Preserv. Asian Bird Conf., Bangkok, Thailand. 2pp.

SUPRECHAKORN, T. 1982. Introduction to forestry. Fac. of For., Kasetsart Univ., Bangkok, Thailand. 180pp.

THAILAND FACULTY OF FORESTRY. 1989. The master plan for Huai Kha Khaeng Wildlife Sanctuary. Fac. of For., Kasetsart Univ., Bangkok. 239pp.

THAILAND ROYAL FOREST DEPARTMENT. 1991. Forestry statistics of Thailand. Planning Div., Royal For. Dep., Bangkok. 89pp.

VON HAARTMAN, L. 1957. Adaptation in hole-nesting birds. Evolution 11:339–347.

THE WORLD RESOURCES INSTITUTE. 1988–89. World Resources. Basic Books, Inc., New York, N.Y. 372pp.

Received 25 April 1994.
Accepted 21 July 1995.
Associate Editor: Ryan.

SHOREBIRD USE OF SOUTH CAROLINA MANAGED AND NATURAL COASTAL WETLANDS

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Abstract: While many migrating and wintering shorebird (Charadriiformes) species face declines in quality and quantity of natural stopover sites, diked wetlands managed for shorebirds may provide supplemental habitat. We describe an integrative shorebird-waterfowl management strategy used at Tom Yawkey Wildlife Center on South Island, South Carolina, during 3 winter–spring seasons (1991–93). We compared shorebird use and invertebrate density between diked, managed wetlands and adjacent natural coastal mudflat areas. About 3,000 shorebirds overwintered each year at the site. Migration numbers peaked at 15,000–19,000 during late May. In 1991, shorebird density and absolute numbers were higher ($P < 0.05$) in managed wetlands at high tide than natural mudflats at low tide. In 1993, we counted shorebird density at low tide both in managed wetlands and Mother Norton Shoals, the largest natural area. During February, shorebird frequency was higher in Mother Norton Shoals and lower in managed wetlands than expected values based on area ($P < 0.005$). In contrast, from March to May, shorebird frequency was higher in managed wetlands and lower in natural mudflats than expected ($P < 0.005$ for each month). Invertebrate density from March to May was generally greater in managed wetlands than at Mother Norton Shoals, which may explain shorebird preference during that time. Greater invertebrate density did not explain the pattern in February. Mean water depth in managed wetlands for each shorebird species was <5 cm except for American avocet (*Recurvirostra americana*) which used deeper water ($\bar{x} = 8.4$ cm, SD = 4.5). Results indicate that an integrative shorebird-waterfowl management strategy provides supplemental shorebird habitat at high tide, and managed wetlands can be preferred to local natural mudflat areas at low tide.

J. WILDL. MANAGE. 60(1):73–82

Key words: Charadriiformes, impoundments, intertidal areas, invertebrate density, invertebrate biomass, shorebirds, South Carolina, waterfowl.

Many migrating and wintering shorebird (Charadriiformes) species face declines in quantity and quality of natural stopover sites (Senner and Howe 1984). Significant population declines recently have been recorded for 9 shorebird species (Howe et al. 1989, Haig and Plissner 1993, Morrison et al. 1994, Page and Gill 1994). Shorebirds are particularly at risk from habitat decline at migration and wintering sites because of their tendency to concentrate at a few sites at precise times (Myers et al. 1987). As a supplement to natural areas, managed, tidally influenced, diked wetlands (sometimes called impoundments) may provide available habitat if appropriate water levels coincide with shorebird passage. These managed wetlands also provide protection from oil spills and other ocean

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catastrophes. About 11% of the half-million ha of marshes along the Atlantic coast of southeastern United States are diked and managed (Montague et al. 1987), representing a substantial refuge for shorebirds if managed effectively. About 60% (28,500 ha) of these diked wetlands lie in South Carolina (Montague et al. 1987).

Value of diked compared to undisturbed wetlands, however, is the center of debate (DeVoe and Baughman 1986, Tompkins 1987). Opponents contend that compared to natural estuarine waters, diked wetlands may have water quality problems that limit their use. These can include diminished circulation, increased sedimentation, and extreme values of temperature, salinity, and dissolved oxygen (McGovern and Wenner 1990). In addition, fish and crustaceans that normally use marshes as a nursery are denied access to, or escape from, diked wetlands (McGovern and Wenner 1990, Rogers et al. 1994). Proponents argue that managed diked wetlands (hereafter called managed wetlands) offer refuge to species that are not always well represented in natural marsh (Miglarese and Sandifer 1982, Gilmore 1987). Alligator (*Alligator mississippiensis*) and bird occurrences are particularly high in managed wetlands (Miglarese and Sandifer 1982, Epstein and Joyner 1986, Breininger and Smith 1990). More individuals of more avian species used managed wetlands than unmanaged marsh in South Carolina (Epstein and Joyner 1986). Dabbling duck occurrence in South Carolina was also higher in managed wetlands and lower in unmanaged tidal wetlands than expected values based on area (Gordon et al., unpubl. data).

