The role of wildlife science in wetland ecosystem restoration: Lessons from the Everglades

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Abstract

There has been little discussion of how and when to integrate wildlife science into ecological restoration projects. The recent emergence of wetland ecosystem restoration offers an opportunity to use wildlife science to increase the probability of a project being successful. This paper traces the evolution of wetland ecosystem restoration in North America and proposes three roles for wildlife science in wetland ecosystem restoration: (1) contribute to conceptual ecosystem models, (2) develop quantitative performance measures and restoration targets that track the progress of restoration, and (3) achieve social feasibility by sustaining long-term public support for a project. The extensive knowledge base for many species of wildlife makes them especially useful for contributing to conceptual ecosystem models. Wildlife species are often the subject of long-term monitoring and research because they have commercial value, are conspicuous, or have aesthetic appeal. Wildlife parameters can be good performance measures for large-scale restoration projects because some species integrate information over large spatial scales and are long-lived. Parameters associated with threatened or endangered wildlife species should get special consideration as performance measures because the information will meet multiple needs rather than just those of the conceptual ecosystem model. Finally, wetland ecosystem restoration projects need to sustain funding over decades to ensure the restored system is self-sustaining. Wildlife are a valued resource that can help achieve the social feasibility of a project by providing a way to communicate complex science in terms that society understands and values.

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The field of wetland restoration has been slow to incorporate wildlife science except in those instances when a wildlife species was the focus of a project. Without integration of the disciplines, the ability to predict the responses of higher organisms to the restoration of lower level ecosystem processes is limited. Understanding the cascading effect of restoring basic ecosystem processes is a precursor to re-establishing natural functions like population control and energy flow through food webs, which are necessary for long-term ecosystem sustainability. Integrating the disciplines can also generate support for a restoration project over the long term because wildlife populations are of concern to the public.
This paper traces the evolution of wetland ecosystem restoration in North America and proposes three roles for wildlife science: (1) contribute to the conceptual ecosystem models that underlie restoration projects (i.e., identify important ecosystem processes and attributes and how they interact), (2) develop quantitative performance measures and restoration targets to track the progress of restoration, and (3) achieve social feasibility by sustaining public support for restoration projects over the long-term. The central theme of this paper is that incorporating wildlife science into wetland ecosystem restoration projects at the onset allows for larger scientific advancements in both disciplines and increases the chances of these projects succeeding. I define wildlife broadly as any species of animal.

1. Braided paths: wildlife and wetlands

1.1. The early years

Pioneering work in the fields of both wetland management and wildlife science can be traced to studies conducted by waterfowl managers in the 1940s (see references in Payne, 1992; Weller, 1994). Studies of these animals and their habitats uncovered the importance of water fluctuations as a driving force for wetland vegetation, an important principle of wetland management even today (Weller, 1990, 1994; Keddy, 2000). Although early waterfowl managers were not restoring wetlands, they were using natural wetland processes like water fluctuations and fire to shift wetland habitat toward some predetermined condition. Their approach was similar to that of contemporary practitioners of wetland restoration, who often use natural wetland processes to alter a wetland that has been degraded so that it is more similar to its condition prior to being impacted. But waterfowl managers often looked across trophic levels because the ultimate test of their hydrologic or vegetation management was based on bird use, even if it was not rigorously quantified (M. Weller, pers. communication). In the modern lexicon, they were using waterfowl density and productivity as performance measures for wetland management.

The close connection between early wildlife science and wetland management was weakened by the 1970s and increased due in part to Section 404 of the 1977 Clean Water Act, which required mitigation for impacts to wetlands associated with federal projects in navigable waters (U.S. Congress, 1977). The same year, legislators passed the Surface Mining Control and Reclamation Act of 1977, which promoted wetland restoration and creation on mines (Brooks, 1990). Eventually, wetland restoration was applied to agricultural lands under the Swampbuster provision of the 1985 Food and Security Act, which provided incentives for protection and restoration of wetlands on farmland (Knutsen and Euliss, 2001; Van der Valk and Pederson, 2003). Agricultural lands also benefitted from the Agricultural Wetland Reserve Program, which was part of the 1990 Food, Agriculture, Conservation, and Trade Act of 1990. This program provided for a conversion of up to 405,000 ha of cropland to wetlands through a reduction of federal subsidies that would otherwise apply to these croplands (National Research Council, 1992). None of this federal legislation contained explicit goals for wildlife responses; rather the focus was on providing acreage of wetlands to offset increasing wetland losses. One notable exception was the 1989 North American Wetland Conservation Act, which allowed the U.S. Fish and Wildlife Service to restore, protect, and enhance wetland ecosystems on federal lands for the benefit of migratory wildlife (U.S. Congress, 1989).

