

Using Waterbirds as Indicators in Estuarine Systems: Successes and Perils

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Introduction

Estuarine resource managers need reliable information about the state of the ecosystem and how it is changing over time due to natural or anthropogenic perturbations. Animal indicators are often used for this purpose, as they are highly visible, reactive, easily measured, and of intuitive value to the wider public (Morrison, 1986; Landres et al., 1988; Kushlan, 1993; Frederick and Ogden, 2003). Various attributes of animal populations or communities (e.g., population size, reproductive success, habitat use, species composition) may provide information about other ecosystem attributes that are more difficult to measure (e.g., trophic structure, hydrology, contamination). When one or a small number of species are used to provide information about other members or attributes of an ecosystem, they are referred to as "surrogate species" (Caro and O'Doherty, 1999). The role of surrogate species may fall into one of the following categories: health indicator, biodiversity indicator, umbrella species, keystone species, or flagship species. There is much literature on the use of surrogate species; Table 26.1 provides definitions of terms commonly used when referring to vertebrate indicator species, and Table 26.2 lists attributes that must be considered when choosing an appropriate indicator species within a specific ecological system.

The term *waterbirds* refers to birds that spend all or key parts of their lifetimes in wetlands, including the avian orders Ciconiiformes, Charadriiformes, Gaviiformes, Podicipediformes, Procellariiformes, Pelecaniformes, Anseriformes, and Gruiformes. Although a highly diverse group of taxa, many waterbird species have similar life-history characteristics, many of which are useful for monitoring. Thus, it seems natural that any program of monitoring the integrity and function of estuaries would include waterbird populations as indicators of ecosystem processes, attributes, and biodiversity (e.g., Gawlik et al., 1998; Frederick and Ogden, 2003). However, it should be noted that investigations of the application, utility, and reliability of waterbirds as indicators are at least partly lacking.

TABLE 26.1
Definitions of Terms Used in Discussions of Vertebrate Indicator Species

Term	Definition	Ref. ^a
Indicator	An attribute of an ecosystem that is used to access the current state or change in state of other features of that ecosystem	4
Indicator species	An organism whose characteristics are used to measure changes in the attributes of other organisms, structures, or functions within an ecosystem	1, 2, 3
Health indicator	An indicator that measures changes in the structural or functional attributes of an ecosystem	1, 2, 3
Population indicator	An indicator that measures changes in populations of other organisms	1, 2
Biodiversity indicator	An indicator that measures the level of biodiversity within an ecological system of interest	1, 2
Umbrella species	A species whose broad habitat requirements are used to represent the composite requirements of a community of organisms	1, 3, 5
Keystone species	A species with a unique and functionally important ecological role within an ecological system, upon which a large part of the biotic community depends	1, 3, 5
Flagship species	A species with broad appeal to the public, which makes it useful as a representative of an ecological system, often one that is threatened by anthropogenic disturbance	1, 3, 5

^a References: (1) Caro and O'Doherty, 1999; (2) Landres et al., 1988; (3) Simberloff, 1998; (4) Kushlan, 1993; (5) Noss, 1990.

TABLE 26.2
Attributes of Vertebrate Indicator Species That Should Be Considered When Designing Monitoring for a Specific Ecological System

Term	Criteria	Ref. ^a
Generation time/life span	Shorter generation times usually mean shorter reaction time to perturbation (but longer lifespan may be useful in some circumstances)	1, 2
Reproductive rate	Faster rates allow more specificity and less time lag but slower rates integrate more information	1, 2, 3
Individual variability	Lower individual variability desirable (reduces noise in signal, easier statistical estimation of parameters)	1, 2
Sensitivity (to disturbance)	High sensitivity to ecosystem attributes desirable; low sensitivity to other disturbances reduces noise	1, 2
Home range	Larger home range allows more integration of information; smaller home range allows more specificity	1, 2, 3, 4
Distribution	More widespread species allows better detection of local changes	3
Diet (generalist/specialist)	Generalists are not as useful as specialists (but may be cases where generalist desirable)	2, 3
Trophic level	Top carnivores most useful (but certain diet specialists may be useful)	1, 2, 3
Habitat specificity	Habitat specialists are the most useful	1, 2, 3
Adaptability	Highly adaptable species not as useful (adaptations mask responses to perturbations)	2

^a References: (1) Caro and O'Doherty, 1999; (2) Landres et al., 1988; (3) Kushlan, 1993; (4) Noss, 1990.

