most extreme environmental conditions had the fewest number of plant species (Table 9.3). Only two species of plants were found in the saltmarsh. The freshwater marsh site (well 12) had the highest plant diversity (41 species) of any of the sites monitored. Wetland sites were relatively rich in graminoids (grasses, sedges) and herbaceous plants. For the upland communities, the driest site, oak scrub (well 16) had lowest diversity, with only 19 species of vascular plants, and the mesic hammock at well 10 had the greatest, with 35 species. Trees, shrubs, and vines were much more diverse in the upland study sites compared to the wetlands.

At all of the monitoring sites, the water table was lowest at the end of the dry season and beginning of the wet season during May, June, and July. Generally the water table was much lower in the upland sites than in the wetlands. Of the upland sites, the mesic hammocks had the highest water tables and the oak scrub had the lowest. Average water levels were about the same for the xeric hammock and pine flatwoods. At the upland sites, average water levels were also generally near the Bh or spodic horizon and ranged from 56 cm to 113 cm below ground. Figure 9.3 shows examples for the wetland sites. Water levels were highest at the saltmarsh site (well 9) and lowest in the hardwood swamp (well 15). Average water levels were near the surface in the saltmarsh and ranged from 16 cm to 24 cm below ground at the other wetland sites.

These data provide a reference condition against which future monitoring data can be compared. Within the period of this initial study (1995--2000), the vegetation at wetland site 7 changed from a Virginia chain fern (*Woodwardia virginica*)-dominated understory to a black rush (*Juncus roemerianus*)-dominated system. The fern, a salt-intolerant species, as well as mature cabbage palms (*Sabal palmetto*), pines, and hardwood trees growing in or at the edge of the wetland died, while the black rush, a salt-tolerant species, survived. The evidence suggests that saltwater intrusion into the bog from the nearby saltmarsh, perhaps due to an extreme event, played a role in causing this shift in plant community. It also makes clear that water quality should be monitored in coastal wetlands. Re-sampling the vegetation every few years at each of the well sites will document changes in the plant communities due to land management activities or changes in environmental conditions. Long-term monitoring of groundwater levels will help to detect hydrologic impacts from the growing urban areas bordering the area.

9.3.3 Conclusion

This research shows how preserved wetland sites are affected by processes occurring outside the boundaries of the preserved area such as lowering of the regional water table. It provides a base from which to assess management activities. This assessment is a vital component of adaptive management. Monitoring the effects of management activities is the focus of the next two sections.

9.4 Managing for Restoration: a Multi-Scale Adaptive Approach in Restoring Coastal Wetlands in Louisiana, USA

Coastal wetland loss was not recognized as a problem in Louisiana until the late 1970s (Craig et al. 1979; Gagliano et al. 1981). This wetland loss is related to

direct human impacts (Fig. 9.1) as well as the natural dynamics based on the deltaic geology of the area. To address the coastal wetlands loss, the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) was signed into United States law in 1990. Since then, the State of Louisiana and six Federal agencies (US Environmental Protection Agency, National Marine Fisheries Service, Natural Resources Conservation Service, US Army Corps of Engineers, US Fish and Wildlife Service, US Geological Survey/National Wetlands Research Center) have jointly developed a series of annual priority project lists to target Louisiana's wetland loss. After several years of planning and establishing the restoration program, construction was completed on the first project in April 1994. As of January 2004, a total of 71 CWPPRA projects have been constructed in Louisiana, projected to restore and/or protect 34 710 ha (CWPPRA 2004). As more projects were constructed, it became apparent that an opportunity existed to improve the program by learning from the existing projects through the application of a 'learning by doing' adaptive management approach (Walters and Holling 1990). The objectives for this review effort were: (1) improve the linkages among planning, engineering and results monitoring, (2) document changes made to the project in the different phases of project development and implementation (i.e., document the adaptiveness of the program), (3) recommend any changes that could improve the project (the assessment and feedback components of adaptive management, and (4) learn from implemented projects so that future projects could be improved.