Although wildlife responses were rarely an explicit component of wetland restoration legislation, the benefits conveyed to wildlife were an important, if unwritten, justification for them. That justification was formalized by the U.S. Supreme Court in 1986 when, based on the wetland habitat needs of migratory waterfowl, the court ruled that Section 404 of the Clean Water Act should be extended to protect isolated wetlands that are not directly connected to navigable waters. This interpretation of the Act, termed the “Migratory Bird Rule” held in the courts until 2001 and served as a powerful tool for protecting wetlands that previously had no protection (Van der Valk and Pederson, 2003).

1.2. The emergence of wetland ecosystem restoration

The 1990s was a decade of increasing state leadership and larger scale restoration projects. In 1990, Congress enacted the Coastal Wetlands Planning, Protection, and Restoration Act, which established a joint
federal-state task force to identify and implement wet-
land restoration projects in Louisiana and a joint plan-
ning group to devise an overall plan for the restora-
tion of coastal Louisiana (National Research Council,
1992). At the same time, Florida and the U.S. Army
Corp of Engineers were pushing ahead with plans for
the Kissimmee River (Koebel, 1995) and Everglades
restoration (Light and Dineen, 1994) and states around
Chesapeake Bay were working collectively on pro-
grams to manage land use and improve water qual-
ity (National Research Council, 1992). Large-scale
restoration of tidal marshes was being done in Delaware
Bay (Weinstein et al., 2001), San Francisco Bay, and
San Diego Bay (Haltiner et al., 1997), and one is being
planned for coastal Louisiana (Bourne, 2000).

2. Characteristics of wetland ecosystem
restoration

The wetland restoration project described previ-
ously share three characteristics, which I believe war-
rant their designation as wetland ecosystem restoration:

(1) Large spatial extent including adjacent uplands:
 improving the quality of polluted water or the
hydrologic properties of impacted wetlands often
require focusing on an entire drainage basin
because the pollutants and water runoff origi-
nate on uplands (Maltby and Dugan, 1994; Baron
et al., 2002). Also, restoring wetlands at that
scale increases the chances of restoring ecological
integrity because important ecological processes
like seed dispersal, gene flow, and predator–prey
dynamics occur over large spatial scales (Zedler
and Callaway, 2000).

(2) Restoring fundamental ecosystem processes and
disturbance regimes like nutrient cycles, sedimen-
tation, and hydrologic fluctuations. Unlike restora-
tion projects aimed at mitigation where the focus
is on the spatial extent of wetlands, ecosystem
restoration wetlands may already be intact and in
public ownership, they simply no longer function
as they once had. This characteristic requires scient-
ists to develop a better understanding of ecosystem
processes and functions, as well as for interpre-
tation of performance measures at an ecosystem
scale. Because ecosystems are unique, they cannot
simply be compared to reference systems (Trexler
and Busch, 2003). This constraint poses new chal-
enges for ecologists and requires new tools and
approaches such as landscape and individual-based
models (e.g., DeAngelis et al., 1998, 2003; Sklar
et al., 2001) and macrocosm and landscape exper-
iments (e.g., Gawlik, 2002; Gawlik et al., 2003).

(3) Viewing humans as legitimate members of ecosys-
tems rather than separate from them. Humans
depend on healthy ecosystems for essential goods
and services (Costanza et al., 1997; Daily et al.,
1997; Baron et al., 2002) and human activity
affects the ecosystems on which we depend, even
in the most remote parts of the globe (Vitousek
et al., 1997). Ultimately, the decision about which
attributes and functions to restore must reflect soci-
etal values (Harwell, 1997; Harwell et al., 1999a;
Cairns, 2000). This is particularly true for wet-
land ecosystem restoration projects, which rely
on billions of publicly funded dollars (Holl and
Howarth, 2000) that demand accountability to tax
payers. Mechanisms that translate societal val-
ues into project components are influenced by the
political process, which tends to favor the val-
ues of the party in control of legislature at any
particular time. Reflecting the entire range of soci-
etal values may therefore take several political
cycles.

