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IMPACTS OF MARSH MANAGEMENT ON COASTAL-MARSH BIRD HABITATS

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Abstract. The effects of habitat-management practices in coastal marshes have been poorly evaluated. We summarize the extant literature concerning whether these manipulations achieve their goals and the effects of these manipulations on target (i.e., waterfowl and waterfowl food plants) and non-target organisms (particularly coastal-marsh endemics). Although we focus on the effects of marsh management on birds, we also summarize the scant literature concerning the impacts of marsh manipulations on wildlife such as small mammals and invertebrates. We address three common forms of anthropogenic marsh disturbance: prescribed fire, structural marsh management, and open-marsh water management. We also address marsh perturbations by native and introduced vertebrates.

Key Words: Disturbance, impoundment, marsh endemic, marsh management, mosquito control, open-marsh water management, prescribed fire, structural marsh management.

IMPACTOS DEL MANEJO DE MARISMA EN HABITATS DE AVES DE COSTA-MARISMA

Resumen. Los efectos por las prácticas de manejo del hábitat en marismas de costa han sido pobremente evaluados. Resumimos la literatura existente que concierne a que ya sea si estas manipulaciones alcanzan sus metas, y los efectos de estas manipulaciones en organismos blanco (ej. Gallinas de agua y plantas de alimento de gallinas de agua) y en organismos no-blanco (particularmente en endémicos de marisma de costa). A pesar de que nos enfocamos en los efectos del manejo de marisma en aves, también resumimos la escasa literatura que concierne a los impactos de la manipulación de marisma en la vida silvestre, tales como pequeños mamíferos e invertebrados. Dirigimos tres formas comunes de perturbación antropogénica de marisma: quemas prescritas, manejo estructural de marisma, y manejo de agua en marisma-abierto. También dirigimos perturbaciones del marisma por vertebrados nativos e introducidos.

Nearly three-quarters of the 2,500,000 ha of coastal marshes of the US are located along the southeast Atlantic (North Carolina–Florida) and northern Gulf of Mexico (Florida–Texas) coasts (Alexander et al. 1986, Chabreck 1988). The extensive gulf and Atlantic marshes of the Southeast are intensely managed by federal and state land management agencies, conservation organizations, and private landowners. Managers disturb these ecosystems, often yearly, through prescribed burns, herbicide applications, ditching, and shallow pond construction. The rationale for these manipulations fall broadly under categories of: (1) wildlife enhancement, (2) flood control, (3) mosquito control, and (4) erosion mitigation (Daiber 1987, Chabreck 1988, Nyman and Chabreck 1995). These manipulations have occurred since historical times, but have been poorly, or only recently, evaluated in terms of their impact on wildlife.

In this chapter we address two primary questions: (1) are these manipulations achieving their wildlife management goals, and (2) what are the effects of these manipulations on non-target organisms, particularly coastal-marsh endemics? The majority of available data focuses on the effects of marsh management on birds. Much less is known about the impacts of marsh manipulations on small mammals, reptiles, and invertebrates. In this review, we address three common forms of anthropogenic marsh disturbance—prescribed fire, structural marsh management, open-marsh water management. Additionally, we address marsh perturbations by native and introduced vertebrates. Several other marsh-management actions we considered beyond the scope of this review including: insecticides targeting mosquitoes, herbicides for exotic or invasive species control, salt-hay cropping, and cattle grazing. These processes, particularly insecticide and herbicide use, often create impacts on nearly all of our marsh lands, but have been so little studied in the wildlife arena that little can be concluded, despite their clearly major impacts.

EFFECTS OF PRESCRIBED FIRE ON COASTAL-MARSH BIRDS

Prescribed fire is widely used to manipulate marsh vegetation. Although prescribed fire traditionally is used in gulf and southeast Atlantic Coast marshes, its application has spread throughout much of the eastern seaboard. For example, in 2002, the USDI Fish and Wildlife Service (USFWS), National Wildlife Refuge System burned approximately 9,500 ha of coastal marsh along the Texas coast; 9,300 ha of tidal and freshwater marshes along the North Carolina–Florida coast; 4,000 ha of coastal marsh in Louisiana; and 2,000 ha of salt and brackish tidal marshes in the Chesapeake Bay watershed (Dave Brownlie, USFWS Region 4, pers. comm.; Mark Kaib, USFWS Region 2 pers. comm.; Roger Boykin, USFWS Region 4 pers. comm.; Allen Carter, USFWS Region 5, pers. comm.). These figures exclude widespread prescribed burning by state agencies, National Park Service, or private individuals.

Prescribed fire in marshes gained initial support as a management tool for improving wintering waterfowl habitat in the 1930s and 1940s along the Gulf Coast (Lynch 1941, Nyman and Chabreck 1995). In the following decades, wildlife managers from the East and Gulf coasts embraced the recommendations of authors who advocated prescribed burning as a tool for conditioning marsh habitats (Lynch 1941, Hoffpauir 1961, Givens 1962, Hoffpauir 1968, Perkins 1968). Such conditioning includes removal of litter and dead vegetation, or vegetation considered to be of little or no value to gamebirds (e.g. cattails [*Typha* spp.] and cordgrasses [*Spartina* spp.]), and reduction of shrub cover. These burns were also purported to stimulate growth or seed production of food plants eaten by waterfowl such as bulrushes (*Schoenoplectus* spp. formerly *Scirpus* spp.), bristle grasses (*Setaria* spp.) and *Echinichloa* spp. Other purported benefits of marsh burning include: (1) maintaining a mixture of open-water and vegetated cover for resting, loafing, and breeding activities by waterfowl and other water birds, (2) facilitating trapping (primarily for muskrats [*Ondatra zibethicus*] and American alligators [*Alligator mississippiensis*]), (3) recycling dead plant material and increasing primary productivity through nutrient release, and (4) reducing the risk of unpredictable or uncontrollable fires, or fires that would damage the marsh system, e.g., peat fires (Nyman and Chabreck 1995, Foote 1996). Despite the long history of fire, and ongoing federal expenditures for prescribed fire programs, critical evaluations of the effects of fire on target and non-target species have been scarce.

In reviewing the available literature on fire in North American wetland ecosystems in 1988, Kirby et al. (1988:iii) declared that the science of using fire in natural and anthropogenic wetlands to perpetuate wildlife and plant communities was still in its infancy. Over a decade later, the predictive science of prescribed fire in wetlands remains weak; few analytical papers have documented fire's effects on marsh wildlife. Many coastal researchers consider marsh burning to be simply a "long-standing cultural practice...apparently done because of tradition or with poorly planned objectives" (Nyman and Chabreck 1995:134). We summarize extant information on the efficacy of prescribed burning on improving waterfowl habitat and populations and examine possible indirect effects of burning on non-target marsh birds.

Effects of Prescribed Burning on Waterfowl and their Habitat

Lynch (1941) advocated prescribed fires to enhance waterfowl wintering habitat. He reported that experimental burning on federal refuges in Louisiana attracted >500,000 geese and thousands of ducks to marshes that had previously held few waterfowl. Lynch (1941) states that these burns removed dense vegetation that interfered with growth of preferred waterfowl foods, increased nutritional quality of forage for cattle and geese, and increased waterfowl access to seeds and rhizomes. No details regarding counting methods, use of control marshes, or historical occurrence of fires or waterfowl in that area were provided. Interestingly, Lynch (1941) recommended that prescribed fires be used only on Gulf Coast marshes until experiments had been conducted in other coastal regions.

For 20 yr after Lynch, burning in coastal marshes continued without critical evaluation. In the 1960s, several authors began assessing marsh-burning efficacy, mostly based on observational and anecdotal data (Givens 1962, Hoffpauir 1968, Perkins 1968). Those authors focused on benefits to waterfowl by the favoring of preferred forage plants and maintaining shrub-free and otherwise open-marsh habitat.

As an example of the anecdotal nature of the evidence presented, Hoffpauir (1968:135) in coastal Louisiana, noted cover or wet burning 2–3 wk prior to arrival of Snow Geese (*Chen caerulescens*) provided fresh green vegetation and increased access to below-ground vegetation; however, geese used these areas for only 3–4 wk. Certain dabbling ducks appeared to use the burned areas extensively, feeding in potholes left behind by the activity of the Snow Geese. However, no information regarding use of controls, numbers of burned areas, or quantitative data were provided.

Despite these claims concerning waterfowl habitat improvement, we found only one study in which investigators surveyed waterfowl response to prescribed burns in coastal-marsh habitats using a standard methodology and comparing burned areas to controls (Gabrey et al. 1999). The authors conducted aerial surveys from December–February immediately following 14 prescribed burns on a 30,700 ha state wildlife refuge in coastal Louisiana. Gabrey et al. (1999) reported that 10 flocks of white geese (Snow Goose and Ross's Goose [*Chen rossii*]), ranging in size between 300 and 17,500 individuals, used recently burned marsh areas exclusively during the December–February period. However, the authors collected no behavioral or dietary data to assess goose activity or possible goose attractants in burned areas.

Habitat enhancement burns are intended to increase biomass and seed production of marsh plants preferred by migrating or wintering waterfowl (Lynch 1941), while reducing competition from less preferred plants such as inland saltgrass (*Distichlis spicata*), smooth cordgrass (*Spartina alterniflora*), or salt meadow cordgrass (*S. patens*) (Lynch 1941, Nyman and Chabreck 1995). DeSzalay and Resh (1997) evaluated late summer burns in inland saltgrass dominated coastal marshes in California and found that percent cover of inland saltgrass was reduced, while that of goosefoots (*Chenopodium* spp.) and purslanes (*Sesuvium* spp.) important in dabbling duck diets was increased, in burn treatments versus controls.

In brackish marshes in Chesapeake Bay, winter burning increased culm density and above ground biomass of live chairmaker's bulrush (*Schoenoplectus americanus*) in burned plots 1 yr post-fire, compared to plots that had not been burned for 2–3 yrs (Pendleton and Stevenson 1983, Stevenson et al. 2001). Biomass of dead bulrush was greater in unburned plots than burned plots. Burning did not affect biomass of plants other than bulrush. Pendleton and Stevenson (1983) concluded that the greater bulruish biomass produced following burning was a consequence of increased stem density rather than increased biomass of individual stems. Standing-dead material limited the total number of living culms in the unburned stands, and shaded new culms, therefore delaying the onset of spring growth.