9.4.1 Approach

The review effort involved members of six federal agencies, four universities, and the State of Louisiana representing the CWPPRA Environmental Work Group, Engineering Work Group, Academic Advisory Group, Monitoring Work Group, and Technical Advisory Group. Projects for review were selected based on length of time since construction, length of monitoring data record, number of variables monitored, availability of project information, and similarity to other projects proposed for review. It became evident during this process that most projects had not been constructed long enough to have a sufficient amount of data with which to conduct a thorough review that assessed the effectiveness of the projects. A total of 15 projects were reviewed by an interdisciplinary team of biologists and engineers from state and federal agencies as well as university scientists. The reviewed projects represent the following wetland restoration techniques: (1) wetland creation, (2) hydrologic restoration, (3) shoreline protection, and (4) freshwater re-introduction. At the smallest scale, project-specific engineering, operational, and biological response aspects were reviewed to answer the basic questions of: (1) is the project working physically as designed, (2) is the wetland response as planned, and (3) if not, why not, and can the project be made to work better? At an intermediate scale, projects were grouped by restoration technique. At the largest, programmatic, scale recommendations were developed for the improvement of design, implementation, operation, and evaluation processes.

9.4.2 Lessons Learned

Lessons learned and recommendations for improving project implementation were presented in project review reports (available from <http://dnr.louisiana.gov/crm/coastres/adaptive/adaptive.asp>). Below, we present the major findings for four restoration techniques as well as recommendations for improvement of the overall CWPPRA program.

Wetland Creation

This restoration technique attempts to create wetlands in areas that have changed from wetland to water. It generally consists of dredging sediments from adjacent lake or bay bottoms and depositing this material to achieve wetland elevation after compaction and dewatering. The reviewed projects show that it is very difficult to attain, or even determine, the correct elevation for a healthy wetland. This is partially due to the past difficulty in measuring actual elevations within the Louisiana coastal zone. Wetland creation requires very accurate elevation measurements in Louisiana's micro-tidal climate (average tidal range <30 cm). Based on the uncertainties of sediment stackability, available quantities, and subsidence rates in Louisiana, estimates of sediment consolidation and compaction rates sometimes resulted in final elevations higher than anticipated. Other problems encountered during construction included containment and dewatering issues confounded by vandalism. Closer construction and post-construction inspections were recommended and are being implemented. Because of subsidence and hence high rates of relative sea-level rise in Louisiana, it was often assumed that it is prudent to err on the high side when creating marsh with dredge material (i.e., overfill with the expectation that the material will eventually settle and compact to the correct elevation some time in the future). However, a more sustainable, although admittedly more costly, alternative may be to achieve the optimal elevation sooner and include a maintenance component in the project after several years. By achieving the correct marsh elevation earlier in the project life, natural, self-sustaining accretion processes (including mineral sedimentation and plant belowground and aboveground productivity) will be initiated and the created marsh will be providing some of the critical wetland functions at an earlier date than if overfilled. As the marsh settles over time, a subsequent, pre-planned maintenance component consisting of marsh nourishment with fluid-dredged material could be utilized to fine-tune the elevation and provide an infusion of sediments and nutrients that would stimulate productivity and enhance the overall natural sustainability of the project, so that the created area does not revert to the degraded habitat that existed prior to project construction.