Societal values also play a role in deciding which
ecosystem attributes to restore. Because of widespread
human impacts to ecosystems (Vitousek et al., 1997),
it is unlikely that any system could be completely
restored to its condition prior to human impacts. In
some cases entire habitats may be permanently lost or
biotic communities greatly changed through the extinc-
tion of native species or the invasion of exotic species.
Thus, a restored wetland ecosystem will have a subset
of the functions or attributes that it had historically but
which should reflect current societal values (Davis and
Slobodkin, 2004).

Over the long-term, society will likely place a
high value on restored wetland ecosystems because
of the valuable services they provide (Costanza et
al., 1997). However, building societal support in the
interim requires consideration of individual stakehold-
ers and of short-term human needs. Balancing these
sometimes conflicting interests is one of the most dif-
ficult challenges for wetland ecosystem restoration projects. In coastal Louisiana, the restoration project must overcome opposition from oyster and shrimp fishermen, farmers, the shipping and petroleum industries, and low lying municipalities (Bourne, 2000). In the Everglades, the main challenges to the restoration have come from farmers, developers, and municipalities (Clarke and Dalrymple, 2003).

A prototype mechanism to translate diverse societal values into restoration objectives is the Governor’s Commission for the Everglades (Harwell et al., 1999b). This appointed commission is comprised of 28 diverse stakeholders (State of Florida, 1999) and is charged with, among other things, promoting economic development that is compatible with the ecological objectives of the Everglades restoration. Not surprisingly, different stakeholders have different views on whether this commission is being successful. Environmentalists charge that the Comprehensive Everglades Restoration Plan has been portrayed to the public as primarily a restoration project, with assurances that it will devote to the environment 80% of any new water that was previously discharged to tide (Clarke and Dalrymple, 2003). However, they are increasingly concerned that water designated for the environment will instead be used to fuel economic development (Clarke and Dalrymple, 2003), thus allowing more people to occupy the surrounding lands and thus exerting more pressure on an already strained ecosystem.

3. The application of wildlife science to wetland ecosystem restoration

3.1. Wildlife responses contributing to a conceptual ecosystem model

Knowledge of how wildlife respond to their environment can be an important part of a conceptual ecosystem model, which should be the backbone of any large-scale restoration project. Conceptual models are a representation of the interconnectedness of ecosystem components that identifies the primary pathways between stressors and ecological attributes (Noon, 2003) and represents the known or hypothesized causal relationships (Michener, 1997; Gentile et al., 2001). Conceptual models are especially useful in the early stages of a project when there is a need to focus on the most important stressors and attributes rather than to develop a detailed ecological model of all possible stressor effects. If the conceptual models include societal drivers, they are also useful for screening the initial set of broad restoration options (e.g., identifying hydrologic regimes that cause flooding and risk human health or are otherwise unfeasible; Harwell et al., 1999a). Wetland ecosystem management is commonly done in an adaptive management framework, which means that conceptual models are continually evolving. The new information that comes from monitoring is channeled back into the project to modify the hypotheses and plans (Gentile et al., 2001; Noon, 2003; Ogden et al., 2003).

Wildlife science can strengthen conceptual models because wildlife species are often the subject of long-term data sets, which are suited for detecting slow ecosystem or landscape effects that are common in large-scale restoration projects (Michener, 1997). Wildlife species are often the subject of long-term data because they have commercial value, are conspicuous, or have aesthetic appeal. Examples include a population index for red grouse (Lagopus lagopus scoticus) based on 160 years of shooting records in moors across the United Kingdom (Haydon et al., 2002). In North America, the public’s fascination with birds led to the creation of the Christmas Bird Count, an annual index of bird abundance conducted largely by amateurs since 1900 (Drennan, 1981) and the Breeding Bird Census, an index that started in 1937 (Johnston, 1990). The U.S. Fish and Wildlife Service has conducted an annual survey of breeding waterfowl in North America (U.S. Fish and Wildlife Service, 2004a), as well as a survey of wintering waterfowl since 1955. In Chesapeake Bay, population or harvest data have been available since the 1950s for diving ducks, blue crabs, and oysters (Herbst, 2002), all species with some economic value that were to prove useful for gauging progress of the Chesapeake Bay restoration.