Shorebirds also may prefer managed wetlands over natural vegetated marsh areas and tidal mudflats. Compared to vegetated marsh areas, managed wetlands generally had higher shorebird numbers in New Jersey and South Carolina (Burger et al. 1982, Epstein and Joyner 1986). Compared to tidal mudflat areas, managed wetlands in New Jersey had higher absolute shorebird numbers during spring and autumn migration (Erwin et al. 1994). Shorebird density was higher in managed wetlands than natural mudflat tidal areas during autumn, but not spring migration. Because results were limited to a few areas, more comparisons of this type are needed to evaluate the importance of diked wetlands from a shorebird perspective.

Despite the potential for shorebirds, most strategies in South Carolina managed wetlands are targeted at wintering waterfowl (Tompkins 1986, 1987; Montague et al. 1987). Presence of waterfowl, however, is not exclusive. Shorebird use-days can surpass waterfowl annual use under traditional waterfowl management (Epstein and Joyner 1986). On the basis of previous work, however, conditions for shorebirds could be enhanced while maintaining high wintering waterfowl populations, by extending the drawdown period currently used to encourage growth of macrophytes consumed by waterfowl (Hands et al. 1991, Eldridge 1992, Helmers 1992).

Our first goal was to describe patterns of shorebird use in diked wetlands under an integrative shorebird-waterfowl management strategy used at our coastal South Carolina site from 1991 to 1993. We also evaluated water depth at which each shorebird species occurred and provided phenology data. Our second goal was to compare shorebird numbers and density between managed wetlands and natural intertidal mudflat areas during 1991–93. With invertebrate prey density information, we speculate on shorebird preference between managed and natural wetlands.

Funding was provided by the U.S. Fish and Wildlife Service through the Patuxent Wildlife Science Center. We thank M. A. Howe for inviting these analyses and R. M. Erwin for continued support of the project. We thank T. A. McCoy, M. Reilly Jacobs, and J. E. Finley for laboratory technical assistance. We acknowledge R. L. Joyner, the Yawkey Foundation Board of Trustees, and the staff of the Yawkey Center for making field work possible. We are obliged to C. P. Marsh for giving advice in the field and in project development, R. Boettcher and J. E. Lyons for helpful discussions and collaboration on South Island, and R. Chappell of the Army Corps of Engineers in Charleston, South Carolina for use of a digitizer. We received logistical help from the Tom Yawkey Wildlife Center, South Carolina Cooperative Fish and Wildlife Research Unit, and South Carolina Department of Natural Resources. We thank S. A. Gauthreaux, D. L. Otis, E. E. Ruppert, D. W. Tonkyn, and 2 anonymous reviewers for reviewing drafts of the manuscript.

STUDY AREA

We conducted field work on South Island (79°15′W, 33°10′N) at the Tom Yawkey Wildlife Center in the Santee Delta-Cape Romain area of Georgetown County, South Carolina. The

Santee Delta-Cape Romain area is a unit of the Carolinian-South Atlantic Biosphere Reserve (Hopkins-Murphy 1989). Counts indicated that the area ranked second as a spring feeding site for eastern North American shorebirds on migration (Marsh and Wilkinson 1991). The Yawkey Center alone qualified as a regional reserve (5% of flyway population) for 4 species in the Western Hemispheric Shorebird Reserve Network (Marsh and Wilkinson 1991). The Center is separated from the mainland by the Intracoastal Waterway and includes North Island, South Island, and portions of Cat Island. The Center is managed by the South Carolina Department of Natural Resources as a wildlife refuge and research area, and encompassed 940 ha of managed wetlands surrounded by 6,200 ha of tidal marsh, forest openings, ocean beach, pineland, and maritime forest. We worked solely on South Island, which had the most shorebird habitat.