Turner (1987) found that late-winter burning in smooth cordgrass marshes in Georgia reduced net aboveground primary production by 35%. Burning significantly reduced mean dry biomass of live rhizomes of smooth cordgrass in the top 10 cm of sediment. Burned plots exhibited a denser growth of smaller, finer smooth cordgrass plants than control plots.

Gabrey and Afton (2001) evaluated the effects of winter burning in 14 burned/unburned plot pairs in Louisiana saline, brackish, and intermediate marshes dominated by salt meadow cordgrass. Burns increased total live above-ground biomass but failed to increase bulrush species. Post-burn, species composition did not change, and post-burn flowering and seed production were nearly nonexistent, therefore, post-burn growth appeared to be from below ground rhizomes and roots of the burned plants (Gabrey and Afton 2001; S. W. Gabrey, pers. obs). Smooth cordgrass biomass in burned plots was lower compared to unburned plots; burning had no effect on inland saltgrass biomass (Gabrey and Afton 2001). The most notable and longest lasting effect of these burns was the dramatic reduction in dead above ground biomass, which remained below unburned levels for at least 3 yr post-burn.

Flores and Bounds (2001) studied six replicate marsh sites in the Chesapeake Bay of Maryland. All plots were burned in winter 1998 and treatment plots were burned again in winter 1999. Vegetation samples collected in the fall of 1999 (following treatments) showed that live above-ground biomass of inland saltgrass, chairmaker's bulrush, and saltmeadow cordgrass was greater in sites burned in 1999 than in those left unburned. Total biomass did not differ between treatments. Sites burned in 1999 had significantly higher mean stem densities than those left unburned. At 6 mo post-burn no significant difference was found in live aboveground biomass of black needlerush (*Juncus roemerianus*) or smooth cordgrass between burned and unburned treatments. The researchers report an overall increase in plant community stem density, but lack of increase in overall plant community biomass, in response to burning. Although burning increased biomass of bulrush, it did not reduce biomass of either cordgrass or saltgrass.

Some researchers report that burning coastal marshes enhances primary productivity. Spring, summer, and winter burns in Texas each increased live gulf cordgrass (*Spartina spartinae*) standing crop and the percentage of flowering plants by the end of the first growing season post-burn. The greatest growth response resulted from spring treatment, possibly because of post-burn rainfall (McAtee et al. 1979). Winter cover burns on the Mississippi coast increased net primary production (NPP) of above ground plant material by 56% and 49% in black needlerush and big cordgrass (*Spartina cynosuroides*) marsh communities, respectively (Hackney and de la Cruz 1981).

Season of burn and frequency of burn may explain in part the variability of vegetation response. In a greenhouse study using small buckets to simulate marshes, Chabreck (1981) showed that varying the season of burn altered the post-fire plant community. October burns appeared the most successful at promoting the growth of bulrush species. while burns between December and February promoted salt meadow cordgrass growth. In addition, O'Neil (1949) recommended 3–4 yr of repeated burning followed by periodic burning at 4-yr intervals to convert salt meadow cordgrass-inland saltgrass dominated marsh to sturdy bulrush (*Schoenoplectus robustus*)-saltmeadow cordgrass marsh in Louisiana. However, numerous other environmental variables, such as air or water temperature, salinity, pre-fire vegetation community, likely influence the composition of the post-burn plant community.

Another popular objective of habitat-enhancement burns in coastal marshes is to increase the nutritive quality of available plant foods. McAtee et al. (1979) report that digestible energy and crude protein content of gulf cordgrass was significantly increased on Texas coastal prairie in response to burning. Smith et al. (1984) conducted fall burning in a Utah alkali marsh; protein increased in inland saltgrass, tule bulrush (*Schoenoplectus acutus*), and cattail (*Typha* spp.), but not in alkali bulrush (*Bolboschoenus maritimus*). Schmalzer and Hinkle (1993) evaluated black needlerush and sand cordgrass (*Spartina bakeri*) marshes burned in December, at Merritt Island, Florida, and found that plant-tissue nutrient concentrations generally declined post-fire. One year after burning, nitrogen (N) content in live vegetation was lower than pre-burn content for all plant species. Phosphorous (P) concentrations increased in sand cordgrass, decreased in bulltongue arrowhead (*Sagittaria lancifolia*) and black needlerush in the black needlerush marsh, and were unchanged in other species. However, the P:N ratio increased in all live biomass types. Potassium (K) concentrations in live tissues declined or did not change significantly in all species whereas calcium (Ca) concentrations increased in black needlerush and sand cordgrass. Magnesium (Mg) concentrations decreased in live and dead black needlerush but increased in live bulltongue arrowhead and cordgrass species. Overall, biomass and nutrient content in these marshes did not return to pre-burn levels at 1 yr post-burn.

A potentially important, but poorly studied effect of prescribed fire is the possible impact on coastal-marsh invertebrates important in waterfowl diets. Some researchers have speculated that burning may reduce invertebrate populations in the short term by altering marsh surface temperature or exposing animals to greater predation risk (Hackney and de la Cruz 1981, DeSzalay and Resh 1997). Komarek (1984: 6) reported that following a single prescribed burn during the winter in a *Juncus-Spartina* marsh at St. George Island, Florida, three species of snail appeared to be more abundant in the burned section of the marsh. He observed higher populations of fiddler crabs (*Uca* spp.) in burned coastal marshes compared to unburned areas. However, because no data were provided to support these comments, it is unclear if such reported increases actually reflect increased invertebrate abundance, perhaps in response to greater nutrient availability, or greater invertebrate visibility in burned areas versus unburned sites.

A few studies demonstrate that various invertebrate taxa may respond differently to fire. On marsh islands in Virginia, Matta and Clouse (1972) collected invertebrates in sweep nets at 2-wk post-burn intervals from six sites representative of four burn treatments. The occurrence of most adult forms was not significantly affected by burning, although the principal insect herbivore, a meadow katydid (*Conocephalus* sp.) did show significant differences among sites, with fewer numbers at recently burned sites. Turner (1987) found that abundance of the periwinkle snail (*Littorarea irrorata*), an important winter food for American Black Ducks (*Anas rubripes*), was reduced by burning in smooth cordgrass in Georgia marshes. In the most extensive study to date, DeSzalay and Resh (1997) found densities of many invertebrates important in the diets of dabbling ducks in California wetlands (for example, *Chironomus* spp. and *Trichocorixa.* spp.) to be greater in burned compared to unburned control marshes. However, densities of other invertebrates, such as copepods and oligochaetes, were lower in open sections of burned marshes compared to unburned marshes. The researchers attributed lower densities and biomass of these invertebrates in burn areas to mortality due to vegetation removal, desiccation, or elevated soil temperatures.

The existing evidence supports the long-standing assumption that winter burning in coastal marshes does attract waterfowl; the evidence is strongest for geese. However, the mechanism for the attraction and the benefits accrued to the waterfowl populations remain unclear. Winter burning removes undesirable plants species and promotes growth of preferred waterfowl plant foods under some conditions (O'Neil 1949, Chabreck 1981, Pendleton and Stevenson 1983, Turner 1987, DeSzalay and Resh 1997, Stevenson et al. 2001) but not others (Flores and Bounds 2001, Gabrey and Afton 2001). Effects of burning on the nutritional quality of marsh vegetation appear ambiguous

(McAtee et al. 1979, Schmalzer and Hinkle 1993). The scant studies on marsh invertebrate community response are also inconclusive (Matta and Close 1972, Turner 1987, DeSzalay and Resh 1997). Plant and invertebrate community changes to burning are variable and likely depend on environmental factors such as season of burn, fire intensity, water depth and salinity, and post-burn rainfall. Although studies of vegetative productivity, plant nutritional quality, and invertebrate abundance are important, it is also necessary to determine if such changes indicate a change in habitat quality and benefit the organisms such as birds that forage on the vegetation or invertebrates. Habitat quality might be assessed by quantifying in these improved areas the: (1) activity or energy budgets, (2) foraging effort and behavior, (3) physiological indices such as sufficient energy stores for migration or breeding activities, (4) or movement among burned and unburned patches. We are unaware of rigorous fire studies that have been designed to answer these questions.

Effects of Prescribed Burning on other Marsh Birds

Given the lack of information on waterfowl response to burning in coastal marshes, it is not surprising that few quantitative studies address the effects of fire on other (non-game) birds (Rotenberry et al. 1995). Herein we summarize the few quantitative studies and include results of qualitative observational work on the effects of coastal-marsh fire on breeding and wintering coastal-marsh birds, including passerines and raptors.

Emberizidae (sparrows)

The Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*) is an endangered passerine whose relationship to fire has come under scrutiny due to recent population declines. Although now restricted to inland subtropical marshes and seasonally flooded prairies of southern Florida (Werner 1975), this subspecies of a primarily coastal-marsh species is one of the best researched passerines with respect to the effects of habitat burning, so we will review these studies in some detail. Werner (1975) tracked sparrow populations in two locations at Everglades National Park, Florida, for which historical fire data indicated that these areas had experienced wildfires in 1969 and 1972. A fire in 1974 also burned one of the two locations. The author reports that at each of these sites breeding densities of sparrows were sparse during the first year post-burn, but increased 3–4 yr post-burn. At one location, breeding densities declined during the fifth breeding season, post-burn. Werner (1975) suggests that sparrows decline in numbers immediately post-burn, then increase in density 3–4 yr after a fire, and may abandon a site after the sixth year after a fire as vegetation density increases. He speculates that optimum sparrow habitat could be maintained if marshes are burned every 4–5 yr. Werner (1975) based his conclusions on a very small sample size without control sites. Of additional interest in this study was the direct observation of individually marked sparrows fleeing the flaming front of a winter wildfire into adjacent unburned areas and flying in circles in areas of smoke and flames. Although sparrow density in the burned area returned to pre-burn levels by the next breeding season, none of the marked sparrows returned.

Taylor (1983) censused Cape Sable Seaside Sparrows at Taylor Slough, Florida. The study design was a randomized-block design, with three different prescribed burn treatments (annual, 3-yr rotation, 5-yr rotation) allocated to a set of three, 20-ha plots; a set of plots was located at each of three different marsh locations (blocks). In addition, a single control site had not been burned for 10 yr, and was not burned during the study. However, the season of prescribed fires differed between blocks, e.g., burns at one marsh were applied only in December (annually, every 3 yr, and every 5 yr), while at another marsh area, all burns were conducted in July. Therefore, the study had no true replication of treatments.