Several reviews of birds as indicators conclude that, more often than not, bird populations are not robust indicators in biological systems (e.g., Morrison, 1986; Temple and Wiens, 1989; Niemi et al., 1997). This is often due to logistical problems, such as the inability or failure to collect data that are repeatable and amenable to statistical analysis, or to poor definition of variables or goals. Many avian monitoring studies have not been long enough or included corollary information about the ecosystem to allow an unbiased test of the indicator's utility. There is a growing recognition that bioindicators in general are only useful for monitoring specific attributes of an ecosystem and should be used only in conjunction with other indicators to make general statements about ecosystem status and function. Ecological relationships are likely to differ widely among species and ecosystems, requiring specific information that may take years

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lations are not robust (Noss et al., 1997). This is because they are not repeatable and are not suitable for monitoring studies to allow an unbiased general assessment. General assessments are only useful in conjunction with other indicators. Ecological relationships are complex and may take years

to collect. For these reasons, it is not surprising that early attempts to use birds as indicators have met with mixed success. However, there are numerous examples of birds that have been successfully used as bioindicators, and the lessons from these examples are becoming clearer.

There are three components to developing a scientifically credible wildlife indicator. First, one must clearly define what attributes of the estuarine system are to be indicated. Examples of ecosystem attributes include biodiversity, energy flow, contamination, habitat structure, or community structure. In contrast, terms such as *wetland health* or *wetland barometer* may convey an intuitive and comfortable sense of completeness, but in practice are too general or complex to be defined as parameters. At this stage, it is important to distinguish between the need to monitor waterbirds for their own sake as a component of the biota and the desire to use some attribute of birds as an ecological indicator. The former is a perfectly sound reason for monitoring birds, but the reasoning and expectations behind the monitoring should be explicitly stated.

Next, a model of how the proposed indicator will respond to perturbations must be defined. This model can be stated qualitatively (i.e., as a narrative) or may be explicitly defined including quantitative predictions of responses to perturbation. For example, if a manager is interested in monitoring changes to forage fish density due to a disruption of wetland hydrology, then a prediction of reduced foraging success by wading birds might be made. Finally, links between ecosystem attributes and the changes in bird indicators must be validated either through literature review or using quantitative methods in pilot studies (Temple and Wiens, 1989; Kushlan, 1993). Establishing such links may take considerable time and effort, and links and relationships vary among ecosystems, so pilot studies of some depth and duration are an almost inevitable part of the process.

A bioindicator might be useful in the absence of a clear understanding of mechanisms, if a statistical association between the bioindicator and the ecological parameter of interest exists (Erwin and Custer, 2000). However, use of such an indicator relies on the assumption that the statistical relationship remains in effect during the period of interest and under the conditions observed. Relying on such untested assumptions is risky. Another alternative approach, advocated by many conservation biologists (e.g., Noss, 1990), is to use surrogate species such as umbrella or flagship species for purposes other than strictly monitoring ecosystem changes (see Table 26.1). For example, a natural resource manager might select one (or a suite of) waterbird species to monitor, under the assumption that when conditions were favorable for that species, they would also be favorable for most others in the system. In this way, the species would serve as an "umbrella" protecting the biodiversity within an estuarine system. The manager might later be interested in determining in more detail the sources of stress to the ecosystem, but initially the surrogate species is used to provide general information about the integrity and functioning of the ecosystem.

Methodological Approach

The scope of this chapter precludes a thorough review of avian indicators, so the goal here is to indicate both the potential benefits and the potential pitfalls of using waterbirds as monitors of estuarine systems; much of the information will also be useful for other wetlands. First, the advantages and disadvantages of using waterbirds as indicators are reviewed. Next, two case studies are used to illustrate the use of waterbirds as indicators in estuarine systems: long-term monitoring of wading bird nesting populations in the Everglades/Florida Bay Ecosystem, and long-term monitoring of wading bird foraging habitat use in salt marshes of the northern Indian River Lagoon system. Finally, recommendations are given for ways to improve the practice of using waterbird populations as indicators in estuarine systems.

Results

Benefits of Using Waterbirds as Indicators in Estuarine Systems

There are many attributes of waterbird populations that could potentially be used as indicators in estuarine systems (Table 26.3). In general, waterbirds are often an abundant, conspicuous, and functionally

TABLE 26.3

Attributes of Waterbird Populations That Could Be Used for Monitoring and Attributes of Estuarine Systems To Be Monitored

Category	Attributes
<i>Waterbird Population Attributes</i>	
Demographic	Population size (nesting, wintering, adults, juveniles), adult survival, juvenile survival, fecundity, philopatry (number returning to nest in colony), colony site dynamics
Foraging ecology	Foraging behavior (individual, group), foraging success (capture rate, total intake, efficiency), diet (prey selection), habitat use, habitat selection
Organismal	Parasite load, chemical contaminant load, development of young
<i>Ecosystem Attributes</i>	
Structural	Trophic structure, habitat availability, habitat suitability, vegetation structure, chemical contamination
Functional	Hydrology, energy flow, nutrient cycling

important component of estuarine systems (e.g., Kushlan, 1976; Christy et al., 1981; Berrutti, 1983; Erwin, 1985; Montague and Weigert, 1990; Frederick, 2001). Waterbirds are highly mobile and may respond quickly to environmental change. As apex predators in aquatic food webs they may be good monitors of bioaccumulative toxins and diseases (Spalding et al., 1993; Erwin and Custer, 2000). They are conspicuous and (compared to soil, vegetation, or small aquatic organisms) relatively easy and inexpensive to quantify. To the public, they are charismatic and thus often serve as emblems of wetland conservation. Finally, their basic ecology, habitat preferences, and systematics are often well established, and there is an abundance of specimens including skins, eggshells, and feathers collected over many decades.