There are 3 main, natural mudflat areas on South Island. Mother Norton Shoals (111 ha) was an intertidal mudflat at the mouth of Winyah Bay, bordered on the east by a barrier island and to the south and west by *Spartina* marsh. Only the north side was contiguous with open water. Front Beach North (8.8 ha) consisted of a mudflat in a tidal creek. Front Beach South (1.8 ha) was a mudflat-shallow water area with water exchange only during spring tides.

There were 12 brackish, managed wetlands on South Island ranging from 9 to 98 ha. Managed wetlands consisted of central flat or slightly sloped, muddy-bottomed, primarily open-water areas surrounded by perimeter ditches. Throughout the study, salinity varied from 9 to 25 ppt and water levels were regulated by wooden water control structures with sliding flapgates and flashboard risers (Williams 1987). Depths were kept highest (35–45 cm) in fall to accommodate waterfowl food plants. Gradual drawdown of water depths throughout the winter allowed waterfowl to feed. Sheet water and temporary dry bed in spring encouraged germination of waterfowl foods such as widgeongrass (*Ruppia maritima*), dwarf spike-rush (*Eleocharis parvula*), and saltmarsh bulrush (*Scirpus robustus*). Sea purslane (*Sesuvium maritimum*) was produced with more prolonged dry bed (Swiderek et al. 1988). The drawdown oxidized and firmed sediments increasing water clarity and providing mudflat and shallow water habitat for shorebirds. Drawdown in areas managed for sea purslane took place gradually throughout the winter until 1 March (Swiderek et al. 1988). Water levels were then reduced more rapidly so that they were at bed level by 1 April and maintained below bed level in perimeter ditches after that. They remained at this level throughout the summer as sea purslane grew. Beginning in August, these areas were gradually flooded to reach a depth of 20–25 cm by 1 September. Those areas managed for widgeon grass, dwarf spikerush, and saltmarsh bulrush were drawn down beginning in early March to sheet water in April and maintained as mudflat until late May. They were held at bed level for 3–4 days in early June then were gradually flooded to 35–45 cm allowing for plant growth. During late fall and winter, water depths were gradually decreased about 10 cm per month providing food for wintering waterfowl, shorebirds, and herons. Water control structures were set to allow continuous exchange and circulation with tidal creeks or other managed wetlands until late stages of drawdown.

METHODS

Shorebird and Waterfowl Counts in Managed Wetlands and Natural Areas

Each week from late January to May 1991–93 we counted shorebirds and waterfowl at all 12 South Island managed wetlands. We conducted counts within 2 hours of high tide because shorebirds were concentrated in managed wetlands at that time (L. Weber, pers. observ.). In gathering phenology data, this seemed the accurate way to access total shorebird numbers for the island because there were virtually no shorebirds in the natural sites at high tide. In 1991, we also made weekly counts of shorebirds in Mother Norton Shoals, Front Beach North, and Front Beach South within 2 hours of low tide, which corresponded with peak shorebird density in intertidal areas. We compared high tide, managed wetland counts to low tide, natural site counts to assess which area received the most use during their peak periods. In 1993, we made weekly counts in managed wetlands and Mother Norton Shoals both at low tide to compare shorebird frequency. Mother Norton Shoals was the only natural site counted because there was not enough time to count all 3 natural sites and all managed wetlands in the same low tide period. We singled out Mother Norton Shoals because it was the largest natural site.

Because raised dikes surrounded managed wetlands, we were able to view nearly every portion of them from a truck. We viewed Mother Norton Shoals from a tower and Front Beach South from behind a nearby sand dune. We counted Front Beach North by traversing the tidal creek edge. At each count we estimated the percent of each managed or natural wetland that was available to shorebirds (mudflat and shallow water). We later calculated total surface area of each site by digitizing aerial photographs. We used those data to calculate available habitat at each site on each date. We calculated shorebird density by dividing total number of shorebirds at each site by amount of available habitat.

To compare shorebird use in 1991, we averaged shorebird density and absolute numbers at each managed or natural wetland by month (Feb–May). We used these values in a repeated measures ANOVA with 2 treatments, managed wetland and natural mudflat. We log transformed data to meet ANOVA assumptions of normality and equal variance. In 1993, we could not use an ANOVA because there was only 1 replicate (Mother Norton Shoals) in the natural mudflat category. Therefore, we confined statistical analysis to a monthly (Feb–May) G-test of shorebird frequency in 2 categories (managed wetland, natural mudflat). For both categories, we summed shorebird occurrences by month to provide observed frequencies. We based expected frequencies on percent available habitat in each category. We could not pool G-tests over months because percent available habitat changed in each category by month.