Taylor (1983) reported that on burned sites with deeper soils (>20 cm), vegetation recovery was more rapid and sparrow populations recovered and peaked earlier than on sites with shallower soils. The former populations re-colonized rapidly and began to decline 4 yr post-fire. In burned sites with shallow soils, plant biomass recovery was slower and sparrows did not even re-colonize these areas until about 4 yr post-fire and densities remained low for up to 10 yr. In addition, post-fire breeding territories were clumped, presumably because birds were forced to use marginal areas following large fires (Taylor 1983). Fires created long edges in which birds concentrated during the first breeding season post-fire and created a mosaic of unburned patches in which birds nested. Taylor (1983) concluded that fire regimes shorter than 8–10 yr could be detrimental to Cape Sable Seaside Sparrow populations.

Curnutt et al. (1998) provides the most comprehensive analysis of fire's effects on Cape Sable Seaside Sparrows. The authors analyzed

227 sites (as surveyed on a 1-km grid within Everglades National Park) that contained Cape Sable Seaside Sparrows between 1992–1996, and for which dates and spatial extent of fires from 1982–1996 were known. Sites had experienced fires caused by lightning strikes, unplanned human ignitions, or prescribed fire activities. The analysis did not control for likely differences beside fire frequency and time since last fire between sites (Walters et al. 2000).

For each site and for each sparrow survey, Curnutt et al. (1998) determined the frequency of fires, the number of days since the most recent fire, and whether the most recent fire occurred during the wet (1 June–31 October) or dry (1 November–May) season. They found that sparrow densities were lowest at sites that had a dry-season fire as their most recent fire occurrence. In contrast to Werner (1975) and Taylor (1983), Curnutt et al. (1998) found no evidence that sparrows abandon a site immediately post-burn and suggest that sparrows are able to occupy marsh sites immediately following a burn due to the patchy nature of natural fire in the Everglades. Curnutt et al. (1998) also found that sparrow populations increase in density with no evidence of eventual declines for up to 10 yr following a fire event. For those sites that held sparrows over the entire period of record, fire frequency ranged from one–seven fires/10 yr, with a mean of 2.97 fires/10 yr. Sparrow densities were highest where there had been one–two fires over the previous 10-yr period, lower where fire frequencies were greater or equal to three–six fires/10 yr, and absent from sites that were burned more than seven times in 10 yr. The authors' findings support those of Taylor (1983) — sparrows will use sites that had burned 10–12 yr previously — and contradict Werner's (1975) suggestions that sparrows decline in numbers and will abandon a site after the sixth year after a fire. The primary conclusion from this study is that frequent fires are harmful to Cape Sable Seaside Sparrows and may be the cause of declines in populations on the northeastern edge of the sparrow's range. Curnutt et al. (1998) also suggested that that the artificially drained nature of the coastal prairies in this region increased the flammability of these habitats, amplifying negative effects on Cape Sable Seaside Sparrows.

In summarizing past studies on the Cape Sable Seaside Sparrow, Walters et al. (2000: 1104) state that catastrophic sparrow population declines in the past decade cannot be directly attributed to fire. Nevertheless, authors of that paper concluded that fire has affected sparrow populations by altering habitat suitability, as demonstrated by direct evidence of immediate, negative effects of burning on sparrow populations, and the reported role of fire in periodically maintaining open habitats attractive to the sparrows (Werner 1975, Taylor 1983, Werner and Woolfenden 1983, Curnutt et al. 1998). Walters et al. (2000) analyzed population census data in Everglades National Park from 1981–1998 and concluded that two northeastern populations appear to have declined due to abnormally high fire frequencies, and that dry-season fires pose greater threats to breeding birds than wet-season fires. They cite evidence that increased fire frequency has been a direct result of anthropogenic water diversions, subsequent reduced hydroperiods, and exposure to human-caused dry-season fire. The authors speculate that occasional fire is necessary for continued occupancy of a marsh by Cape Sable Seaside Sparrows because it inhibits invasion by woody shrubs, including non-natives such as paper barked tea tree (*Melaleuca quinquenervia*; Curnutt et al. 1998), which can eliminate sparrow nesting habitat. Finally, Walters et al. (2000) stress the need to incorporate prescribed burning into rigorous experimental studies, including studies of the dispersal patterns of the birds through telemetry, to determine the direct effects of fire frequency on habitat and sparrow populations.

Effects of fire on other coastal sparrow populations, such as the Louisiana Seaside Sparrow (*Ammodramus maritimus fisheri*) and Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*), have received recent attention (Gabrey et al 1999, Gabrey and Afton 2000, Gabrey et al. 2001). Gabrey et al. (1999) surveyed bird-species composition and abundance and vegetation structure on 14 pairs of winter-burned and unburned marshes in Louisiana. Winter bird surveys were conducted immediately following burns and again one full year post-fire. Immediately following burn treatment, plant community visual obstruction and percent cover were lower in burned plots; at 1 yr post-burn, vegetation structure was similar between treatment and control plots. Wintering Seaside Sparrows were absent immediately following burns, but were present in unburned marshes; Seaside Sparrows were present in burn-treatment plots 1 yr post-burn. Nelson's Sharp-tailed Sparrows, a migratory species that winters exclusively in coastal marshes (Greenlaw and Rising 1994), were present in burned marshes during the first winter but only in scattered patches of unburned vegetation; however, they were recorded frequently in unburned plots during both survey periods and in burn treatment plots 1 yr post-burn. The authors conclude that winter burning reduces the suitability of the marsh as winter habitat for these marsh-dependent sparrows, but only for a few months immediately following the burn.

Most studies of fire effects on birds rely on relative abundance as the response variable; rarely are demographic parameters such as nest success or survival addressed. Gabrey et al. (2002) used artificial nests to investigate effects of winter marsh burning on nest success of two coastal-marsh endemics—Louisiana Seaside Sparrows and Mottled Ducks (*Anas fuligula*). They recorded apparent nest success of nests containing quail eggs (to simulate sparrow nests) and chicken eggs (to simulate duck nests) in four pairs of burned and unburned marshes, during the breeding season prior to and following experimental burns. They found no difference in vegetation structure or success of either type of artificial nest in the post-burn breeding season. Although no effect of winter burns on artificial-nest success was detected, the authors caution that their study involved only four marshes and that the timing of burning may affect success of those birds that nest early in the season before sufficient vegetation re-growth has occurred (Gabrey et al. 2002).

Gabrey and Afton (2000) examined effects of winter marsh burning on Louisiana Seaside Sparrows nesting activity. Measurements were made during the breeding season (April–July) prior to experimental burns and during two breeding seasons post-burn. Male sparrows were absent from burned marshes during the start of the first breeding season after burns, but had reached abundances comparable to control marshes by June of that season. During the second breeding season post-burn, numbers of male sparrows were greater in burned marshes than in unburned marshes. Nesting activity indicators showed a similar but non-significant pattern in response to burning. The authors linked sparrow abundance and nesting activity to dead-vegetation cover, which was lower in burn plots during the first breeding season post-burn but recovered to pre-burn levels by the second breeding season post-burn. Gabrey and Afton (2000) speculated that reduced vegetation cover might provide less invertebrate prey and nest material for Louisiana Seaside Sparrows. During the study, the researchers recaptured birds banded as adults in unburned marshes during subsequent breeding seasons, but failed to recapture birds banded in burned marshes. The authors suggest that the sparrows move to nearby unburned marsh following a fire and that such displacement could affect short-term reproductive success by forcing dispersal into lesser quality habitats, increasing population density, interfering with pair bonds, and delaying territory establishment and nesting activities.

In other fire studies in the Chenier Coastal Plain in Louisiana, Gabrey et al. (2001) found that total abundance of sparrows (primarily Seaside Sparrows) did not differ between burned and unburned marshes during the first or third summers, post-burn, but were two times greater in burned than unburned marshes during the second summer post-burn. The peak in sparrow abundance coincided with the recovery of dead vegetation cover to pre-burn levels. Gabrey et al. (2001) concluded from both wintering and breeding season studies that periodic but infrequent fires that remove dense, dead vegetation benefit sparrow populations on the Chenier Coastal Plain.

Baker (1973) reported that two wildfires in December 1972 and January 1973 burned about 690 ha at St. Johns National Wildlife Refuge in Florida, leaving few patches of unburned sand cordgrass. Immediately following these fires, color-banded individuals of the now-extinct Dusky Seaside Sparrows (*Ammodramus maritimus nigrescens*) were displaced from burned areas. In early May, however, banded males reappeared and defended territories in burned areas. Baker (1973) speculates that rather than occupying small, unburned cordgrass patches within burn areas, the birds moved to nearby, unburned cover. Three birds banded on the area prior to burns were recaptured immediately after the burn in unburned cover, 900 m from their original locations.

Walters (1992) reported that in 1975, a fire intentionally set on private land escaped control lines and burned nearly 850 ha of Dusky Seaside Sparrow habitat on the St. Johns National Wildlife Refuge. Thirty-six male sparrows had occupied this area pre-fire; however, only seven were recorded post-fire. The refuge reported that six Dusky Seaside Sparrows escaped the fire to an adjacent private land area, which was subsequently burned by its owner. The sparrows then disappeared from the site.

Although difficult to quantify, fire may also have more direct effects on the survival of sparrows. Legare et al. (2000) captured and banded five Swamp Sparrows (*Melospiza georgiana*) on the St. Johns National Wildlife Refuge, in Florida. A sparrow banded on 20 March 1994 was recovered dead in burned sand cordgrass within 50 m of the original banding location on 5 January 1995, following a prescribed fire on the refuge. Although the authors report that the bird had most of its feathers burned, a conclusive cause of death was not reported.

Other passerines

In studies of wintering bird populations in coastal Louisiana marshes, Gabrey et al. (1999) found that several species of sparrows and wrens avoided recently burned marshes but reappeared one winter later. Common Yellowthroats (*Geothlypis trichas*) and Sedge Wrens (*Cistothorus platensis*) were absent from recently burned marshes, during the first winter, but present in unburned marshes. One year post-fire, Marsh Wrens (*Cistothorus palustris*) were found more frequently in unburned versus burned marshes. The authors concluded that winter habitat for several passerine species was reduced during the winter in which the burns occurred, particularly if a high proportion of the plot burned. In contrast, Boat-tailed Grackles (*Quiscalus major*) and Red-winged Blackbirds (*Agelaius phoenecius*) preferred recently burned plots, possibly because burns reduced visual obstruction and increased visual contact with conspecifics, and reduced ground cover, facilitating foraging for aquatic prey.