One of the greatest strengths of using waterbird populations as indicators is the ease of monitoring them. They are often numerous and conspicuous components of their ecosystems, making them both energetically important and also well suited to estimation of numbers over time. Many species congregate at feeding, roosting, or nesting sites during particular times making it easy to survey their populations within focal areas (Bibby et al., 2000; Erwin and Custer, 2000; Williams et al., 2001). Similarly, demographic information is often obtained by marking nests and individuals in breeding colonies (Erwin and Custer, 1982; Erwin et al., 1996; Cezilly, 1997; Bibby et al., 2000). Waterbirds also have great appeal to the general public, making it easier to obtain resources necessary for monitoring, than it might be for other, less well-known components of estuarine systems (Frederick and Ogden, 2003). Some waterbird species are protected by laws, which often mandate monitoring; for example, the wood stork (*Mycteria americana*), snail kite (*Rostrhamus sociabilis*), and piping plover (*Chararius melodus*) are protected by the Endangered Species Act in the United States.

For many species of waterbirds, their relatively large body size and position near the top of food chains enable them to integrate information about the trophic structure of the ecosystem. For example, a waterbird population or community may be a good indicator of an estuarine system's prey base, which is itself of ecological importance. Waterbird populations are often key components of ecosystems through vital functions such as predation effects (Kushlan, 1976; Hafner and Britton, 1983; Hafner et al., 1993), nutrient deposition at nesting or roosting colonies (Onuf et al., 1977; Bildstein et al., 1991; Frederick and Powell, 1994), and soil perturbation during foraging (Bildstein, 1993). Many waterbirds are opportunistic in their resource use, shifting their foraging habitat or prey preferences between seasons (Butler, 1993; Stolen et al., 2002), making foraging locations reliable indicators of prey location. Similarly, through large-scale movements, waterbirds serve as integrators, providing information about average conditions across large wetland or coastal ecosystems.

When several different species co-occur within an estuarine system, monitoring the waterbird community allows greater specificity for indicating changes within the estuary. Although many are termed "generalists" because of their large movements and use of widely different habitats, waterbird species

can be divided into more specific foraging niches, especially within taxonomic groups. For example, the various waterfowl, shorebird, and wading bird taxa all include an array of foraging specialists such as species specializing on fish or invertebrate prey. This allows flexibility in aligning an indicator with a specific attribute within an ecosystem. Monitoring multiple species within the same estuarine system also provides information about multiple levels of ecosystem function. Finally, because the overall level of biodiversity is an important component of an estuarine system, monitoring a diverse waterbird community may be useful in itself (Caro and O'Doherty, 1999).

Pitfalls of Using Waterbirds as Indicators in Estuarine Systems

The most basic problem in the use of waterbirds as indicators is determining which species, attribute, or population is to be monitored within a given ecosystem, especially given the diversity of life histories, spatial habitat use patterns, ecological interactions, and behaviors. It is crucial to understand a species and its role in the ecosystem prior to attempting to use it as an indicator. It is also important to consider how to define the study population and the factors that influence its dynamics, as home ranges of waterbirds range from endemic flightless rails to highly mobile nomadic waterfowl, ibises, and storks (Frederick and Ogden, 1997). An indicator species may be present in the estuary year-round, or may only occur during certain seasons (e.g., wintering or breeding populations). If a nonresident population is selected, factors outside of the estuarine system may affect its performance as an indicator. Another complication occurs when an indicator species has two or more overlapping populations present at various times, as when breeding populations are supplemented by wintering birds from more northern breeding populations during part of the year (Mikuska et al., 1998). In some cases, highly mobile species may not be suitable as indicators.

In addition to regular seasonal patterns of movements, many populations of waterbirds are highly nomadic. For these, it is important to consider the potential environmental attractants and repellents in other parts of their range when interpreting local fluctuations. For example, declines in numbers of white ibis (*Eudocimus albus*) in Florida were observed during the late 1980s (Runde, 1991) and could have been interpreted as an indication of changes in habitat conditions in the region. However, it was later learned that a large increase in white ibis was occurring in Louisiana where the birds were attracted by an increasing crayfish aquaculture industry (Fleury and Sherry, 1995; Frederick et al., 1996; Frederick and Ogden, 1997).