Hydrologic Restoration

This restoration technique attempts to restore a more natural hydrologic regime in areas that have human-induced altered hydrology. The technique generally consists of creating a closed hydrologic unit by connecting natural and artificial hydrologic barriers and controlling water exchange through the use of different water-control structures. Two of the reviewed projects will likely not have the desired restoration effect without modification. For one, this is due to the fact that the construction, operation, and maintenance are under control of the landowner and some features were not completed. The water control structures funded by CWPPRA were a subset of a larger group of structures proposed by the landowner. Some of these proposed structures were not completed. In addition, the operations of the water-control structures are the landowners' responsibility and are not always consistent with the objectives of the CWPPRA project. Documentation of operational changes is not always available. For the second project, the construction of one of the designed features has been deferred to another project that is still in the design phase. The third project has structures that were built as designed, but one of the key structures was vandalized and has been inoperable for most of the project life. It was also discovered that the operational plan for this project was based on an erroneous marsh level, but this has been corrected. Preliminary monitoring data suggest that the project seems to have the desired effect of reducing the rate of land loss.

Two of the three hydrologic restoration projects reviewed had issues that hindered their effectiveness (e.g., landowner control of operations, deferred construction of a project feature). However, the three projects were constructed early in the CWPPRA program; and improvements in the planning, design, and construction process minimized these problems in recent projects. The use of hydrodynamic models for the design and operation of water-control structures, combined with geotechnical investigation of the substrate supporting these structures is strongly recommended for future hydrologic restoration projects and has been incorporated into the planning and engineering and design process of projects not yet constructed.

Shoreline Protection

This restoration technique uses engineered structures to reduce wave energy and protect the adjacent wetland shoreline. Two reviewed projects used techniques (gabion foreshore dike, PVC wall) that were developed for poor soil conditions. Both these techniques have promising results, with material accreting behind the structures and the reversal of shoreline erosion. The other five projects used foreshore rock dikes, which all appear to reduce and even reverse shoreline erosion.

Freshwater Re-Introduction

This restoration technique uses diversion structures to re-introduce Mississippi River water into coastal marshes in an attempt to restore the pre-flood protection levee connection between the river and the adjacent wetlands. The projects reviewed here are not CWPPRA projects, but were included since this restoration technique is highly recommended for future CWPPRA projects. Operating diversion structures is a challenge in Louisiana as they affect many different resource user groups along the estuarine gradient. This results in conservative use of the structures, which limits evaluation of the potential benefits. However, in spite of the conservative operations, all reviewed projects seemed to have a positive effect on vegetation composition and biomass. Louisiana Department of Wildlife and Fisheries (LDWF) sampling in one of the project areas indicates that white shrimp (*Panaeus setiferus*), redfish (*Sciaenops ocellatus*), and speckled seatrout (*Cynoscion nebulosus*) catches, as well as alligator (*Alligator mississippiensis*), waterfowl, and muskrat (*Ondatra zibethica*) counts are all greater since the re-introduction of river water. Monitoring results show that the two projects that use siphons to divert water have minimal impacts on water levels in the project area and that concerns about erosion from the flow are not substantiated by observations.

9.4.3 Program Recommendations

The three main components for an effective adaptive management plan for a restoration project are: (1) a clear goal statement, (2) a conceptual model, and (3) a decision framework (Thom 2000). All of these should be developed during the CWPPRA planning process. Project goals should be identified early in the process and should not change unless the intent of the project changes. Currently, there is a perceived success/failure decision associated with goals and objectives. The goals and objectives are deliberately vague to prevent such a decision. This can be improved by clearly defined effectiveness criteria and targets. Evaluation of the project would document the project's ability to move towards the target (for an example of this approach, see Zedler and Callaway 2000). If a project is moving away from the target, the cause can be determined and the operation and maintenance plans can be adjusted. Causes of wetland loss were often based on landowner and local observation, not on data collection and scientific review. If