Gabrey et al. (2001) evaluated relative abundance of birds during the breeding season immediately following winter burns and for two consecutive breeding seasons thereafter. Structural vegetation characteristics (visual obstruction and percent cover) did not differ between burned and unburned plots by the first summer post-burn. Neither treatment affected bird species richness or species composition. Of the 10 most abundant bird species, only Sedge Wrens were absent from burned marshes but present in unburned marshes during the first post-burn breeding season. Sedge Wrens were present in burned marshes by the second breeding season post-burn. Total birds/survey for all species combined and for sparrows (primarily Seaside Sparrows) did not differ between burned and unburned marshes during the first or third summers post-burn, but were two times greater in burned than unburned marshes during the second summer post-burn, coinciding with the recovery of dead vegetation cover to pre-burn levels. The researchers concluded that managed burns for winter waterfowl foods appear compatible with maintaining populations of certain other marsh birds, provided that large contiguous marsh areas are not burned in any single winter, and >2 yr are allowed between burns.

Gabrey and Afton (2004) conducted multivariate analyses of breeding bird abundance in four pairs of burned and unburned marshes in the breeding season prior to experimental burns and in two breeding seasons post burn. Louisiana Seaside Sparrows, Red-winged Blackbirds, and Boat-tailed Grackles were the dominant species in these marshes. Winter burns dramatically lowered Seaside Sparrow abundance but increased blackbird and grackle abundance in the first breeding season post-burn. During the second breeding season post-burn, sparrow abundance increased and blackbird and grackle abundance decreased in burn treatment plots to the point where each variable was similar to pre-burn conditions (Gabrey and Afton 2004). Bird community changes were strongly correlated with percent cover of dead vegetation and live salt meadow cordgrass—plots with greater percent cover had greater sparrow densities and lower blackbird and grackle densities.

Raptors

Some research suggests that raptors use smoke and fire as a foraging cue, suggesting that raptors feed opportunistically upon prey either chased from cover by fire or left without cover by the burn (Baker 1940, Komarek 1969, Tewes 1984). Anecdotal evidence suggests that this occurs in marsh burns as well. Following two burns in gulf cordgrass communities at Aransas National Wildlife Refuge (ANWR), White-tailed Hawks (*Buteo albicaudatus*) reportedly dived through smoke to capture cotton rats (*Sigmodon hispidus*), pocket mice (*Perognathus* spp.), and grasshoppers (Acrididae) (Stevenson and Meitzen 1946). Tewes (1984) reported similar behavior during a 40-ha prescribed burn in gulf cordgrass at ANWR, when 14 White-tailed Hawks appeared near the fire, hovering near the ground and grasping prey in the ash. Other raptors noted soaring in the smoke column and hunting in the burned area included two Northern Harriers (*Circus cyaneus*), a White-tailed Kite (*Elanus leucurus*), an American Kestrel (*Falco sparverius*), and a Short-eared Owl (*Asio flammeus*). No raptors were noted during post-fire strip-transect counts, suggesting that the enhanced foraging opportunities afforded the raptors was extremely short lived. Tewes (1984) speculated this could be due to extensive and complete removal of vegetative cover forcing small mammals, snakes, and other prey species to abandon the site.

The Possible Role of Lightning Fires

Lightning-ignited fires are a common occurrence in coastal marshes, especially on the Gulf Coast and southeast Atlantic Coast. Such fires likely would have little detrimental impact on bird species endemic to these areas. Some evidence exists to support the idea that Seaside

Sparrow habitat, for example, in the Gulf Coast and southeast Atlantic Coast depends on periodic but relatively infrequent fires (Taylor 1983, Gabrey and Afton 2000); we are unaware of published studies that address effects of burning on Seaside Sparrows in the northern part of their range—habitats which naturally experience a lower frequency of lightning-ignited fires. In southern marshes in the absence of fire, vegetation density increases to a point at which the marsh is no longer suitable to Seaside Sparrows. Immediately post-fire, it appears that while numbers of breeding Seaside Sparrows and Marsh Wrens and wintering Nelson's Sharp-tailed Sparrows are reduced, these species may subsequently show a positive response for one or more years following the immediate post-burn season. However, as fire frequency increases (i.e., to every year), fires suppress vegetation density, rendering both breeding and wintering habitat unsuitable for several passerines (Common Yellowthroats and Sedge Wrens) including species dependent upon coastal-marsh habitats (Seaside and Nelson's Sharp-tailed sparrows). Frequent fires would likely also increase habitat availability for widespread habitat-generalist species such as blackbirds and grackles at the expense of habitat for endemic Seaside Sparrows or Nelson's Sharp-tailed Sparrows (Gabrey et al 1999, Gabrey and Afton 2004). Therefore, periodic but infrequent fires (Gabrey et al. 2001), possibly mimicking the historic fire regimes of these coastal habitats, are probably most likely to benefit sparrow and other passerine populations on the southeast coast. Whether such patterns occur in coastal marshes outside of the Southeast is unknown. Few studies have addressed effects on demographic parameters.

No studies to date have adequately addressed the likely effects of fire, either natural or prescribed, on other marsh-bird groups, such as raptors or colonial waterbirds. Research on population responses of these species to controlled fires in marsh habitats using standard methodologies and sound statistical design is needed to increase our understanding of the effects of prescribed burning on the entire coastal-marsh avian community.

Mechanisms of Change in Coastal Marsh-bird Communities in Response to Fire

Because few scientific studies have focused on the effects of prescribed burns on marsh birds, the best we can do at present is to speculate about the potential effects of fire on various species and recommend that these potential relationships be investigated fully. This has been done based upon documented fire effects on coastal-marsh vegetation and known breeding or wintering habitat requirements of coastal-marsh birds. Prescribed burns may indirectly affect bird populations through a variety of pathways. Some of the more obvious mechanisms include direct or indirect effects on vegetation structure, changes in amount and distribution of open water, or changes in availability and quality of plant or animal food items. A summary of potential mechanisms is presented in Table 1. We emphasize that these are possible short-term impacts, based on the few quantitative studies that have been published. Long-term impacts have not yet been investigated. For example, Seaside Sparrow numbers may be temporarily reduced immediately following a fire but may increase for a period afterwards. In addition, many other variables such as water depth, salinity, and precipitation could influence vegetation responses to fire.

EFFECTS OF STRUCTURAL MARSH MANAGEMENT ON COASTAL-MARSH BIRDS

In addition to prescribed burns, marsh managers frequently alter marsh habitat by interrupting normal tidal cycles and manipulating the timing, depth, and duration of flooding, and salinity. Structural marsh management (SMM; Chabreck 1988, U.S. Environmental Protection Agency 1998) involves the use of weirs, dams, tide gates, canals, or other structures that alter the hydrology of coastal marshes. These structures allow managers to manipulate water depth, timing of flooding or drying, and salinity, to achieve the following objectives:

1. Prevent encroaching isohaline lines from changing the distribution of marsh types.
2. Encourage production of preferred waterfowl and muskrat foods while discouraging growth of plants with less waterfowl value (primarily cordgrass species).
3. Create or maintain shallow water or open water areas.
4. Reduce loss of existing marshes to erosion, sea-level rise, and saltwater intrusion.
5. Create new emergent wetlands from previously inundated areas.
6. Provide for ingress and egress of selected estuarine organisms (e.g., shrimp and larval fish).
7. Control biting insect populations (mosquitoes).

Although the scientific and management communities have begun to evaluate the effectiveness of SMM on coastal-marsh ecosystems,

TABLE 1. EFFECTS OF PRESCRIBED BURNS ON VEGETATION STRUCTURE AND POSSIBLE IMPACTS ON MARSH AVIFAUNA.

Effect of prescribed burn	Marsh appearance	Impact	Guild(s) potentially affected	Representative species
Cover burns reduce or remove emergent vegetation	Vegetation height and density temporarily reduced due to loss of standing vegetation	+	Waterfowl, gregarious, visual surface feeders	Snow Goose (*Chen caerulescens*), blackbirds (Icteridae).
Frequent fires inhibit woody vegetation establishment	Lack of shrubby cover, perches (live or dead) absent, standing dead vegetation cover removed, canopy removed	–	Species nesting in or foraging from strong perches; species nesting in shrubs or otherwise require woody structure	Colonial waterbirds, Belted Kingfisher (*Ceryle alcyon*), Peregrine Falcon (*Falco peregrinus*), Swamp Sparrow (*Melospiza georgiana*), American Bittern (*Botaurus lentiginosus*).
Cover burns reduce or remove surface litter	Marsh surface exposed, no decumbent vegetation above water level, cover for small mammals and tunnels removed	–	Species that nest in/on this material or that nest on mats of previous year's grasses; species that prey on rodents	Black Rail (*Laterallus jamaicensis*), Black Tern (*Chlidonias niger*), Forster's Tern (*Sterna forsteri*), Least Bittern (*Ixobrychus exilis*), Northern Harriers (*Circus cyaneus*), Short-eared owl (*Asio flammeus*).
		+	Species that forage on ground no longer inhibited by dense vegetation	Seaside Sparrow (*Ammodramus maritimus*)?
Peat or root burns expose underlying mineral soil	Open water more abundant; emergent vegetation replaced by shallow to moderately deep ponds; long-term inundation inhibits re-vegetation	–	Species using emergent vegetation in unbroken marsh; species that nest or forage on ground	Sedge Wren (*Cistothorus platensis*) and Marsh Wren (*Cistothorus palustris*), Red-winged Blackbird (*Agelaius phoeniceus*), Common Yellowthroat (*Geothlypis trichas*), Seaside Sparrow (*Ammodramus maritimus*), other sparrows (*Aimophila* spp.).
	Ponds remain as open water, submerged vegetation increases; or pond bottoms exposed due to tides or drought	+	Species using broken, hemi-marsh or mudflats for foraging or loafing	American Coot (*Fulica americana*), Pied-billed Grebes (*Podilymbus podiceps*), waterfowl, waders, shorebirds.
Fire suppression	Dense emergent vegetation and litter accumulation, woody shrubs colonize; small open-water ponds obscured	?		

few quantitative studies have been published. The greatest extent of SMM application to coastal marshes are in Louisiana and South Carolina (Day et al. 1990, U.S. Environmental Protection Agency 1998); consequently, most published studies of impacts on wetland vegetation and wildlife comes from these two states. We summarize below the current state of knowledge regarding effects of hydrology manipulations on coastal-marsh birds.