Surveys of individual birds or their nests within some prescribed area produce an estimate of the total number of individuals comprising a population (Bibby et al., 2000). Examples include systematic aerial surveys conducted over large areas, ground counts of successive waves of migrating shorebirds at a stopover point, or repeated boat surveys along transects through a coastal marsh or creek system. Although these methods of estimating population size are the least expensive and easiest to use, they may have many unstated or unmeasured biases that lead to interpretation problems. For example, nearly all attempts by humans to count or estimate numbers of birds larger than ten tend to be underestimates (Caughley, 1974; Erwin, 1982; Frederick et al., 2003) and the degree of bias is highly variable among investigators (Frederick et al., 2003) and may have little relationship to training, experience, or age, making it difficult to estimate the degree of bias.

Many surveys must also deal with visibility interference, in which some unknown number of targets is blocked by vegetation, diving patterns, or are easily confused with other species (Caughley, 1974; Pollock and Kendall, 1987; Frederick et al., 2003). These problems may be generally addressed by measuring the degree of error within and between observers or techniques (Erwin, 1982), and adjusting to obtain a less-biased estimate of population size (Dolbeer et al., 1997). It is often valuable to use complementary techniques with different strengths. For example, systematic aerial surveys at colony or foraging locations can yield spatially reliable information over a large area, while site visits can yield accurate information about species composition, status and behavior, population size, and biological interactions. The best advice is to measure and understand the limitations of the survey technique prior to widespread use, and especially prior to interpretation of data. The use of surveys in any ecosystem should be iterative, involving pilot studies, accuracy measurement, modeling of bias, and field validation.

Surveys may be inappropriate for species that are cryptic or especially where individual-specific information is needed (e.g., demographic studies). In this case, mark-recapture/resighting and radiotelemetry may be used. Mark-recapture/resighting studies are conducted by capturing a portion of a waterbird population and applying marks such as conspicuous wing tags or leg bands, which allow individuals to be identified later in the field using observation or capture (Williams et al., 2002). This may yield information on location, movements, population size, and population parameters (e.g., survival). Radio or satellite transmitters can also be used to follow movements and habitat use of individuals, and can be used as a means of estimating survival (Cezilly, 1997).

Case Study 1: Long-Term Monitoring of Nesting Wading-Bird Populations in Everglades/Florida Bay Ecosystem

The Everglades is a large, flat wetland (>4000 km²) located at the southern end of the Florida peninsula that includes a mosaic of freshwater and estuarine components (Gunderson and Loftus, 1993). Most rainfall occurs May to October, with a distinct dry season November to April; variation in dry season rainfall typically exceeds 80% of the long-term mean (Gunderson and Loftus, 1993). Wading birds are dominant predators in this ecosystem in terms of position in the food web and biomass (Frederick and Powell, 1994; Ogden, 1994), and both foraging and reproduction are directly affected by estuarine conditions.

Reproduction by wading birds is in general strongly affected by the availability of prey (Frederick, 2001), which in the Everglades is largely controlled by the timing and degree of seasonal drying. During the dry season, surface water levels can recede by 2 to 8 mm/day, forcing fishes and macroinvertebrates into shallow ponds and pools where they become available to the birds. At the interface of the freshwater marsh and tidal mangrove regions, aquatic fauna are concentrated by numerous streams and short rivers (Lorenz, 1999, 2000). Fish and macroinvertebrate densities can increase during the dry season by up to one, and biomass by up to two orders of magnitude (Loftus et al., 1986; Loftus and Eklund, 1994; Lorenz, 2000). Historically, most of the large colonies of wading birds were concentrated in the estuarine regions of the Everglades (Pierce, 1962; Frohring et al., 1988; Ogden, 1994). The colonies were probably located there for a variety of reasons, including protection from mammalian predators and production and availability of prey due to the close proximity of a variety of foraging habitats with a range of hydrological conditions (McIvor et al., 1994; Ogden, 1994; Gawlik, 2002).

Several important inferences have emerged from historic records, which go back discontinuously for nearly 100 years (Pierce, 1962; Robertson and Kushlan, 1974; Frohring et al., 1988; Ogden, 1994). First, historical nesting patterns suggest very high interannual variability, ranging from 0 to 100,000 pairs, sometimes in consecutive years (Ogden, 1994). Second, pairs of nesting wading birds have decreased by 80 to 90% compared with averages and peaks established in the 1930s (Ogden, 1994; Frederick and Ogden, 2003). Third, timing of nest initiation by wood storks changed from November to December in the period prior to the 1970s, to January to March in the recent period. Fourth, the success of nesting by at least one species (wood stork) was documented to have declined markedly after the mid-1960s (Ogden, 1994). Finally, the location of nesting changed dramatically, with coastal nesting having been largely abandoned by the mid-1980s, and 80 to 90% of nesting moved to freshwater marshes farther inland (Frederick and Ogden, 2003).