causes of wetland loss are not accurate, the likelihood of failure to reduce land loss is increased. A good conceptual model of the controlling physical factors and the resulting system structure and function is necessary for a successful restoration project (Thom 2000). If the project is not moving towards its structural goals, the project manager can go back to the conceptual model to understand what is going wrong and recommend corrections to the operation and maintenance plan of the project (Thom 2000). The process of writing down the controlling factors along with the desired system structure and function is a useful exercise for providing the basis for the design of the project (Thom 2000). Zedler (1996) used flow charts to show how project results fit into the decision process. Design changes, whether before or during construction, need to be coordinated with monitoring, operation, and maintenance to ensure that the project achieves its anticipated outcomes. This could be accomplished by having a project management team, consisting of the personnel involved in all aspects of the project and two academic advisors. This team should improve the communication among the biologists and engineers involved with the project. In addition, such a team can provide the institutional memory, which is sometimes lost with changes in personnel and associated changes in project managers. Projects should be planned, monitored, and evaluated in the context of their place in the surrounding environment. Interdisciplinary support from the academic community is recommended for the evaluation of project effectiveness and cumulative effects. The Coast wide Reference Monitoring System (Steyer et al. 2003) recently approved for implementation by the CWPPRA Task Force could provide this context.

The review of CWPPRA projects resulted in multiple recommendations for individual project and program improvements (details for all of which are available from <http://dnr.louisiana.gov/crm/coastres/adaptive/adaptive.asp>). This is part of the adaptive management feedback loop. The CWPPRA program continues to adapt and improve; and these improvements are resulting in more efficient and beneficial projects. This ability for management programs to adapt based on current information is an important component for any adaptive management program.

9.4.4 Conclusion

This section stresses the need for planning, review, and monitoring; and it notes the absence of long-term monitoring as a constraint on project evaluation in dynamic landscapes.

The next example reports the results of a relatively long-term monitoring project that used a multivariate method to assess impacts of management in a situation where the priority management objective is to reduce disease vector mosquitoes in wetlands near human settlements.

9.5 Managing the Environment to Reduce Insect Pests: a Multivariate Approach to Assess Impacts of Disturbance on Saltmarsh Processes in Subtropical Australia

Not all environmental values of intertidal saltmarshes are beneficial to humans. To conserve and restore wetlands are commendable objectives, but wetlands may also be the source of mosquito-borne diseases such as malaria, West Nile virus in the United States, and Ross River virus in Australia. That usually generates a public demand to manage the insects; and this in turn may obviate restoration efforts and may be in conflict with conservation efforts. This section explores an innovative multivariate method applied to long-term data to identify processes and to assess the effects of marsh modification. The assessment links directly

back to management aims and site inventory and thus advances the adaptive process. In terms of Fig. 9.1, it is exploring the change from a natural to an altered wetland ecosystem with an emphasis on process, assessing impacts of disturbance on the process, and informing future planning and management.

The study area is in southeast Queensland, Australia, close to a major tourist destination, and with a high rate of population growth. The disease vector mosquito population is managed by modifying the environment by an Australian innovation known as runnelling (Hulsman et al. 1989). This alters the marsh hydrology, allowing increased connection between marsh and tidal source that in turn allows access to predators and may flush larvae out into the estuaries or reduce the oviposition of adult mosquitoes. The aim of the research reported here was to assess the impacts of runnelling on the vegetation over 14 years, using a minimal message length (MML) clustering approach as described in Wallace and Dowe (2000). The results are used to inform an integrated adaptive management process, as described in Sipe and Dale (2003).

9.5.1 Approach

This case study is part of a more comprehensive study into the impacts of runnelling, using field and remotely sensed data. As vegetation reflects environmental characteristics and is relatively easy to observe, it is relevant for managers who are often resource-limited. Here we identified system states as reflected by the vegetation, using multivariate clustering models. First, we identified states, or classes, based on the density and size of the two species: *Sporobolus virginicus* and *Sarcocornia quinqueflora*. Changes of state were shown using a transition matrix and this indicated that the states or classes identified formed cycles within the system (Dale and Dale 2002). This confirms and illustrates the interactions shown in Fig. 9.1. There were three cycles with weak linkages (Fig. 9.4). One was from tall dense *Sporobolus virginicus* to bare ground, another was from tall dense *Sporobolus virginicus* to a mix with *Sarcocornia quinqueflora*, and the third was a cycle with *Sarcocornia quinqueflora* dominant in all states. Next we asked whether the disturbance affected the underlying processes of the system or whether there was only a shift in state (this is important in the process model shown in Fig. 9.1). This was modelled with a continuous hidden Markov model, allowing for multiple processes. The result was that a single model provided the best fit to the data. Thus only one process was operating and this was also unrelated to runnelling (Dale et al. 2002) and we concluded that runnelling had no significant impact on the saltmarsh vegetation processes. This was also supported by other research at the site (e.g., Dale et al. 1996; Chapman et al. 1998; Breitfuss and Dale 2004; Jones et al. 2004).