Bird Use of Impoundments During Winter

Waterfowl

As with prescribed burns, habitat management for waterfowl, particularly wintering habitat, has been a major justification for SMM. SMM became a common practice in the 1950s and the first evaluation of its effectiveness was presented by Chabreck (1960). He reported that prior to construction of impoundments in 1954, about 75,000 waterfowl wintered on Rockefeller State Wildlife Refuge in southwest Louisiana. In post-construction surveys, however, >320,000 waterfowl wintered in the new impoundments, with another 120,000 in surrounding areas within the refuge. He attributed the dramatic increase in numbers to increased food production and constant shallow water. Chabreck et al. (1974) later compared duck use of impoundments with that of control areas—unimpounded marshes and marshes that had been drained and converted to pasture. They reported that in general duck usage was highest in freshwater impoundments; numbers varied with vegetation type, water depth, and time of year.

Gordon et al. (1998) compared relative duck abundance between abandoned rice fields that were diked and managed for waterfowl and adjacent tidal (unimpounded) wetlands in South Carolina. Winter use of managed wetlands by seven dabbling duck species was greater than expected; winter use of unmanaged tidal marshes was less than expected for six of the seven species, American Black Duck (*Anas rubripes*) being the exception. The authors attributed these findings to differences in hydrology of the two types of marshes. Tidal marshes are flooded and drained daily; hence, availability of open water for foraging is unreliable. In addition, the intertidal period, in which the marsh surface is exposed, allows for denser vegetation growth that inhibits waterfowl access. In managed marshes, however, water level may remain relatively constant at a depth suitable for waterfowl foraging and the continuous flooding may prevent dense vegetation growth while maintaining large areas of open water suitable for dabbling duck foraging (Gordon et al. 1989). Finally, Gabrey et al. (1999) conducted five aerial counts of white geese (Snow Goose and Ross' Goose) wintering in managed marshes in southwestern Louisiana from December 1995 to February 1996 and found several flocks present in recently burned, unimpounded marshes or recently burned, impounded marshes; however, no description of goose behavior (e.g., foraging was reported). No geese were observed in unburned, unimpounded marshes.

Other bird species

Most assessments of the value of structural marsh management evaluate relative abundance of birds during winter or migration periods, and focus upon birds associated with ponds, mudflats, or open water, i.e., waterfowl, shorebirds, herons, egrets, gulls, and terns. Habitat within impounded marshes may supplement natural habitat in unmanaged marshes or provide protection from oil spills or other coastal catastrophes. Weber and Haig (1996) counted shorebirds and waterfowl in managed and unmanaged coastal marshes in South Carolina. Managed marshes were drawn down through April then re-flooded in June, July, or August. They found that throughout the winter and spring seasons (January–May), shorebird density at high tide (when natural marshes were flooded) was greater in managed exposed mudflats than in natural marshes. Even during low tides, shorebird density was generally greater in managed than in natural marshes. They concluded that managed marshes provide alternative or supplementary feeding or roosting habitats during high tides or adverse weather. Differences in shorebird density were attributed to consistently shallower water depth and greater invertebrate occurrence in managed marshes.

Impoundments in South Carolina are typically managed for production of wigeongrass (*Ruppia maritima*), spikerushes (*Eleocharis* spp.), bulrushes., and other waterfowl foods through spring drawdowns and summer re-flooding (Epstein and Joyner 1988). Consequently, vegetation composition differs between impounded marshes and natural tidally influenced marshes, which are dominated by big cordgrass (Epstein and Joyner 1988). Epstein and Joyner (1988) compared relative abundance of waterbirds in six managed (impounded) and two unmanaged (unimpounded) South Carolina marshes. Except for Clapper Rails (*Rallus longirostris*) and Northern Harriers, most bird species groups (particularly shorebirds, waterfowl, and waders) were more abundant in managed than in unmanaged marshes. The authors felt that the greater number of species and of individuals in managed marshes was due to moist soil conditions that increase access to invertebrates and seeds and to fish prey concentrated in progressively smaller ponds.

The above studies have addressed to some extent the question of whether waterbird use differs between impounded and natural or unimpounded marshes. However, birds that do not use open water or mudflat habitats but nest or forage in the emergent vegetation (e.g., passerines, rails, some herons, and egrets) have received less attention. Gabrey et al. (1999) addressed the issue of wintering passerines in impounded versus unimpounded coastal marshes in Louisiana. They found that some species (Seaside and Nelson's Sharp-tailed sparrows) were found almost exclusively in unimpounded marshes, possibly because of a preference for shorter vegetation and because ground-foraging behavior required exposed marsh surfaces. However, impoundment effects were confounded with salinity effects. This raises the question of the importance of vegetation variables in habitat selection. While most avian ecologists agree that vegetation structure is an important criterion, other factors such as invertebrate abundance, salinity, competitors, or predators may influence bird community composition differently in managed compared to unmanaged marshes.

It is interesting to note that three of the species listed above as being more abundant in unimpounded, natural marshes are coastal-marsh endemics (Clapper Rail, Seaside Sparrow, and Nelson's Sharp-tailed Sparrow). Consequently, although impounded marshes benefit a large suite of species, conservation of unimpounded coastal marshes is necessary for coastal-marsh endemics.

Bird Use of Impoundments during the Breeding Season

Waterfowl

Several waterfowl species breed in coastal marshes of the northeast Atlantic coast (e.g., Mallard [*Anas platyrhynchos*], American Black Duck, Blue-winged Teal [*A. discors*], and Gadwall [*A. strepera*] although most such populations are small (Bellrose 1976, Sauer et al. 2004). In southern marshes Mottled Ducks nest in large numbers (Moorman and Gray 1994). However, we are unaware of any published studies that address effects of marsh impoundment on any waterfowl nesting in coastal marshes.

Other bird species

Bird use of impounded and unimpounded marshes during the breeding season has received little attention. Brawley et al. (1998) compared breeding bird abundance in two restored (formerly impounded) marshes with that of three reference sites in Connecticut. They found that marsh specialists—those species that breed only in coastal marsh (Seaside Sparrow, Willet [*Catoptrophorus semipalmatus*], Marsh Wren, and Saltmarsh Sharp-tailed Sparrow [*Ammodramus caudacutus*])—were more abundant in the restored marshes than in the reference marshes. Three of these four species are listed as threatened (Willet) or of special concern (both sparrows), in the state. The authors state that these species were absent from the restored marshes prior to the re-establishment of tidal activity. Brawley et al. (1998) suggest that the frequent tidal inundation and exposure maintained the low-marsh community dominated by short-form smooth cordgrass in which Seaside and sharp-tailed sparrows prefer to nest. Marsh areas in the high-marsh zone are not flooded frequently enough or of sufficient duration to allow for establishment of short-form smooth cordgrass. Marsh areas below the low-marsh zone are permanently flooded and so also do not support smooth cordgrass.

Brawley et al.'s (1998) findings, that marsh impoundment benefits a diversity of bird species but limits habitat availability for marsh-specialist species, supports results from other regions. In New Jersey, Burger et al. (1982) found greater biomass and diversity of birds in impounded marshes compared to ditched or unimpounded marshes. However, species that nest exclusively in coastal marshes (Seaside and sharp-tailed sparrows, and Clapper Rails) were recorded only in unimpounded marshes. They (Burger et al. 1982) stated that while generalist or relatively abundant species used impounded marshes, maintaining natural unimpounded coastal marsh was necessary for the conservation of coastal-marsh specialists.

Gabrey et al. (2001) detected different bird communities present in impounded and unimpounded marshes in southwestern Louisiana. Red-winged Blackbirds and Boat-tailed Grackles were more abundant in impounded than in unimpounded marshes, whereas Seaside Sparrows were more abundant in unimpounded than in impounded marshes. The authors attributed these differences to vegetation structure and hydrology. Vegetation of impounded marshes included patches of cattails (*Typha* spp.) and common reed (*Phragmites australis*); blackbirds and grackles readily nested in these patches of tall vegetation. Unimpounded marshes, on the other hand, were dominated by low-growing salt meadow cordgrass and inland saltgrass. These two plant species form a low, densely interwoven canopy of relatively uniform height (<1 m), which presumably provides protection from predators for the ground-foraging Seaside Sparrow. In addition, the surface of impounded marshes is often continually flooded. The marsh surface of unimpounded marshes is exposed during part of the tidal cycle; hence sparrows are able to forage on the ground.

Mechanisms of Change in Coastal-marsh Bird Communities in Response to SMM

Structural marsh management influences coastal-marsh bird communities through its effects on open water or mudflat availability, timing and frequency of flooding, modification of the plant community, and salinity (Table 2). In general, SMM appears to benefit waterfowl and other species such as herons and blackbirds that are attracted to open water, exposed mudflats, lower salinity, or tall, dense vegetation. This likely is due to reduced diurnal variability in flooding due to the exclusion of tides. Thus, impoundments that are drawn down to moist soil conditions maintain those conditions until managers flood the impoundment. In contrast, unimpounded marshes flood at daily high tides; mudflats are then exposed for only about half a day. Disruption of tidal hydrology often increases the area of open water and decreases the amount of grass and short herbaceous vegetation. Consequently, although SMM provides habitat for a diversity of bird species, certain species such as Seaside Sparrows, sharp-tailed sparrows, and Clapper Rails, that require grassland-like conditions and alternating cycles of inundation and exposure of the marsh surface, likely do not benefit from impoundments.