3.1.1. Wading birds in the Everglades: a century of learning

A well-known example of commercial exploitation leading to a long record of wildlife data is the chronicle of wading birds in the Everglades of Florida. The Everglades is a wetland of international importance that is designated an International Biosphere Reserve, World Heritage Site, and a Ramsar wetland (Maltby
and Dagan, 1994). Historically, the Everglades was an expansive (1,200,000 ha) oligotrophic freshwater marsh that flowed slowly southward from Lake Okeechobee to the Gulf of Mexico and eastward to the Atlantic Ocean (Davis and Ogden, 1994). Water depth fluctuated seasonally, driven by the differential precipitation between wet and dry seasons, and annually, driven by years with extreme high and low rainfall. Concentrations of nutrients were local and patchy, mostly restricted to alligator holes and tree islands. The vegetation was a matrix of herbaceous wetland plants overlain by scattered islands of trees and shrubs. A noteworthy feature of the landscape was the aggregation of large numbers of wading birds of many species into nesting colonies along the Gulf of Mexico (Davis and Ogden, 1994).

Since the 1940s, the Everglades has been drained and compartmentalized to provide farmland, flood protection, and water supply for the growing human population (Sklar et al., 2005). The spatial extent is roughly half of what it was historically and water level fluctuations do not match the historic rainfall driven patterns (Sklar et al., 2002). Runoff with high levels of nutrients has drastically altered soil formation processes, vegetation communities, algal communities, fish densities, and bird densities over large areas (McCormick et al., 2002). Hydrologic changes were linked to a decrease in the number of nesting wading birds in the coastal areas where they were most numerous historically (Ogden, 1994).

The decline in nesting wading birds was one of the first and most visible signs that the Everglades ecosystem was being degraded. Researchers were able to identify impacts to wading birds because of a long-term monitoring program, which began out of concern for an even earlier population crash driven by market hunting. News stories of slaughtered birds in nests prompted conservationists and the public to implement protection for wading bird colonies and initiate nest surveys in the coastal Everglades as early as 1903 (Fig. 1). Surveys have been conducted during most years since that time and coverage has been expanded to include all of the extant Everglades and a greater range of species (Crozier and Gawlik, 2003). The long nest record provided convincing evidence that population declines since the mid-1900s occurred coincident with hydrologic changes in the ecosystem (Robertson and Kushlan, 1974; Ogden, 1994).

A string of intensive ecological studies starting in the 1960s (e.g., Kahl, 1964; Kushlan, 1976; Ogden et al., 1976; Frederick and Collopy, 1989) revealed how hydrologic changes can cause declines in prey availability and subsequent nest failure. Prey animals are produced in the Everglades during the rainy season, but they are largely unavailable to wading birds because the water is too deep. As water levels decline during the 6-month dry season, prey are concentrated into small pools where they are captured by wading birds. Bands of habitat containing these drying pools move down the gently sloping elevation gradient of ~1.6 cm/km.

Fig. 1. Estimated number of wood stork nests 1903–2004 in area currently within Everglades National Park. Data from 1903 to 1999 based on Crozier and Gawlik (2003). Data from 2000 to 2004 based on South Florida Wading Bird Reports (http://www.sfwmd.gov/org/wrp/wrp_reg/projects/wading01/).
(Holling et al., 1994) as water levels slowly drop (~0.5 cm/day; Kushlan, 1979, 1986; Hoffman et al., 1994; Gawlik, 2002). If water levels increase quickly because of rainfall or water management, prey disperse and nests will fail (Kahl, 1964; Frederick and Collopy, 1989).