9.5.2 Conclusion

Not only does the research inform mosquito management (an intended consequence) but it also has the potential to inform marsh management for restoration or creation purposes, by indicating which classes may optimize success. That is, a restoration project, for example, may be well advised to restore the most dynamic assemblage (*Sporobolus* and some *Sarcocornia*) to maximize saltmarsh sustainability.

The runnelling management concept is to be extended to mangrove forests, which may also be mosquito problem areas. Since hydrology is the driver for managing the saltmarsh mosquito, a critical issue is how to identify mosquito breeding sites under the mangrove canopy and how water moves between them. This is addressed in the next section.

9.6 Use of Remote Sensing to Monitor Hydrologic Processes in Mangrove Forests and to Integrate Across the Adaptive Management Framework

The last case study exemplifies the potential of remote sensing to inform all stages of an adaptive management strategy. It has been used in all the case studies reported here. In terms of the process model in Fig. 9.1, it mainly addresses the process (hydrologic) part of the system, whether natural or modified, but uses the environmental characteristics (vegetation, substrate) to identify the processes.

The study area is at the tidal Lake Coombabah, in southeast Queensland, Australia. The study site is a mangrove basin forest characterized by tidal flooding and summer rainfall. The basin forest has a complex hydrology that produces ideal conditions for mosquito breeding, often resulting in a significant human health risk and requiring mosquito management.

Extension of the runnelling concept to mangrove basin forests has potential for mosquito management. However this requires detailed information describing the forest substrate structure and complex hydrologic function such as water distribution and hydrologic connectivity. Methods for extracting information about extent of flooding beneath forest canopies do not usually describe substrate structure nor provide information about hydrologic processes such as water connectivity and depth. Responding to these information needs, the current research to use thermal imagery in order to provide information about the substrate structure of the basin forest, including its hydrology.

9.6.1 Approach

In order to satisfy a range of scientific, planning, and legislative requirements, an adaptive management framework was proposed as a suitable tool to guide the research. This was because an adaptive management framework offers a coherent method for integrating initial research and evaluation with subsequent modifications and re-evaluations as the research develops towards its goal -- in our case an operational mosquito control strategy.

An adaptive management framework for minimizing the health risk of mosquito-borne disease needs to consider a number of factors in developing a response strategy. As indicated in the examples given in other sections, the adaptive management framework identifies management aims, makes an inventory/environmental assessment, plans management actions, implements these, assesses outcomes, and provides feedback to iterate the process. Using this approach, an adaptive management framework for the research is presented in Table 9.4, where each management stage and corresponding strategy is outlined for this case study.

Remote sensing is an integral tool for providing the necessary information for problem solving within an adaptive management framework approach (Table 9.4). Not only does the remote sensing activity (Table 9.4, Stage 2) provide the required hydro-environmental data, it is also needed to inform other adaptive management framework stages. In this particular research, at Stage 1, achieving management aims is feasible only when considered using remote sensing methods, as other data collection methods are either too expensive, impractical or potentially too damaging to the mangrove environment. Stages 3 and 4 depend on maps provided from Stage 2 to develop and undertake a plan of action. Evaluation in Stage 5 requires consideration of maps from Stage 2 and possibly revised remote sensing data, especially if the feedback in Stage 6 involves substantial modification or alternate planning.