1991 Water Depth and Invertebrate Measurements in Plots

We used 10- × 10-m plots from February to May 1991 to record water depth at which each shorebird species occurred and to compare shorebird feeding in managed and natural wetlands. We measured invertebrate density in each plot to compare values in managed and natural wetlands. Invertebrates present were mainly polychaetes, oligochaetes, and insect larvae (Weber 1994). Sites included the 3 natural sites already described and 5 managed wetlands (Gibson, Lower Reserve, Sand Creek Basin, Twin Sisters, and Wheeler Basin) frequently used by shorebirds. Generally, we placed 2 groups of 5 plots in each site. We placed only 1 group per site in Front Beach North and Front Beach South because these sites were <20% of the average size of other sites. We randomly placed 5 plots in an area chosen as typical habitat for that managed or natural wetland, yet viewable from a vehicle. We marked plots with 4 wooden stakes 120 cm long (5 cm × 5 cm). We determined water depth by a stake in each plot marked with nails at heights of 5, 10, 15, and 30 cm.

To estimate mean water depth for each shorebird species, we took scan samples (Altmann 1974) in plots twice a week. For each plot at each scan we recorded number of each shorebird species, whether each shorebird was feeding or not, and water depth. Because shorebird density in these small plots was very low (generally <1.0 shorebirds/100 m^2) and highly variable, we do not present shorebird density data. To estimate invertebrate density, we took 1 sediment core (10 cm deep) randomly from each plot once in mid-month (17–22 Feb, 15–23 Mar, 14–23 Apr, 14–18 May) using a beveled edge PVC pipe (10-cm diam). We washed each core sample through a 0.5 mm mesh sieve then preserved the material on the sieve in buffered 10% formalin stained with Rose Bengal. Using a stereomicroscope at 30×, we sorted and counted invertebrates.

For invertebrate density, we compared means of each site using ANOVA for each month (Feb to May). If the overall test indicated there were significant differences, we used a Tukey test to identify differences between pairs of means. If necessary, we log or square root transformed data to meet ANOVA assumptions. Although there were 4 months of data, we could not perform a repeated measures ANOVA because there were some missing data points; some plots were too deep for shorebirds (>10 cm) in February and March, February samples from Front Beach sites were not taken, and Lower Reserve plots dried out after March. Because we used 4 tests, the level of significance was set at $P = 0.05/4 = 0.013$ for the overall monthly tests.

1993 Invertebrate Measurements

We made additional invertebrate comparisons in 1993 to explain shorebird preference patterns during February. We compared invertebrate density and biomass in Lower Reserve, the only managed wetland extensively drawn down in February, and Mother Norton Shoals, the largest natural mudflat. We set up 2 transects (60 m) at each site. We intentionally placed Lower Reserve transects in areas with highest shorebird use. We placed Mother Norton Shoals transects in the center (north–south orientation), but within 200 m of the west shore, in an area that seemed typical for Mother Norton Shoals. There were 3 sampling stations at equally spaced intervals across the center of each plot. On 2–3 February 1993, we took 2 pairs of core samples within 1 m of each station. A pair consisted of 2 core samples (5-cm diam × 10-cm deep) 0.5 m apart, which were combined before sorting. On 28 February–2 March 1993, we took 1 pair of samples within 1 m of each station. We sieved, preserved, and counted samples as in 1991. We measured invertebrate biomass (all species combined) per pair after drying at 105 C for 24 hours. We tested for differences between Mother Norton Shoals and Lower Reserve using a *t*-test for each date. We log transformed data when necessary to meet ANOVA assumptions of equal variance and normality.

RESULTS

Shorebird and Waterfowl Counts

About 3,000 shorebirds overwintered each year on South Island, and spring shorebird migration peaked at 15,000–19,000 in May (Fig. 1). Semipalmated sandpiper (*Calidris pusilla*) was the most numerous shorebird species (Fig. 2). Information on regular but less common species is included in Weber (1994).

In 1991, shorebird density in managed wetlands at high tide was greater ($P < 0.001$) than in natural mudflats at low tide (Fig. 3). There was no effect due to month ($P = 0.33$) or month versus treatment ($P = 0.08$). Absolute numbers of shorebirds also were greater ($P = 0.03$) in managed wetlands at high tide than natural areas at low tide with no effect due to month ($P = 0.07$) or month versus treatment ($P = 0.08$). For absolute numbers, monthly means in the managed treatment ranged from 62 shorebirds per site (SE = 36) in February to 1,022 (SE = 386) in May. Means in the natural treatment ranged from 12 (SE = 5) in March to 160 (SE = 60) in May.