The population decline, change in timing and success of nesting, and change in location of nesting for wading birds occurred during a period of dramatic, anthropogenically induced hydrological change during the latter half of the 20th century (Ogden, 1994). During this period the flow of water through the Everglades was interrupted by a series of canals that lowered water levels and reduced flow to the coastal regions, thereby altering their estuarine nature (Light and Dineen, 1994). The most intensive period of alteration was between 1950 and 1970, when the freshwater portion of the Everglades was divided by levees into a series of large pools. The net effect of these hydrological alterations was to reduce water flow to estuarine systems by more than 60%. In addition, because water flow was subsequently managed for both flood control (wet season) and water supply (dry season), the timing of surface flows was also dramatically changed.

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The alterations in wading bird population size as well as the timing and success of nesting were greatest during the period of most rapid and intense hydrological change — between the 1950s and 1970s. There are mechanistic links between reduced water flow to the coast and nesting. Both survey and experimental studies have demonstrated that the densities of small forage fishes are strongly affected by hydroperiod and freshwater flows, in both freshwater marshes (Loftus and Eklund, 1994; Trexler et al., 2003) and, particularly, in coastal mangrove areas (Lorenz, 1999). Coupled with experimental work demonstrating that wading birds give up foraging at specific densities of prey (Gawlik, 2002), this is strong support for the hypothesis that wading birds stopped nesting in the region because reduced flows resulted in substandard prey production or availability.

Ornithologists first noted changes to wading bird populations during the 1960s (Ogden, 1994), but it took nearly 20 additional years to uncover the specific mechanisms by which secondary productivity of the coastal zone had undergone dramatic collapse (Browder, 1985; McIvor et al., 1994; Lorenz, 1999; Frederick and Ogden, 2003). Thus wading birds were the first biological indicator of ecological problems, by some 20 years when compared with other animal populations. The data demonstrating the estuarine indicator function of Everglades' wading bird populations have been sound enough to allow the formulation of hypotheses for restoration of the ecosystem. A central goal of the Comprehensive Everglades Restoration Plan is to restore freshwater flows to the coastal regions as a means to restore wading bird breeding. Both volume of freshwater flow and the size of the wading bird nesting population also serve as metrics for the determination of restoration success (Frederick and Ogden, 2003).

Wading bird populations in the Everglades have also served as indicators of contaminants. The Everglades ecosystem is highly contaminated with mercury (Hg) from local waste incineration (Dvonch et al., 1999; Frederick, 2000). Although the problem of mercury contamination was initially discovered through monitoring of fish flesh for human health standards (Ware et al., 1990), the history and trends of mercury contamination have been successfully monitored using wading birds (Spalding et al., 1994; Sunlof et al., 1994; Frederick et al., 1999, 2002, 2004; Sepulveda et al., 1999). Annual monitoring of mercury in the feather tissue of nestling great egrets (*Ardea albus*) between 1993 and 2000 has shown that mercury contamination declined by over 73%, a change not detectable through analysis of water and air samples (Frederick et al., 2002). An analysis of wading bird museum skins has similarly yielded a record of mercury profiles in Everglades' biota extending back for nearly a century (Frederick et al., 2004).

Case Study 2: Using Wading Birds to Monitor Estuarine Habitat Restoration

Located on the Atlantic Coast of Florida, the Kennedy Space Center/Merritt Island National Wildlife Refuge encompasses the northern quarter of the 250-km-long subtropical estuary known as the Indian River Lagoon System. Historically, the eastern shore of the Indian River Lagoon System was extensively vegetated with irregularly flooded salt marsh habitat (Schmalzer, 1995). Human impacts on saline and brackish marshes of this system culminated in the impoundment of nearly all of the fringing marshes by 1970. Permanent flooding of these impoundments resulted in a profound change in vegetative and animal communities. The isolation of wetland habitat from the Indian River Lagoon System is believed to have reduced ecological benefits of the system, and efforts are under way to reconnect over three quarters of all impounded wetlands in the estuary (Brockmeyer et al., 1997). The Indian River Lagoon System supports abundant wading bird populations that utilize freshwater and salt marsh habitats for feeding, roosting, and nesting (Schikorr and Swain, 1995; Sewell et al., 1995; Smith and Breininger, 1995; Mikuska et al., 1998; Stolen et al., 2002).