9.6.2 Conclusions

Table 9.4

The research reported here addresses a variety of dimensions of adaptive management in the context of wetlands. The overall aim of each piece of research is to contribute to the sustainable and adaptive management of the wetland systems. The main conclusion is that adaptive management needs to be informed by rigorous science, yet communicated in a way that can be easily interpreted and used by the end-user (the wetland manager).

Each case study approaches the use of scientific study to inform management action, using a multi-disciplinary or interdisciplinary approach. Reference to the process model of coastal wetlands (Fig. 9.1) and the first case study shows how a variety of approaches converge to help managers and others to understand the system and inform management actions. The geochemical analysis of acid sulfate soils indicated the need also for in-depth assessment in order to identify those areas most vulnerable to acidification. The Louisiana case study is an example of applying adaptive management principles to a large wetland restoration effort. It used interdisciplinary teams consisting of the project managers, biologists, engineers, and coastal scientists, resulting in the direct transfer of information among the different disciplines.

The Florida example shows how the baseline inventory is used to assess the efficacy of management activities and to monitor the effect of urban development close to conservation areas. Feedback will improve environmental outcomes. The multivariate approach used in the saltmarsh research provides an example of how underlying processes can be discovered at a fine scale relevant to the system, providing an inventory of process, a method for monitoring and potential for feedback to the broader management system, including the potential to inform restoration. The final project illustrates, for all stages of the adaptive management framework, the use of remote sensing in the context of a difficult-to-survey dense forested wetland.

Some common themes emerge from these examples in the context of wetland management. Hydrology appears to be a driving variable in all the examples and may be impacted by various forms of development. The projects highlight the importance of monitoring water table levels and water quality, especially, though not exclusively, salinity; as saline intrusion may be an issue in some wetland environments. Because of the complexity of the system, all of these projects involve interdisciplinary teams, bringing together skills from a wide range of areas including pedology, geomorphology, palynology, hydrology, plant science, entomology, remote sensing, and, for all of them, aspects of management.

The final message is that the sustainable management of coastal wetlands relies on knowledge of ecosystem processes, so that the rates and direction of ecosystem change can be assessed, whether due to ongoing environmental changes or to direct human impacts. This facilitates the development of effective and sustainable management strategies to maintain, create or restore coastal wetlands. The adaptive management approach outlined by Walters and Holling (1990) is strongly recommended, to improve the use of both existing and new knowledge of ecosystem processes in order to inform wetland management actions.

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Fig. 9.1 A process model for wetlands (numbers refer to case studies in this chapter). Adapted from Maltby et al. (1994).

Fig. 9.2 Cross-section of study area, showing microfossil pollen zones and stratigraphy.

Fig. 9.3 Seasonal variation in the water table (*left*) and range of water table variation (*black bars*) and means (*stars*) at three wetland monitoring sites within Stokes Landing Conservation Area, St. Johns County, Florida.

Fig. 9.4 Model of changes and their cycles in the saltmarsh. Adapted from Dale and Dale (2002).

Table 9.1 Elements of adaptive management and the case studies, with emphasis on the key issues and activities for each.

Section/case study	Aim	Inventory	Plan	Action	Monitor/assess	Feedback
9.2/Logan, Qld	Understand process to minimize impacts of land use	Soils/sediment profiles, climate, vegetation, and land use	Plan research	Collect data	Analyse data, identify monitoring priority -- soil acidification	Process model with feedback
9.3/Florida	Conserve wetlands, understand process	Vegetation, soils, water table depth, rainfall	Plan research	Collect data	Analyse data, identify key elements -- water quality	Reference for future monitoring, recommendations
9.4/Louisiana	Restore lost wetlands (four approaches)	Sites identified and assessed	Plan new restoration projects and improve existing projects	Implement new projects and change existing projects	Assess outcomes	Recommendations
9.5/Coomera, Qld	Minimize impact of habitat modification on wetlands	14 years data: vegetation (and other environmental variables)	Plan research	Collect data (14 years)	Multivariate analysis, identify impacts, processes	Information to managers and permitting bodies
9.6/Coomabah, Qld, remote sensing ^a (details in Table 9.4)	Minimize impact and mosquito problem	Identify and classify mosquito breeding habitats	Plan hydrologic modification	Modify	Monitor impacts	Provide feedback to managers

^a Remote sensing is a generic tool that has been used in all the case studies reported here.