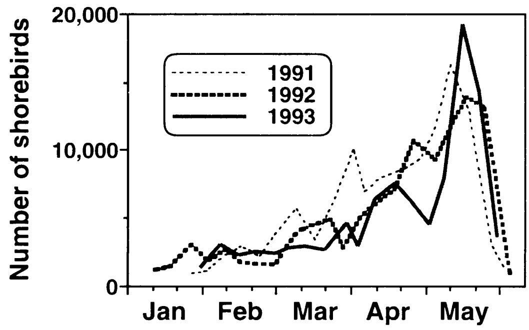

Fig. 1. Shorebird counts in South Island, South Carolina managed wetlands at high tide from January to June, 1991 to 1993.

In 1993, when comparing shorebird numbers in both areas at low tide, frequency during February was higher in Mother Norton Shoals and lower in managed wetlands than expected ($P < 0.005$, Table 1). From March to May, frequency was higher in managed wetlands and lower in Mother Norton Shoals than expected ($P < 0.005$ for each month).

1991 Water Depth and Invertebrate Measurements in Plots

There were differences in invertebrate density among sites in every month, February through May in the overall ANOVA for each

Table 1. Comparison of shorebird frequencies by month in brackish managed wetlands and a natural intertidal mudflat in coastal South Carolina during 1993 at low tide.

	Observed	Expected	G value[a]
February			
Managed wetlands	5,372	5,694	32.7
Mother Norton Shoals	7,570	7,248	
March			
Managed wetlands	6,213	2,723	5,200
Mother Norton Shoals	4,100	7,590	
April			
Managed wetlands	13,355	6,742	10,831
Mother Norton Shoals	3,500	10,113	
May			
Managed wetlands	32,603	18,488	146,308
Mother Norton Shoals	2,950	17,065	

[a] $P < 0.005$; $\chi^2_{0.005,\,1} = 7.79$.