EFFECTS OF MOSQUITO CONTROL AND OPEN-MARSH WATER MANAGEMENT ON COASTAL-MARSH BIRDS

The history of coastal-marsh alteration to control the mosquito as a human pest and disease vector, or for agriculture (livestock grazing and salt-hay farming), goes back centuries in the US (see Daiber 1987 for a review). During the early part of the 20th Century, the Old World notion of draining much of the high marsh was popular, and thus began an ambitious campaign of ditching both by hand and with horse or mule during the 1930s and 1940s (Daiber 1987, Chabreck 1988). Ditches approximately 2–4 m wide and 1–2 m deep were dug in parallel fashion every 50 m in high-marsh areas from the upland-marsh ecotone bayward. The amount of Atlantic Coast marsh altered by this method has been estimated at about 90% and extends from Massachusetts to Florida (Tiner 1984, The Conservation Foundation 1988).

With the increasing awareness of the high productivity of coastal marshes in estuaries (e.g., the rise of the Odum school in ecology during the late 1950s and 1960s) and recognition of the importance of natural tidal flooding and hydrology to the integrity of marsh systems, improvements in marsh management were attempted. Experimentation began in New Jersey with a method that became known as open-marsh water management (OMWM) (Cottam 1938, Ferrigno and Jobbins 1968). This method substitutes biological control of mosquito larvae using predatory fish, and by altering mosquito egg-laying habitat, instead of drainage and pesticide applications. In short, mosquito depressions in the marsh not connected to existing ditches are either connected to ditches using new spurs or, if the depressions are very dense, a pond is constructed. The ponds originally were small (<0.05 ha), deep (often >60 cm), and had a deeper area or sump added to enable mummichog (*Fundulus* spp.) to survive during summer droughts. The material dredged to create the new ditches and ponds was spread thinly over the marsh surface to reduce the prospects that common reed (*Phragmites australis*) or woody vegetation such as marsh elder (*Iva frutescens*) might invade. Later, in other regions such as Delaware, the practice expanded but some modifications were added, such as adding sills to the ends of large ditches to retain ground water (Meredith et al. 1987). In spite of the popularity of the method in New Jersey and Delaware and its expansion to other states, little research on effects on wildlife has been performed and published in the peer-reviewed literature (Erwin et al. 1994 and references therein). In addition, Wolfe (1996) provided a summary of the effects of OMWM on birds, fish, mammals and other tidal resources in the Atlantic region. The practice remains somewhat controversial among wetland ecologists and federal and state resource managers because of concerns for converting and altering pristine marsh (Table 3).

Post (1974) was one of the earliest to demonstrate the behavioral and ecological effects of ditching on marsh birds, specifically Seaside Sparrows, revealing that ditches could alter the shape and sizes of territorial boundaries.

TABLE 2. EFFECTS OF STRUCTURAL MARSH MANAGEMENT (SMM) ON VEGETATION STRUCTURE AND POSSIBLE IMPACTS ON MARSH AVIFAUNA.

Effect of SMM	Marsh appearance	Impact	Guild(s) potentially affected	Representative species
Marsh ponds not subject to tides	Ponds retain water year-round; ratio of open water to emergent vegetation increases, submerged vegetation increases	+	Species that feed or loaf on shallow to moderately deep ponds	Waterfowl, coots, herons, egrets, terns.
	Marsh surface inundated year-round; access to invertebrates limited?	–	Ground-foraging or ground-nesting species	Seaside Sparrow (*Ammodramus maritimus*), Sedge Wren (*Cistothorus platensis*).
Timing of drawdowns controllable, not dependent on droughts; wetland manager actively conducts seasonal draw downs	Open mudflats may be available during spring or fall migration; summer drawdowns may enhance production of seed-producing annual plants; open water may be available throughout winter	+		Shorebirds, waterfowl, gulls.
	Marsh surface may be inundated year-round; access to invertebrates may be limited?	–	Ground-foraging or ground-nesting species	Seaside Sparrow, Sedge Wren?
	Availability of open water habitat may be limited during drawdowns	–	Species that feed or loaf on shallow to moderately deep ponds	Waterfowl, coots, herons, egrets, terns.
Flood-tolerant vegetation dominates; wetland manager favors out deep-water management regime	Cattail (*Typha*) or reeds (*Phragmites*) distribution increases	+	Species that nest in tall dense vegetation	Red-winged Blackbird (*Agelaius phoeniceus*), Boat-tailed Grackle (*Quiscalus major*), Marsh Wren (*Cistothorus palustris*), Common Yellowthroat (*Geothlypis trichas*).
	Short vegetation (*Distichlis* spp., salt meadow cordgrass) distribution decreases	–	Species associated with grassland-like habitats	Seaside Sparrow, Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*).

TABLE 3. POTENTIAL ECOLOGICAL EFFECTS OF OPEN-MARSH WATER MANAGEMENT ON COASTAL EMERGENT MARSHES OF THE ATLANTIC COAST.

Negative effects	Positive effects
Loss of salt meadow cordgrass habitat for Seaside (*Ammodramus maritimus*) and sharp-tailed sparrows (*Ammodramus nelsoni* and *A. caudacutus*); loss of short-form smooth cordgrass (*Spartina alterniflora*),	Reduction of mosquito breeding sites.
Fragmentation of inner marsh with pools and radials; exacerbation of erosion and marsh loss in the face of sea-level rise	Increased forage fish populations and enhanced waterbird (wading birds, shorebirds) feeding habitats.
Compaction of emergent marsh due to operation of heavy equipment on marsh surface	Restoration of hydrology (with ditch plugging).
Invasion of shrubs, (*Iva* spp., *Baccharis* spp.), and reeds (*Phragmites australis*) due to slight elevation changes; change in vegetation community structure	Augmentation of perches and nesting substrates for passerines (marsh sparrows and wrens), wading birds.

For larger waterbirds, more recent studies in California have revealed that under certain circumstances, waterfowl use of marshes originally ditched and then diked for mosquito control can achieve positive results for both objectives (Batzer and Resh 1992). Along the Atlantic Coast, studies in New England demonstrated that draining of high marshes reduced their use by waterbirds because of the loss of ponds and pannes (Clarke et al. 1984, Brush et al. 1986, Wilson et al. 1987).

Other, early studies often examined marsh-alteration effects only at one local site and only on one or a few species, such as Herring Gulls (*Larus argentatus*; Burger and Shisler 1978) or Clapper Rails (Shisler and Schultze 1976). A more comprehensive analysis of OMWM effects on waterfowl at five New Jersey sites from 1959–1984 was attempted (Shisler and Ferrigno 1987); however, counting techniques and personnel changes rendered interpretation of the results difficult.

In a study of effects of OMWM on waterbirds in New Jersey, Erwin et al. (1994) determined year-round relative abundance of waterfowl, shorebirds, waders, gulls, and terns in ponds in OMWM-managed marshes, unmanaged tidal ponds, and managed impoundments (>400 ha). They found that spring and summer densities of American Black Ducks were greatest in the two large impoundments when compared to OMWM and tidal ponds.

In New England, several authors monitoring shorebirds, wading birds, and waterfowl have concluded that use of marsh sites treated with OMWM resulted in little difference when compared with sites with natural ponds. However, the method in New England did not include creation of new ponds (Clarke et al. 1984, Brush et al. 1986, Wilson et al. 1987). In Delaware, a 2-yr study by Meredith and Saveikis (1987) revealed that waterfowl use of OMWM ponds was only about one half that of natural ponds. The conclusions of that study are problematic however, because natural ponds were larger than were OMWM ponds. Walbeck (1989) conducted a study with limited information (only conducted for 1 yr) on the Eastern Shore of Maryland where large impoundment use by waterfowl was greater than use of OMWM ponds.

Several studies conducted in the mid-Atlantic region, examining many waterbird species, revealed that sizes of ponds and the water/marsh ratio of the study site were the most important determinant of use. Burger et al. (1982) examined six different marsh sites in New Jersey and found high use of larger ponds by some shorebird and wading bird species; however, they cautioned that adding ponds to the high marsh could adversely affect breeding Clapper Rails. Erwin et al. (1991) found among nine marsh sites in three states that the water/marsh ratio was positively correlated with use by waterfowl, and separately, American Black Ducks, but pond number was not. Larger ponds (>0.25 ha) tended to be used more than smaller ponds by most bird species, but no treatment effect (OMWM vs. natural pond) was found. In a later experimental study at Forsythe National Wildlife Refuge in New Jersey, Erwin et al. (1994) compared use by larger waterbirds of OMWM, small natural ponds, and nearby impoundments. They reported results that varied by guild and season. Higher densities were not always found in larger ponds for waterfowl, but this did seem to be the case for spring-summer shorebirds. When comparing small pond use (both OMWM and natural) with impoundment use, however, American Black Ducks and other waterfowl used impoundments in higher densities for both fall and winter feeding and nesting than they did small marsh ponds. They recommended that a smaller number of larger ponds be created in the high marsh if mosquito control is deemed necessary, and that ponds have shallow and sloping sides to accommodate shorebird, wading bird, and rail use. The authors also concluded that in areas near large impoundments, small water bodies would add little waterbird habitat value.

ANIMALS AS MARSH ARCHITECTS/ MANAGERS (AND THEIR MANAGEMENT)

Although wildlife managers tend to think of marsh management as a strictly human endeavor, many animal species have demonstrated quite remarkable abilities to manipulate the structure, and hence functions, of marshes to differing degrees (Table 4). In some regions, as their populations have increased, some of these species have created conditions considered undesirable from the perspective of resource managers. Thus, managing the animal managers has become simultaneously a challenge and an ethical paradox, i.e., managing the marsh environment for human values is acceptable but for other animals to do so requires corrective (often lethal) measures (Table 5). We will explore and summarize some of the major aspects of animal architect activities in the US in the following sections.

Birds

The effect of marsh grazing by the Snow Goose can be significant in coastal marshes, because the birds typically pull up the aboveground stems to gain access to the rhizomes (Belanger and Bedard 1994, Jefferies and Rockwell 2002). In brackish marshes, geese tend to uproot primarily bulrush species while in saltmarshes along the Atlantic, the principal plant affected is smooth cordgrass. Larger patches of denuded marsh were referred to as eat-outs.

In the early years of study (1940s–1970s) of the Snow Goose, such goose eat-outs in winter were believed to be beneficial to wildlife, as apparently they opened up parts of the monotypic marshes and allowed access for feeding by a variety of other birds and fur bearers (Lynch et al. 1947, Chabreck 1988). In fact, small patches of eat-outs in the cordgrass marshes of New Jersey and Delaware, which make small fishes and invertebrates more available to predators, can attract over six species of feeding spring migrant shorebirds, as

Table 4. Examples of major animal species that act as marsh architects in modifying the structure of coastal marshes (primarily in the United States).