The early studies led to experiments focused on the mechanisms by which prey density and water depth interact to make prey available to wading birds (Gawlik, 2002). The results showed that three species of wading birds, the wood stork (Mycteria americana), white ibis, and snowy egret (Egretta thula), require both high prey densities and shallow water with highly vulnerable prey. When habitat quality begins to decline, these species move to new habitat patches rather than stay and compete with other species. These three species require the narrowest range of habitat conditions, but they have adaptations that enhance their ability to find good habitat conditions anywhere in the landscape if they exist. They can be viewed as searchers or cream skimmers, moving readily and feeding in only the highest quality patches, whereas the other species, which are more likely to stay in one place and feed longer as habitat quality declines, act as exploiters or crumb pickers. Other studies demonstrated how wading birds move around the landscape and depend on a particular landscape configuration and seasonal water fluctuation to acquire enough food to breed (Robertson and Kushlan, 1974; Kushlan, 1979; Bancroft et al., 1994; Hoffman et al., 1994).

Thus, the Everglades restoration benefited greatly from knowledge of how hydrologic processes interact with landscape topography to produce a key ecosystem function and attribute; the ability for an oligotrophic system to support large numbers of aquatic predators (Robertson and Frederick, 1994). These landscape and hydrological connections are critical aspects of the Everglades restoration and have led to conceptual models that are structured spatially (Ogden et al., 2003), and reflect landscape hydrogeological similarity. Wading bird research also led to a monitoring plan (RECOVER, 2004) that includes tracking prey densities during the time they are available to wading birds rather than just focusing on the production of prey animals during the wet season when there is no connection to wading bird foraging. This is a specific example of matching the spatial and temporal scale of an ecosystem response to that of the driver.

As with ducks in Chesapeake Bay, wading birds in the Everglades have defined a clear connection between a stressor, in this case altered hydrology, and a response at upper trophic levels. Moreover, because the amount of research focused on wading birds is so large, confidence in the corresponding hypotheses is fairly high. Assessing the level of certainty for each hypothesis represented in the conceptual model is an important exercise because it will affect the selection of performance measures and decisions about where to direct more focused research (Ogden et al., 2003).

3.2. Wildlife parameters as performance measures

An ecosystem performance measure, or indicator, is a parameter that reflects that status of an attribute of an ecosystem. Performance measures can be structural, such as a particular density of vegetation, or they can be functional, such as a rate of population growth, or the transfer of energy across community boundaries (Haufler et al., 2002; DeAngelis et al., 2003). They can range in scales from molecules to landscapes. Performance measures can be used both during the evaluation phase of restoration alternatives, and during the monitoring phase, to track progress of the restoration (Ogden et al., 2003). The performance measures can be the same in both cases but their use as screening tools is best achieved when they are integrated into predictive models (e.g., Curnutt et al., 2000).

Wildlife performance measures span the entire range of spatial scales as well as the structural and functional dichotomy (Haufler et al., 2002). Several characteristics common to wildlife species require special consideration prior to the development of performance measures. First, many wildlife species are long-lived and have high adult survival rates. Therefore, a common performance measure like population size is a poor choice (Temple and Wiens, 1989). Other measures like habitat selection, reproductive output, and juvenile survival may respond quickly to a stressor or change in resource levels, even for a long-lived species.
Many wildlife species have large home ranges or move great distances among years so they are integrating information across a large area. For large restoration projects this characteristic may be highly desirable and missing from other ecosystem performance measures. For smaller projects this characteristic may be undesirable because an animal’s response will only be loosely related to conditions at the restoration site. Deciding whether a parameter associated with a particular wildlife species will be a good performance measure requires considerable knowledge of how the particular ecosystem will influence the target animal. There are likely to be certain responses, such as habitat use or feeding success, that are closely tied to individual sites, so powerful performance measures may exist even if more common measures are undesirable.

3.2.1. Wading bird nesting

Both wildlife characteristics above are exhibited by wading birds in the Everglades, which have emerged as one of the key performance measures for the Everglades restoration. The data record spans more than 100 years and 13,000 km² (Fig. 1), and careful attention was given to the selection of quantitative performance measures so as to exploit the desirable characteristics of wading birds (Ogden et al., 1996). Declines in the number of wading bird nests in the Everglades provided the first evidence that the ecosystem was being degraded (Robertson and Kushlan, 1974; Kushlan, 1986; Ogden, 1994), so it is intuitive that nest numbers would be a good indicator for ecosystem restoration. Also, this measure is simple and well understood by the public, which is valuable for sustaining support for restoration projects over the long-term.