To assess the impact of space vehicle launch operations on impounded wetland habitat, 13 focal impoundments were selected from among 75 impoundments on the Kennedy Space Center/Merritt Island National Wildlife Refuge. These impoundments contained roughly one fifth of the nearly 11,000 ha of impounded marsh habitat. Monthly wading bird habitat use surveys were conducted between April 1987 and April 2002 using a helicopter flying at an altitude of 60 m, and a speed of 110 km/h. Impoundments were flown systematically such that all area within was observed, and all individuals visible within the impoundment were counted. Between 1987 and 2002, 6 of the 13 impoundments

were reconnected to the estuary through the installation of culverts, 1 was restored by completely removing the perimeter dike, and 5 remained isolated from the estuary. One of the 13 impoundments was restored prior to the study period and represented the probable condition of salt marsh in the system prior to impounding.

Although this study was not designed to monitor the effects of reconnection, wading bird foraging habitat use may be used to illustrate the use of waterbirds to detect changes in estuarine systems. In this case, the specific hypothesis tested was that reconnection would strongly affect wading bird use of foraging habitat by altering productivity and availability of prey within impoundments. To focus the analysis on the resident populations of wading birds, the mean monthly density of individuals observed in impoundments between April and August was used as a metric of habitat suitability. In this analysis wading birds were divided into piscivores (great blue heron, *Ardea herodias*; great egret, snowy egret, *Egretta thula*; tricolored heron, *E. tricolor*; and reddish egret, *E. rufescens*) and probers (white ibis, and glossy ibis, *Pelegadis falcinellus*). An investigation of visibility bias (E. Stolen and G. Carter, unpubl. data) showed that detectability of white-plumaged wading birds within impoundments was nearly 0.9 (i.e., one in ten missed), while dark-plumaged birds were more likely to be missed (detectability around 0.7).

Over the study period, the mean density of piscivores was 0.19 individuals/ha and the mean density of probers was 0.12 individuals/ha. Snowy egret made up 51% of all piscivores and white ibis made up 79% of all probers. The annual mean density of piscivorous wading birds observed foraging within the 13 impoundments varied by a factor of 30, ranging from 0.06 to 1.8 individuals/ha, demonstrating the extreme variability in the use of foraging habitat by wading birds in the system. Although some of the impoundments showed an increase in the density of foraging piscivorous wading birds following reconnection with the estuary, the patterns were inconsistent and the effect size was similar to variation in the impoundments that remained unconnected with the estuary (Figure 26.1A and B). The variation in monthly density observed within impoundments was very high, making it difficult to interpret differences between years. Regression models were used to test the hypothesis that restoration had an effect on the density of foraging wading birds when the effect of year was controlled. Only two of the six restored impoundments showed any evidence of such an effect (Figure 26.1A). Similarly, the annual mean density of probing wading birds observed foraging within the 13 impoundments varied by a factor of 155, ranging from 0.009 to 1.400 individuals/ha. As was the case with piscivores, the density of probers within impoundments following reconnection with the estuary did not differ from the density before, and monthly variation within the impoundments was high (results not given due to space limitations).

As a result of the high variation between monthly estimates of abundance, wading bird use of foraging habitat was not a sensitive indicator of the effect of reconnection on impounded salt marsh habitat at the Kennedy Space Center/Merritt Island National Wildlife Refuge. Although it may be that reconnection did not alter food supply or availability enough to affect wading birds, it is not possible to make any conclusions from the data available. There are factors that made it difficult to use this monitoring data to indicate change within this system. First, using impoundments as a sampling unit may not provide a good metric for the way the birds view habitat. Foraging wading birds commonly move between foraging locations within and between impoundments over time periods spanning minutes to hours. A better approach would have been to measure wading bird foraging success within impoundments, before and after reconnection. This could also have been coupled with measurement of prey density within the impoundments. In addition, information regarding other factors such as hydrology and management history that may have affected wading bird use of foraging habitat more than reconnection status was not available. Such information might be obtained, even after a disturbance event occurred, by using aerial photography and hydrological modeling incorporating historical water level data; such analysis is currently under way for this system (E. Stolen and D. Breininger, in prep.).

This example illustrates the importance of critically evaluating the usefulness of waterbird populations as indicators prior to investing heavily in their use. Had this study been designed to indicate environmental change within this system, it would not have succeeded in that goal. In this case, a

pilot study of the use of wading bird populations would have quickly revealed the high variability in monthly densities and the need for habitat mapping and collection of management and hydrologic data. It might also have been decided that investigations that focus on the relative magnitude of intrinsic vs. extrinsic factors influencing wading bird use of foraging habitat would improve the usefulness of wading birds as indicators in this system (i.e., monitoring movements of birds at a larger spatial scale).