Species	Area[a]	Effects on marsh (at high densities)	Effects on birds[b]
Snow Goose (*Chen caerulescens*)	East and Gulf coasts	Large eat outs of smooth cordgrass (*Spartina alterniflora*),	- for breeding rails, marsh sparrows, terns + for shorebirds and wading birds.
Muskrat (*Ondatra zibethicus*)	US wide	Eat outs especially Olney threesquare (*Schoenoplectus americanus*)	+ for waterfowl (roosting), open-water species, - for rails, marsh sparrows, waterfowl (feeding).
Nutria (*Myocastor coypus*)	LA, TX, MS, MD	Destruction of bulrushes (*Schoenoplectus* spp.); fragmentation of eat-outs	+ for waterfowl, open-water species, - for rails, marsh sparrows.
Horses (*Equus caballus*)	Southeast US islands (MD–GA), southern Europe	Reduced structure, trampling reduces cover and destroys nests	+ for total species richness of birds; - for nesting gulls, and total *numbers* of birds.
Cattle/sheep (*Bos taurus/Ovis aries*)	Atlantic and Gulf coasts in US; nearly global (cattle)	Trampling reduces both annual grasses and invertebrates, destroys nests	- for wintering waterfowl and shorebirds, rails due to reduced food.

[a] State names are abbreviated.
[b] + indicates a benefit for the target species/group, whereas a - sign indicates a negative effect.

TABLE 5. MANAGEMENT METHODS EMPLOYED TO CONTROL DENSITIES OF SPECIES THAT ACT AS MARSH ARCHITECTS IN MODIFYING THE STRUCTURE OF COASTAL MARSHES.

Species	Methods adopted	Outcome
Snow Goose (*Chen caerulescens*)	Special early season hunts, scare decoys and noisemakers, shooting on the breeding grounds (Canada)	Scaring and fall-winter hunts mostly ineffective; recent spring hunts in Canada under evaluation.
Muskrat (*Ondatra zibethicus*)	Trapping	Ineffective currently since market value is so low.
Nutria (*Myocastor coypus*)	Trapping; shooting, poisoning	Ineffective to date with low market values; shooting effective in some winters in Maryland.
Horse (*Equus caballus*)	Reducing size of herd by culling; use of exclosures, and sterilants	Sterilants costly and time consuming; exclosures only for local control. Roundups may be most effective (e.g., annual pony roundup in Chincoteague, Virginia).
Cattle/sheep (*Bos taurus/Ovis aries*)	Reducing size of herd by culling, exclosures, and pasture rotation	Pasture rotation (seasonal) and annual cull and sale most effective.

well as summering egrets, herons, and Glossy Ibis (*Plegadis falcinellus*; R. M. Erwin, unpubl. data). In the past few decades, however, Snow Goose populations have exploded, resulting in major marsh damage on the breeding grounds especially near St. James Bay, Canada, on staging areas along the St. Lawrence River, and on wintering areas from New Jersey to Maryland (see Batt 1998 for a summary of the goose problem). Intense grazing by large numbers of these social birds has resulted in rather large eat-outs that may require a decade or more for the vegetation to recover (Smith and Odum 1981, Young 1987). In some cases if the bare areas were extensive, they have lost their organic composition and became hypersaline; the marsh may have shifted to an alternative stable state (Jefferies and Rockwell 2002). Early attempts to remedy the goose problem relied on using hazing techniques and special extended season hunts during fall and winter on national wildlife refuges, initially at Forsythe National Wildlife Refuge, New Jersey (M. C. Perry, USGS, pers. comm.), Bombay Hook, and Prime Hook national wildlife refuges, Delaware (P. Daly, USFWS, pers. comm.). These proved largely unsuccessful however in reducing regional populations, and in recent years, the Canadian Wildlife Service is directing a special large-scale spring breeding season harvest (Batt 1998; Table 5).

The manager's challenge concerning the Snow Goose becomes one of partial suppression of a native species that is an important game species, a popular species among bird watchers and photographers, a charismatic species that precludes some types of draconian control methods (e.g., poisoning), and a species that has had a long co-evolutionary history with marsh-vegetation dynamics.

MAMMALS

Muskrats

The muskrat is a native species that, like the Snow Goose, has evolved in the marshes of North America. The role of muskrats and their management in marshes remains one of the classics in North American wildlife literature (Errington 1961). Without muskrats, fresh and brackish marshes may often become dominated by cattail although moderate muskrat densities control the cattail and keep the marsh open. Waterfowl managers speak of an ideal hemi-marsh with 40–50% open water in which muskrats are dense enough to control cattails and keep some open water, but are in turn kept under control by regular trapping (O'Neil 1949, Bishop et al. 1979). In coastal marshes along the Atlantic and Gulf coasts, the species that may benefit most from muskrat foraging activities and tunneling include migrant and wintering Blue-winged Teal, Green-winged Teal (*Anas crecca*), Mallard, American Widgeon (*A. americana*), and American Black Duck. During the breeding season, Coastal Plain Swamp Sparrows appear to achieve their highest densities in association with intense muskrat workings (B. Olsen and R. Greenberg, pers. comm.).

On occasion, muskrat population densities and associated tunneling activities may result in conflicts with wildlife management in marshes (Lynch et al. 1947). Examples include eroding the earthen plugs that marsh managers use in constructing OMWM sill ditches in Delaware (W. Meredith, Delaware Division of Fish and Wildlife, pers. comm.) and plugging old tidal ditches in New England (C. T. Roman, National Park Service, pers. comm.). Although poisons have been used on occasion as control, regular trapping remains the most widely acceptable method to control populations (Table 5); in recent decades however, with declining fur prices, reduced trapping has rendered population control ineffective (Chapman and Feldhammer 1982).

Nutria

The nutria (*Myocastor coypu*), a native of South America, was released in the Louisiana marshes in 1938 as part of a fur-bearing animal experiment and rapidly expanded throughout the Gulf Coast brackish marshes (Kinler et al. 1987, Chabreck 1988). Along the East Coast, nutria are found sporadically from Georgia north to the Blackwater National Wildlife Refuge in the Chesapeake Bay, Maryland, where they have created much controversy because of significant marsh losses on refuge lands (Chapman and Feldhammer 1982). As with the Snow Goose, small and localized nutria populations did not damage marshes, and it had been claimed that only for giant cordgrass (*Spartina cyanosuroides*) did nutria have any major impact (Harris and Webert 1962). In moderate numbers, nutria were felt to benefit some waterfowl, because the animals created open patches in otherwise dense marsh grass (Chabreck 1988). However, like the muskrat, the fur-trade decline has resulted in fewer trappers, and hence less control of local and region populations by trapping. As a result, large populations of these herbivores have caused very extensive eat-outs, resulting in marshes reverting to open water pools and lakes. In Maryland, the state natural resource agency is attempting to eradicate the species by trapping and shooting on all public lands (B. Eyler, Maryland Department of Natural Resources, pers. comm.).

Horses

In a relatively small number of regions today (e.g., southern France, Spain, and southeastern US), domestic or feral horses (*Equus caballus*) occur in coastal marshes, at times in high densities (Keiper 1985, Menard et al. 2002). As in previous examples, light to moderate grazing probably has little effect, but with more intense grazing impacts accumulate. In Georgia, significantly more periwinkle snails (*Littorea irrorata*), a potential waterbird prey, were found inside compared to outside of exclosures, and trampling by horses reduced above ground biomass of vegetation by 20–55% (Turner 1987). In southern Europe, horses reduced plants more than did cattle (*Bos taurus*), removed more vegetation per unit body mass, and maintained a mosaic of patches of short and tall grasses (Menard et al. 2002). This suggests potential indirect competition between horses and dabbling ducks (Menard et al. 2002). In the mid-Atlantic region of the US, horse grazing was thought to reduce the density of smooth cordgrass (Furbish and Albano 1994). In North Carolina, marshes subjected to moderate grazing by feral horses supported a higher diversity of foraging waterbirds, a higher density of crabs, but had less vegetation and a lower diversity and density of fishes than ungrazed marshes (Levin et al. 2002). Horse trampling of bird nests has occasionally been detected (I. Ailes, USFWS, pers. comm.) but is probably a minor factor in most locations.

The primary method of controlling feral horse numbers is simply reducing herd sizes and alternating the use of pasturage and wetland areas. On Assateague Island National Seashore and the Chincoteague National Wildlife Refuge in eastern Virginia, a fixed percentage of the annual foal production is removed from the herd during a July drive and managed roundup and are auctioned to the public in what has been a major tourist event (Keiper 1985). Experimentation with sterilization of horses has also been tried at several island locations along the Atlantic Coast, but with limited success (J. Schroer, USFWS, pers. comm.). Sterilization of dominant stallions without other control measures is unlikely to control feral horse populations.

Cattle and sheep

As with horses, light-to-moderate numbers of livestock (0.5–1.0 animal/ha) probably are not deleterious to marsh vegetation or to the associated bird life (Chabreck 1988). Cattle graze forbs and shrubs and may retard the invasion of woody vegetation into emergent marshes (Menard et al. 2002). In Europe, cattle grazing has been cited as benefiting grazing waterfowl as well as a common nesting shorebird (Redshank [*Tringa tetanus*]) by maintaining early successional stages and a diverse array of halophytic plant species, (Norris et al. 1997, Esselink et al. 2000). Along the US Gulf Coast, Chabreck (1968) mentioned that moderate cattle grazing in marshes might benefit the Snow Goose (Chabrek (1968) and, more interestingly, the Yellow Rail (*Coturnicops noveboracensis*; Mizell 1999). On the other hand, overgrazing by cattle reduces biomass of many annual seed-producing grasses and sedges, reducing food availability for wintering waterfowl, especially ducks (Chabreck 1968). In addition, in Germany an experiment conducted using three levels of grazing (0.5–2.0 animals/ha) over 9 yr demonstrated that grazing could depress population densities, species richness, and community diversity of invertebrates (Andresen et al. 1990); hence, many shorebird species could potentially be affected.

Sheep (*Ovis aries*) grazing in wetlands is most common in Europe. In general, as wetlands revert to upland pasture for sheep and cattle by drainage or diking into polders, potential wetland-dependent birds suffer habitat loss; such has occurred in The Netherlands (Hotker 1992) and elsewhere in Europe (Finlayson et al. 1992). In England, some attempts have been made to reduce the potential conflict between sheep grazing and wintering waterfowl use by imposing seasonal restrictions for sheep grazing from April–October in designated wet pastures (Cadwalladr and Morley 1973).