When wading bird performance measures were first being developed by Ogden et al. (1996), it was recognized that nest numbers alone were inadequate to provide quantitative information on the ecosystem restoration at time scales relevant to managers. Nest numbers vary tremendously from year to year, particularly for the white ibis and wood stork (Crozier and Gawlik, 2003). In years with low numbers, it is almost certain that birds are not dead but rather nesting somewhere else or forgoing nesting altogether. The movement of birds over their lifetimes is very large (Melvin et al., 1999), and species like white ibis are nomadic (Frederick et al., 1996). This high annual variability may require several decades of surveys before declines in wading bird nest numbers are evident. Also, the total number of nesting birds may be influenced by factors outside the Everglades. For example, studies have speculated that increased food resources from aquaculture in Gulf Coast states may have attracted birds away from the Everglades (Walters et al., 1992; Fleury and Sherry, 1995). In addition, the number of birds produced in other southeastern states may influence the pool of potential breeders in the Everglades because wading birds throughout the southeast spend winter in south Florida (Frederick and Spalding, 1994).

Two additional wading bird performance measures, location of nests and timing of nesting, were proposed (Ogden et al., 1996) because they are more closely tied than is bird abundance to conditions in the ecosystem during the year that they are measured. The location of nests has changed dramatically since historic times. The large colonies that historically occurred along the coastal Everglades have disappeared completely and the number of nests in the southern Everglades now represents only 17% of all Everglades nests (Crozier and Gawlik, 2003). The reason for the loss of large coastal colonies is thought to be related to prey availability and hydrologic conditions in that area. During the nesting season, wading birds must find food close enough to the colony so that daily flights to feed their young are energetically feasible. If foraging distances are too great, birds will abandon their nests (Bancroft et al., 1994). The Everglades restoration is expected to produce more prey in coastal areas because the primary stressor there, reduced fresh water flows, will be greatly improved.

A change in the timing of hydrologic patterns is thought to be responsible for a change in the timing of nesting for wood storks (Ogden, 1994). This species now nests about 2 months later than it did historically and it is thought that food is becoming available later now than historically, although the precise mechanism has yet to be confirmed.

A fourth potential wading bird performance measure that should closely reflect conditions in the ecosystem is the interval between years with large nesting events (Crozier and Gawlik, 2003). This measure is based on the pattern of periodic large nesting events often following droughts (Frederick and Ogden, 2001). This performance measure addresses limitations in the 100-year wading bird data set that are common with historical survey data; inconsistencies in survey effort
and methodology and unknown detection probabilities. Both the magnitude of, and interval between, large nesting events have increased since the 1930s (Fig. 2). These periodic nesting events are thought to reflect pulses in productivity (Frederick and Ogden, 2001) or prey availability (Crozier and Gawlik, 2003), which are closely linked to the primary ecosystem stressor: altered hydrologic patterns. Crozier and Gawlik (2003) acknowledged that estimates of nest numbers are imprecise because of the limitations mentioned above. However, they argued that early surveyors could detect the obvious difference between very good nesting years and average or poor nesting years with a high degree of reliability. Thus, if the data are rank-transformed to two categories (high and other), the time interval between the highs should provide a reliable estimate of the frequency at which ecosystem productivity is reorganized and transferred up the trophic web into wading bird nestlings. This performance measure has the added appeal of being linked to ecosystem function rather than just structure.

3.3. Bundling performance measures into a monitoring plan

Because of the size and variability of wetland ecosystems, it is critically important to focus monitoring on the most relevant management hypotheses, which presumably relate most directly to ecosystem stressors. There is a greater danger in spreading the monitoring too thin across too many performance measures or spatial units and then not being able to sustain it over the long-term, than in leaving gaps in understanding. Scientists, who typically work on 2–3 year funding cycles, must begin to explicitly consider whether a monitoring plan has the ability to provide critical information for decades, well beyond their professional lifespan. Selection of the proper performance measures is vital to meeting that challenge.