Conclusions

Many problems with the current use of waterbirds as indicators are due to a lack of information about the structure and demography of their populations. In the majority of situations, managers do not have adequate information about factors affecting waterbird populations that are only resident in the system for part of the time. The Everglades/Florida Bay ecosystem is quite large and this has allowed a good understanding of waterbird populations within. By contrast, the northern Indian River Lagoon site is smaller, and is a part of a larger ecosystem. In this case, information about factors affecting waterbird populations outside of the system was lacking and this made use of waterbird populations as an indicator difficult. These examples highlight the need for a thorough understanding of waterbird populations before their use as indicators in estuaries. However, the development of this type of information may be beyond the ability of individual managers to obtain. In many cases, collaboration between adjacent areas and within regions will be needed to gain such knowledge about the dynamics of waterbird populations.

Monitoring waterbirds has often been justified based on their value as indicators of environmental changes, and there have been several examples that have proved this to be true (e.g., brown pelican, *Pelecanus occidentalis*; osprey, *Pandion haliaetus*). But there will be many cases in which waterbirds will not be particularly efficient indicators of changes in estuarine systems. In such cases, it is important to remember that waterbirds are important elements of biological diversity that often depend on estuarine systems, even if they are sometimes not the best indicators of particular environmental changes within those systems. Time lags in population responses can mask the consequences of habitat change for long periods (Nagelkerke et al., 2002), and there is ample evidence that many populations of waterbirds are declining (e.g., Kushlan and Hafner, 2000). For these reasons, continued research and monitoring of waterbird populations as important elements of biological diversity are justified.

The most useful aspects of waterbird populations as indicators within estuaries include the large spatial extent sampled, often numerous species from which to target an indicator, the ability to tailor the indicator to a specific ecosystem attribute, their sensitivity to contaminants, and the rapidity with which populations can respond to perturbations. Although the most powerful applications of indicators include detailed validation of links between ecosystem changes and indicator response, some useful knowledge can be gained from even the most preliminary investigations incorporating waterbird indicators. For example, most current knowledge of wading birds populations came from monitoring studies that were initially blind (or mostly blind) to ecological relationships. Therefore, we encourage the continued use of waterbird populations as bioindicators within estuaries, and we challenge investigators to improve on the reliability of the information obtained from such studies.

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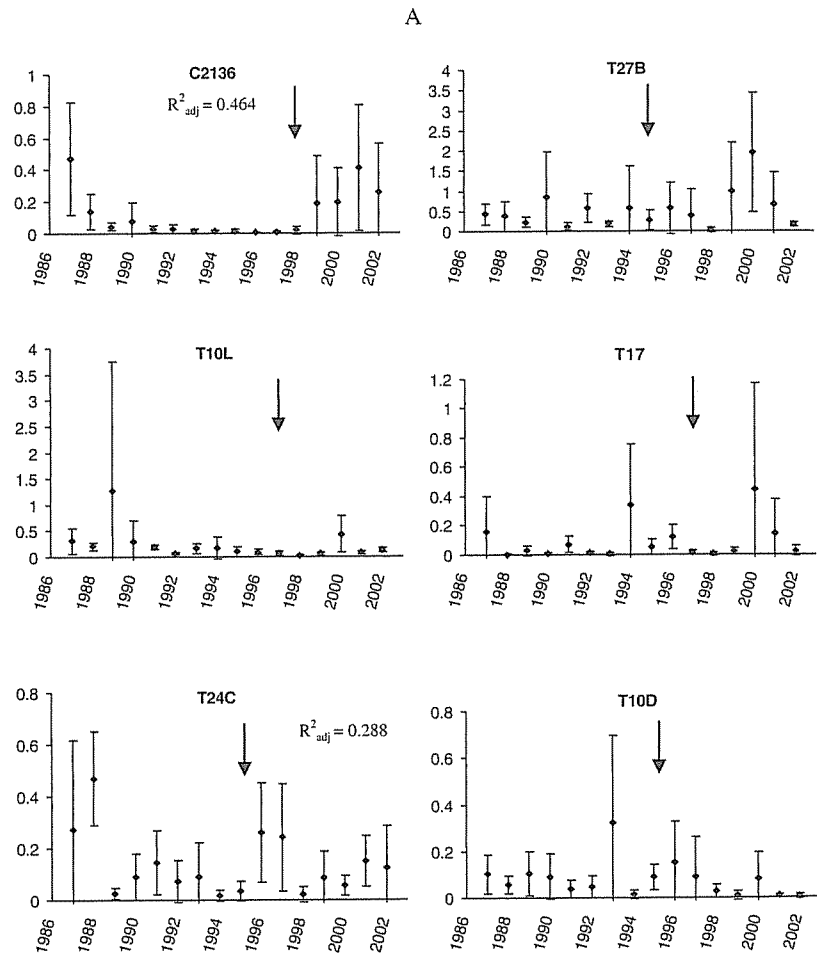


FIGURE 26.1 (A) Yearly mean density of foraging wading birds within impoundments that were reconnected with the estuary at Kennedy Space Center/Merritt Island National Wildlife Refuge showed inconsistent evidence of positive ecological effects. Shown is yearly mean density (individuals/ha) of monthly aerial foraging habitat use surveys (April to August) within each of six impoundments that were reconnected to the estuary by culverts; arrows indicate year of reconnection. Error bars are 95% confidence intervals of mean. R^2_{adj} values are given for sites with evidence of significant difference between years before and after restoration (other sites not significant at $\alpha = 0.05$ level).