Comment [CE1]: Page: Andrea: the left- and right-arrows in Table 9.1 need to be accurately aligned between "Aim" and "Monitor/assess".

Table 9.2 Selected pore water data at Carbrook site. *btI* Below testing level.

Source	Cl (mg/l)	SO ₄ (mg/l)	Cl:SO ₄	Fe (mg/l)	Al (mg/l)	pH
Seawater	19 500	2700	7.2	<1	<1	8.2
Mangroves						
Shallow	20 000	2650	7.5	0.19--14.0	<0.16	7.4
Deep	19 000	2600	7.3	0.5	btI	7.1
Saltmarsh						
Shallow	20 500	2075	9.8	0.09--58.0	btI	6.3
Deep	20 000	2300	8.6	35	btI	6.4
Casuarina						
Shallow	4800	1100	4.4	220--440	61--811	4.2
Deep	6475	1800	3.6	440	0.1	4.1
Melaleuca						
Shallow	4400	800	5.5	0.38--14.0	22--31	4.6
Deep	4375	2000	2.2	150	0.1	6.0

Table 9.3 Plant species richness at monitoring sites in the Stokes Landing Conservation Area, St. Johns County, Florida.

Conservation Area, St. Johns County, Florida.

Well/wetland site number	Natural community	Number of species					
		Trees	Shrubs	Vines	Herbs	Graminoids	Total
Wetland sites							
7	Chain fern bog	3	2	1	3	2	11
9	Saltmarsh	0	0	0	1	1	2
12	Freshwater marsh	2	0	5	21	13	41
14	Chain fern bog	3	1	0	11	11	26
15	Hardwood swamp	8	6	3	3	0	20
Upland sites							
8	Xeric hammock	4	11	4	3	0	22
10	Mesic hammock	8	3	6	10	8	35
11	Mesic hammock	7	3	5	6	1	22
13	Pine flatwoods	5	11	3	4	0	23
16	Oak scrub	4	8	3	2	2	19

Table 9.4 An adaptive management framework for the control of mosquito breeding in a mangrove basin forest.

Adaptive management framework stage	Application overview	Application strategy
1. Identify management aims	Minimal impact hydrologic intervention of mangrove basin forest	Aim: to achieve control of mosquito-breeding (oviposition and larval production) by modification hydrologic processes leading to enhanced tidal flushing of potential mosquito-breeding habitats
2. Make inventory/initial assessment	Define mosquito-breeding habitat requirements; identify and describe related hydrology of mangrove basin forest	Identification of potential mosquito breeding habitat; remote sensing information for developing maps of forest structure depicting: a. potential mosquito breeding habitat b. substrate structure identifying basin connectivity
3. Management action plan	Plan hydrologic modification to	Plan for placement of channels increasing tidal flushing between mosquito-breeding areas and tide

	establish/improve tidal flushing of mangrove basin forest	source
4. Implementation of action plan	Undertake hydrologic modification as planned	Construction of channels increasing magnitude and frequency of tidal flushing in target areas
5. Assess outcome	Evaluation of effectiveness of modification for required outcome	Has hydrologic modification produced an effective mosquito oviposition and larval production reduction result; is ongoing monitoring required?
6. Provide feedback	Iterative decision strategy: ongoing evaluation, modification response or alternative strategy response	Is longer-term environmental monitoring required; does modification require alteration; is an alternate strategy required, e.g., rotational impoundment management