If the conceptual model is structured so that the effects of the stressors are traced step by step as they move through the ecosystem, then model structure will be representative to some degree of trophic levels or landscape organization (Fig. 3). Predictions that hold across multiple trophic levels are good tests of the underlying hypotheses in the conceptual model. However, if all performance measures are selected from the upper trophic levels, then it is impossible to know whether a response, or lack of, was caused by a change in the ecosystem stressor. Likewise, if performance measures are selected from only the lower trophic levels, there is no information on how the effects of the stressor resonate through the entire ecosystem.

A better approach for increasing the certainty of inferences from monitoring is to select a suite of performance measures longitudinally across trophic
levels that have a common link (e.g., RECOVER, 2004, Fig. 3). This longitudinal suite of performance measures allows for effects of the stressor to be tracked stepwise as they move through the ecosystem. From a logistical standpoint, this arrangement may allow for sampling of several measures simultaneously and lead to more efficient monitoring that will allow for greater spatial and temporal coverage.

When selecting a suite of performance measures for the monitoring plan, it is prudent to have some redundancy (i.e., more than one longitudinal suite) because the large spatial and temporal variation in ecosystems is almost certain to produce unexpected responses and conflicting responses between performance measures. For example, in the Everglades, fish population sizes and wading bird nesting are linked in the conceptual models. However, wading bird species differ in their sensitivity to water depths (Gawlik, 2002). Previous observations have shown that following rapid increases in water levels, snowy egrets will readily abandon their nests whereas tricolor herons (E. tricolor) and little blue herons (E. caerulea) may not (P. Frederick, pers. communication, University of Florida). If those differences in sensitivity were unknown and unaccounted for, the effect of hydrologic changes would be difficult to interpret. In this case, interpreting the effects of hydrologic patterns correctly requires monitoring data on water levels and nesting by two or three species of wading bird species, as well as supplemental information obtained from focused research studies.

An additional consideration for selecting performance measures should be whether there are any species listed as Endangered or Threatened. There are currently 519 federally listed animals in the United States (U.S. Fish and Wildlife Service, 2004b), about half of which are found in freshwater (Jackson et al., 2001). The Endangered Species Act and the National Environmental Policy Act could require that these animals are monitored if they occur at restoration sites. If the funding for the monitoring comes from the restoration project, it will reduce the amount of money available for other performance measures. However, if a performance measure can be devised for a listed species, even if it is not the ideal measure, it will aid...
restoration monitoring as well as meet the requirements of federal laws. In addition, there may be good reasons to include the listed species irrespective of legal requirements. During the process of listing, the U.S. Fish and Wildlife Service often gathers or generates data on population trends, habitat requirements, and the factors limiting population size. This can be a rich source of information that can enhance interpretation of any subsequent monitoring data.

3.4. Wildlife species as a valued resource for achieving social feasibility

One characteristic of wetland ecosystem restoration projects that sets them apart from smaller-scale efforts is the need for decades of sustained funding. Beyond the years required for feasibility studies, planning, and implementation, monitoring is required to ensure that the restored ecosystem is self-sustaining. The question of who pays for ecosystem restoration bears directly on how to sustain the funding. Unlike smaller counterparts, ecosystem restoration projects are usually financed to some degree with general taxes (Holl and Howarth, 2000). This approach has been criticized because it does not target the party responsible for the damage, but it is inevitable when the responsible parties cannot be identified or the ecosystem damage was caused by a publicly financed project in the first place (Holl and Howarth, 2000). This was the case with the massive Central and South Florida Flood Control Project; a publicly financed project that made a large portion of South Florida wetlands suitable for human development but caused serious damage to the Everglades ecosystem, which is now being restored with public funding (Sklar et al., 2001).

An outcome of funding from a general tax base is that politicians, who appropriate funds each year, and ultimately the public, who influence the politicians, must be continually supportive of the restoration effort, even in tight financial times. It surely will be harder to sustain support for expenditures on environmental restoration if spending on other public priorities like education, health care, and defense are seen to suffer as a result. Even the simple passing of time since the implementation of a restoration effort and the fading from the public’s memory will increase the likelihood that support will dwindle (Cairns, 1995). The restoration profession has yet to discuss seriously the willingness and ability of society to support ecosystem restoration projects over the long-term, an issue that Cairns (2000) termed social feasibility. Yet so fundamental is this issue to the long-term success of a project that it should be an explicit part of any pre-project feasibility study. Restoration is thought to be the “acid test of our understanding” of ecosystems (Allen and Hoekstra, 1992), but it is equally an acid test of society’s value of ecosystems. Societal goals and values drive the creation of ecosystem restoration projects (Harwell et al., 1999a,c) so it is the social feasibility of a project, not the technical feasibility that must first be met.