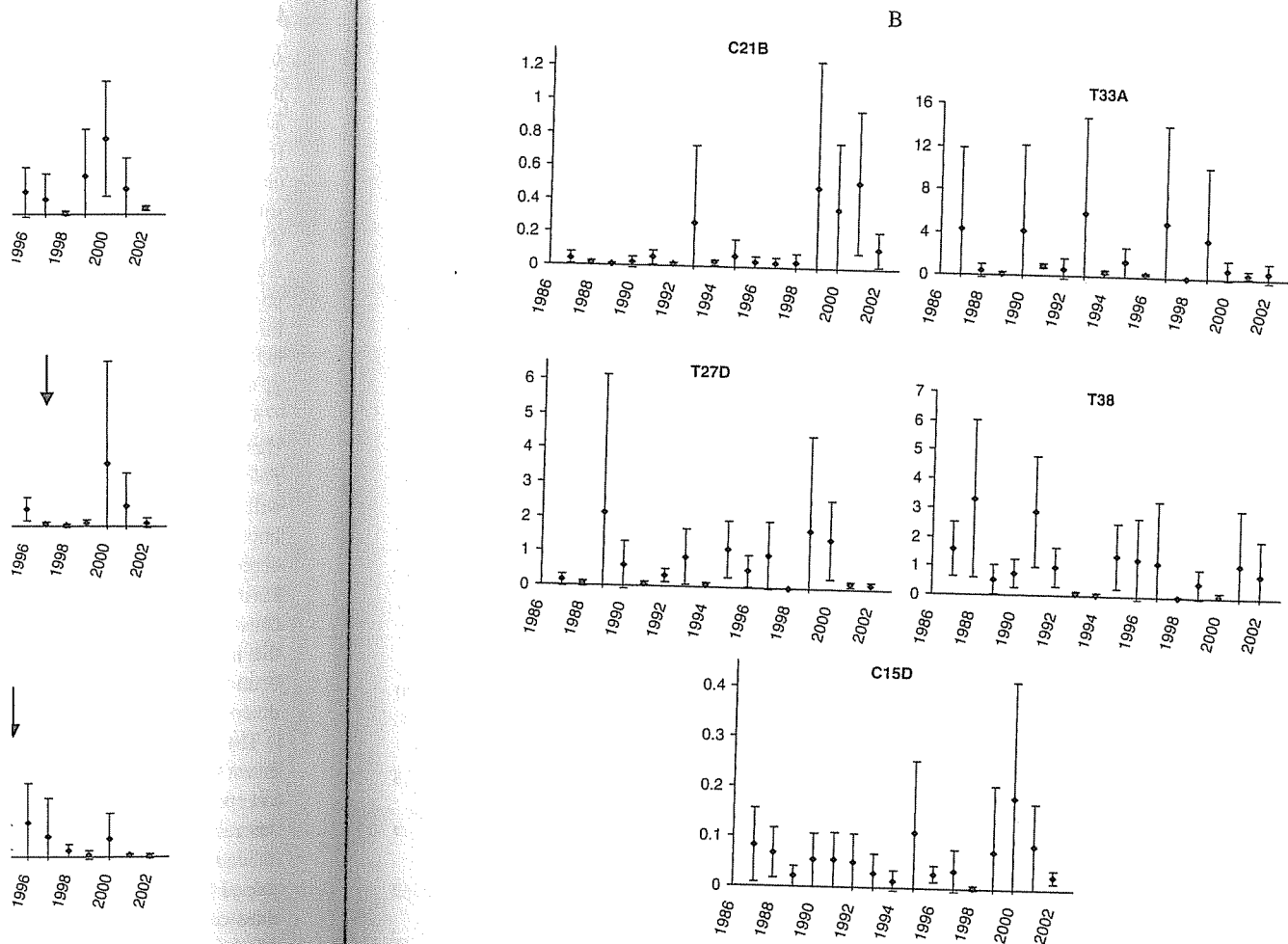


FIGURE 26.1 (CONTINUED) (B) Yearly mean density of foraging wading birds within impoundments that remained isolated from the estuary at Kennedy Space Center/Merritt Island National Wildlife Refuge showed similar patterns as did those that were reconnected. Shown is yearly mean density of monthly aerial foraging habitat use surveys (April to August) within each of five impoundments that were not reconnected to the estuary.

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