Management of potential deleterious effects of cattle and sheep involves reducing the herd periodically or alternating pasturage areas. Also, where significant waterfowl populations arrive in fall and winter, seasonal closures of some marshes from October through March may be appropriate to reduce disturbance.

SUMMARY AND FUTURE DIRECTIONS

Coastal marshes are subject to lightning-ignited fires that typically occur during the summer when thunderstorms are most frequent, and vegetation is actively growing. On the other hand, marsh managers typically burn marshes during late fall or winter, the time when migratory or wintering waterfowl are present, and vegetation, at least at higher latitudes, is generally dormant. Observational data provide limited evidence that these management burns attract some species of waterfowl (wintering Snow Goose in particular), at least occasionally. Unfortunately, lack of comparisons with unburned or control marshes limit inferences that can be made from these observations. We only can speculate as to what feature(s) of these burned marshes are attractive (e.g., food availability and nutritional content of vegetation, changes in predator communities, social interaction, and/or altered vegetation structure facilitating animal movement), or under what other environmental conditions waterfowl will use burned marshes (e.g., availability of food in the surrounding landscape).

Results of studies of vegetation responses indicate that prescribed burns sometimes, but not always, produce the desired results (i.e., changes in plant community composition, biomass, or seed production). Numerous environmental or other factors, including water depth or salinity, ambient or water temperature, humidity, fuel load, fire intensity, and season of burn likely strongly influence vegetation responses but have not been investigated. In particular, comparisons between biological responses to winter management burns and summer lightning fires could improve our understanding of the pre-management-era role of fire in these systems, and possible marsh community alterations caused by human-imposed fire regimes. Similarly, effects of prescribed fires on invertebrate foods are unclear.

Gulf Coast marshes in which Seaside Sparrows breed are prone to lightning-ignited fires; thus, these birds have likely evolved behavioral or other responses that allow their persistence in a frequently disturbed habitat. Prescribed fires appear beneficial to breeding sparrow populations, presumably because vegetation that inhibits the birds' movements along the ground is removed. Wrens and other small passerines apparently avoid recently burned marshes for about 1 yr, likely due to loss of vegetative cover. Burning marshes during the fall and winter reduces winter habitat quality for migratory species such as Sedge Wrens and Nelson's Sharp-tailed Sparrows, which winter almost exclusively in coastal marshes. Widespread and abundant species such as Red-winged Blackbirds and Boat-tailed Grackles seem to prefer recently burned marshes. Observations of fire effects on raptors and waterbirds are far too limited to make any significant inferences. Although these species do not necessarily nest in the marsh itself, they are important components of the marsh system as predators and vehicles of nutrient cycles; their responses should be investigated further.

Impounded marshes appear to attract waterbirds in greater numbers than do neighboring unmanaged, tidally influenced marshes and may contribute significantly to shorebird conservation because they provide supplemental feeding and roosting areas, particularly when natural marshes are inundated by high tide. However, passerines and other species that do not frequent large open-water ponds or mudflats may be negatively affected by conversion of tidal marshes into non-tidal marshes. Impounded marsh habitat differs sufficiently from unimpounded marsh habitat in that distinctive bird groups use one but generally avoid the other. Thus, managers are faced with a difficult task of integrating and improving management of impounded marshes with the management and preservation (in as natural a state as possible) of unimpounded marshes. Areas in which information appears to be lacking for coastal impounded marshes include effects of timing and duration of drawdown on wildlife use and invertebrate communities

Management values of impounded marshes during the breeding season are similar to those during winter and migration. Birds that benefit are typically those associated with open water ponds or mudflats; the specific nature of benefits for even these species have not been rigorously evaluated. At the same time, water levels within impoundments often are too deep to be suitable for ground-foraging passerines. These species appear to depend on periodic exposure of the marsh surface, possibly to facilitate foraging or because invertebrate prey are more vulnerable at low tides. Habitat structure may also play a role in the distribution and abundance of bird species because salinities and plant communities differ between impounded and unimpounded marshes. Invertebrate communities and availability may also differ between managed and unmanaged marshes.

Mosquito-control ditches drastically alter the hydrology, hence vegetation communities, of the marshes and set the stage for more dramatic marsh transformations. Since the 1960s in the mid-Atlantic region, OMWM has been developed to facilitate the biological control of mosquitoes. OMWM attempts to enhance fish populations while decreasing ovipositon sites for mosquitoes by creating high-marsh pools and radial ditches isolated from daily tides. In spite of the appeal of depending upon biological rather than chemical means to control mosquitoes, the practice has proven controversial with some marsh ecologists remaining concerned about the mechanical alteration of marshes.

The effect of OMWM on waterbirds has been studied in several locations, but relatively little research has been done on a larger suite of potential ecological effects that might accrue due to OMWM treatment. Some of these potential effects are being addressed presently through research projects on six national wildlife refuges from Maine to Delaware (James-Pirri et al. 2004). Additional work is needed in other areas as well over longer time frames to determine the immediate versus longer-term effects of altering the hydrology and structure of the marsh. With the onset of sea-level rise, any additional interior fragmentation of marshes may prove inimical to a healthy marsh ecosystem.

In general, larger OMWM ponds (>0.1 ha) and pools attract more shorebirds and waterfowl than do small ones, although densities may not be greater. Several studies attempting to assess bird use of ponds were compromised due to either insufficient controls, or inappropriate survey methods. One experimental study in New Jersey indicated that, although larger ponds may be used by more birds than smaller ones, no treatment effect was detected (i.e., created versus natural pond use); also, at least for waterfowl, nearby large impoundments (100s of hectares in size) harbored both a larger number and higher density of birds than did the created ponds in fall and winter. Thus, the entire landscape surrounding the treatment areas of the marsh must be considered when addressing habitat use. Recent improvements in the design of small OMWM ponds include using very shallow, sloping perimeters to maximize shorebird use, and creating larger ponds unless dredged material deposition precludes that option.

Many animals other than humans have been marsh managers for years; however a limited amount of research has been conducted to evaluate effects of such activity. In general, removing animals (annual sales or culls) or rotating pasture lands have been effective in preventing overgrazing. In some cases, permanent fencing of selected areas may be necessary where critical species require increased protection (e.g., Piping Plovers [*Charadrius melodus*]) in the beach-marsh complexes of Chincoteague National Wildlife Refuge where feral horses are managed). Additional work is needed to assess the level of grazing and trampling that can be sustained by the local soil invertebrates and native grasses and sedges before community dynamics are altered.

Ironically, in light of the species' importance as an impetus of coastal-marsh management, recent increases in the Snow Goose in much of North America have been a major concern for state and federal wildlife managers and coastal wetland managers because of their potential to damage marshes and nearby crops. Special hunts have been used to attempt to reduce these populations; however, the effectiveness of these measures is unclear. Additional research and monitoring are necessary to determine the effectiveness of different levels of control in altering goose populations.

Medium-sized fur-bearing mammals also modify marshes considerably. The native muskrat, however is less cause for concern in its marsh plant consumption and tunneling than is the exotic nutria. Where population levels are moderate for each species, the opening of small pockets in the monoculture of marsh grasses may benefit waterfowl, rails, and other species. However, nutria have caused extensive marsh fragmentation and loss, especially in Louisiana and Maryland. Trapping no longer is viable economically nor is it effective in population control. An extermination program is underway in Maryland and Louisiana, and research efforts are underway to evaluate how population reduction rates are affecting declines and demographic aspects of the Maryland population.

Although some evidence suggests that we can improve marshes for waterfowl, herons, and, possibly in some cases, passerines, using certain marsh-management activities, success is often hit or miss. Additionally, the effects on non-target organisms, particularly those that depend on coastal marshes for at least part of their life cycle (e.g., endemic sparrows, rails, small mammals, snakes, and fish) are at best ambiguous and at worst harmful. As a result, many generally abundant and widespread species may benefit, whereas the few coastal-marsh specialists probably do not.

Nearly all studies of avian responses to coastal-marsh management document simple abundance or density measures that may not best reflect habitat quality (Van Horne 1983). Unknown are the effects of actions on biological parameters closely related to fitness, such as survival, nesting success, and physiological condition, or shifts in intrinsic (e.g., foraging behavior and social organization) or environmental factors (food availability and predator populations) that lead to changes in these parameters. In addition, most studies have attempted to relate bird responses local habitat features alone. Landscape scale variables such as area and extent of prescribed burns, proximity of other foraging areas, food sources, open water, or emergent vegetation, and habitat diversity and juxtaposition have also been largely ignored. Longer-term effects of changes in ecosystem processes (vertical accretion, compaction, sedimentation, and nutrient cycling) have also received comparatively little attention.

Finally, given the variable nature of coastal marshes, we should consider the merits of continuing to manage these habitats as we have historically (occasionally achieving some objectives) while risking potential irreversible ecosystem effects, such as the loss of a coastal-marsh endemic species. An alternative is to revise management goals and procedures to emphasize restoration of natural marsh processes (hydrology) and historic disturbances (fire). We suggest that scaling back the use of prescribed burning by reducing extent and frequency, particularly in areas in which fire is historically not a frequent disturbance, is certainly advisable, given the levels of uncertainty. In a similar vein, taking a go-slow approach on OMWM, especially in relatively pristine, unaltered coastal marshes is recommended. Coastal-marsh restoration, such as ditch plugging in the Northeast and opening up diked marshes (Cape Cod, Delaware Bay marshes; San Francisco Bay salt ponds; Merritt Island, Florida) should be encouraged.

A precautionary approach that uses adaptive resource management and attempts several experiments simultaneously to compare and evaluate model parameters is well advised. We encourage researchers and managers to work together to monitor and evaluate management activities while emphasizing an experimental approach (Ratti and Garton 1996). Such collaborations should emphasize well-designed long-term studies that document meaningful ecological responses (e.g., avian productivity or nutrient cycling). Only by treating each management activity, when possible, as a field experiment, complete with suitable control treatments and true replication, can significant advances in the science of coastal-wetland management be made. Information gleaned from these sound practices can be used to justify or alter coastal-marsh management activities with greater confidence.

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