One approach for increasing the social feasibility of a project is to emphasize the value of the entire range of goods and services provided by a restored wetland ecosystem. Scientists have developed quantitative models that value ecosystem goods and services (e.g., Costanza et al., 1997, 2002; Fernandez, 1999) using the same currency that has historically justified development because of perceived economic gain. The results show that wetland ecosystems provide a much wider range of goods and services with higher collective economic value than generally appreciated by the public (Costanza et al., 1997; Daily et al., 1997; Baron et al., 2002; Zedler, 2003). Still, public policies have yet to reflect a system of wetland valuation based on collective ecosystem services (Cairns, 2000). Policies are based on a narrower range of societal values, such as traditional economically important species or endangered species. Generally, animals garner more public support than plants, particularly animals that are large and aesthetically appealing. For example, the Endangered Species Act protects endangered animals regardless of where they occur, but endangered plants are only protected if they occur on federal land or are impacted by a federal project (U.S. Fish and Wildlife Service, 2004c). Even more telling is the absence of legislation protecting endangered habitats, ecosystems, or ecosystem processes.

It is imperative that restoration ecologists do not wait for the field of ecological economics to broaden society’s view of ecosystems, nor for philosophers to convince the public of the intangible value of ecosystems, although both outcomes are in the long-term interests of conservation and restoration. There is urgency to ecosystem restoration and protection because of the rapid loss of the world’s natural systems (Wilson, 1992). Restoration ecologists can move ahead
by adopting a complementary approach for achieving social feasibility; emphasizing society’s “valued resources”. By linking ecosystem attributes that are essential to ecological restoration but esoteric to the public, with a valued resource, scientists can greatly increase the chances that the public will both understand and support the overall restoration effort. For example, the essence of the Everglades restoration is to restore a more natural hydrologic pattern, which in turn drives soil formation, maintains microtopography, produces aquatic animal communities, and supports large numbers of predators like the American alligator (*Alligator mississippiensis*) and wading birds. Scientists know well that success hinges on restoring the lower-level processes. Yet, each spring, South Florida newspapers print stories, not about soil formation or water flow rates that are so critical to the restoration effort, but about the numbers of nesting wading birds, something that reflects lower-level processes but to which the public can more easily identify. Newspaper editors know instinctively what scientists are learning slowly: the scientific basis of restoration projects is most effectively communicated to the public in terms of what the public values and understands. As Leopold (1949) observed, “our ability to perceive quality in nature begins, as in art, with the pretty.”

One of the simplest ways to capitalize on society’s view of valued resources is to use them in a report card that conveys the status of a restoration effort annually to the public through local media outlets. This report card is not a substitute for a monitoring plan or an ecosystem integrity report card (Harwell et al., 1999c), which is more comprehensive in what is monitored and reported. The individual measures reported in the report card should be a very small subset of the performance measures in the monitoring plan that best reflect societal values and can be classified as valued resources. It also must reflect the status of an ecosystem but need not be at the level of resolution provided by a monitoring plan. The grading scheme should be simple (e.g., letter grade or numeric score) even if the computation behind the grade is more complex.

In the Chesapeake Bay, a wide range of data are collected in a comprehensive monitoring network, but the focus of ecosystem status reports is on the blue crab (*Callinectes sapidus*), American oyster (*Crassostrea virginica*), and striped bass (*Morone saxatilis*), three highly valued resources in that region (Herbst, 2002). There is not yet an official report card for the Everglades restoration but one is being developed that will probably contain about eight performance measures, which are both valued resources to the public and that reflect the state of the ecosystem (A. McLean, pers. communication, South Florida Water Management District). Although restoration report cards are intended for adults, there may be benefits to having measures that can also be understood and appreciated by older children. Today’s youth will be the ones completing the wetland ecosystem restoration projects currently underway.

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