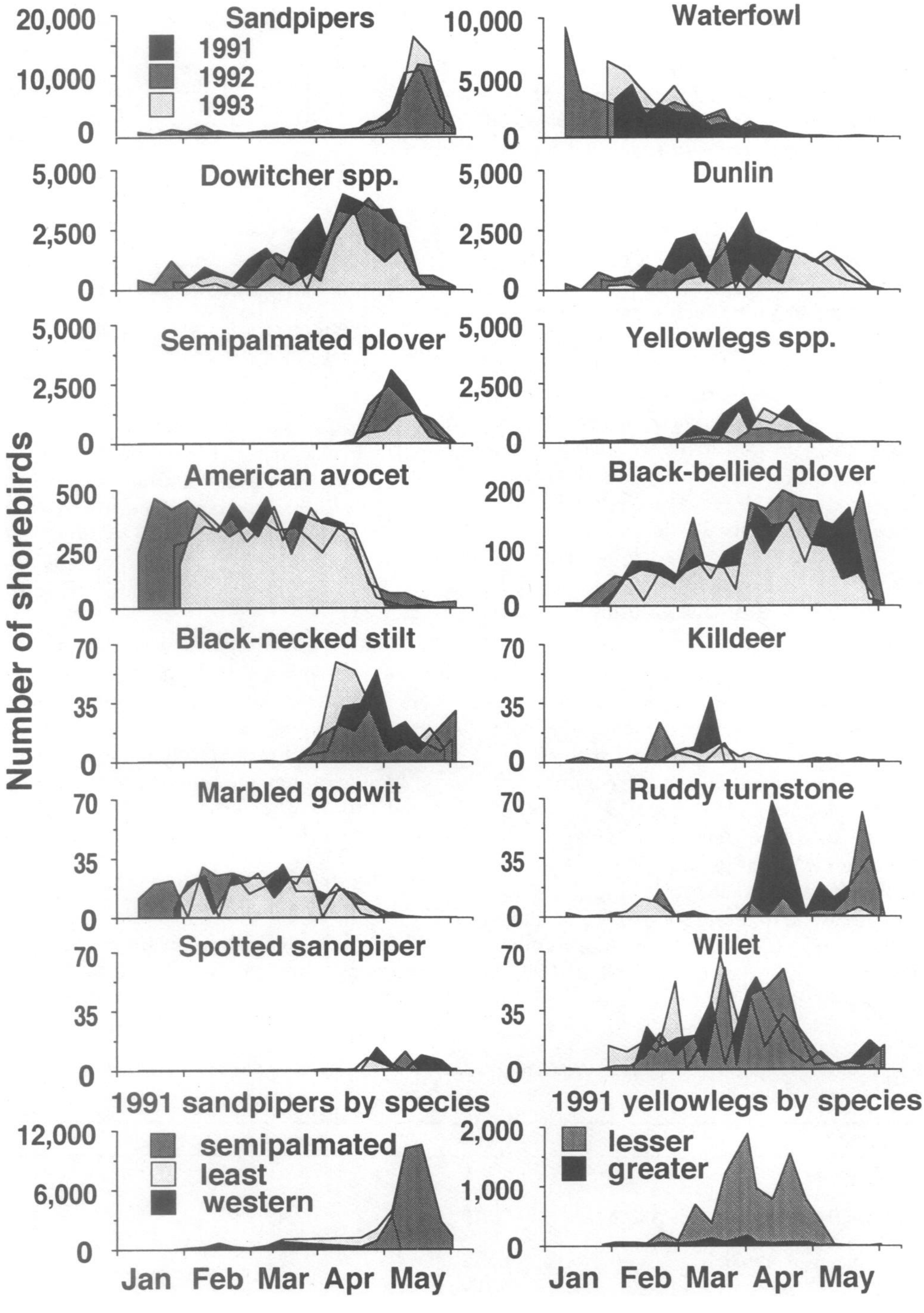

Fig. 2. Number of shorebirds in South Island, South Carolina managed wetlands by species and date. Sandpipers include semipalmated (*Calidris pusilla*), least (*C. minutilla*), and western (*C. mauri*). Dowitcher include long-billed (*Limnodromus scolopaceus*) and short-billed (*L. griseus*). Yellowlegs include greater (*Tringa melanoleuca*) and lesser (*T. flavipes*). Other species include dunlin (*C. alpina*), semipalmated plover (*Charadrius semipalmatus*), black-bellied plover (*Pluvialis squatarola*), black-necked stilt (*Himantopus mexicanus*), killdeer (*C. vociferus*), marbled godwit (*Limosa fedoa)*, ruddy turnstone (*Arenaria interpres*), spotted sandpiper (*Actitis macularia*), and willet (*Catoptrophorus semipalmatus*).

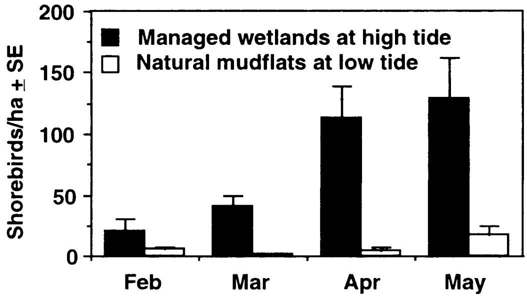

Fig. 3. Whole site counts during 1991 measuring shorebird density in managed wetlands and natural areas on South Island, South Carolina.

month ($P < 0.0001$). In paired comparisons, Front Beach South and Front Beach North invertebrate densities were as high as many managed wetlands (Fig. 4). However, invertebrate density at Mother Norton Shoals was consistently low compared to most other sites. Although density at Mother Norton Shoals was not different from Lower Reserve in February and March, it was lower than all sites in April and May ($P < 0.05$). Mean water depth for each shorebird species in managed wetlands generally corresponded to belly depth (Fig. 5). Depth in natural wetlands was almost always zero. Observations indicated that shorebirds did not merely use managed wetlands as a loafing site. They fed at least as much when in managed wetlands ($\bar{x}$ = 80%, SE = 15, n = 6 sites) as in natural sites ($\bar{x}$ = 68%, SE = 6.9, n = 3 sites).

1993 Invertebrate Measurements

In the early February sampling, there was greater invertebrate density in Lower Reserve than in Mother Norton Shoals ($P < 0.0001$, Fig. 6). Invertebrate biomass during this sampling period was not different between sites ($P = 0.26$). In the later sampling period, values were higher in Lower Reserve for both invertebrate density ($P = 0.001$) and biomass ($P = 0.025$).

DISCUSSION

Clearly, managed wetlands provided refuge for large numbers of feeding shorebirds at high tide. In fact, managed wetlands received more concentrated shorebird use at high tide than natural mudflats at low tide. This high tide aggregation is not surprising and is consistent with others who have noted that diked wetlands can be important in providing feeding or roosting alternatives at high tide, in adverse weather (Burger 1984, Davidson and Evans 1986), or for

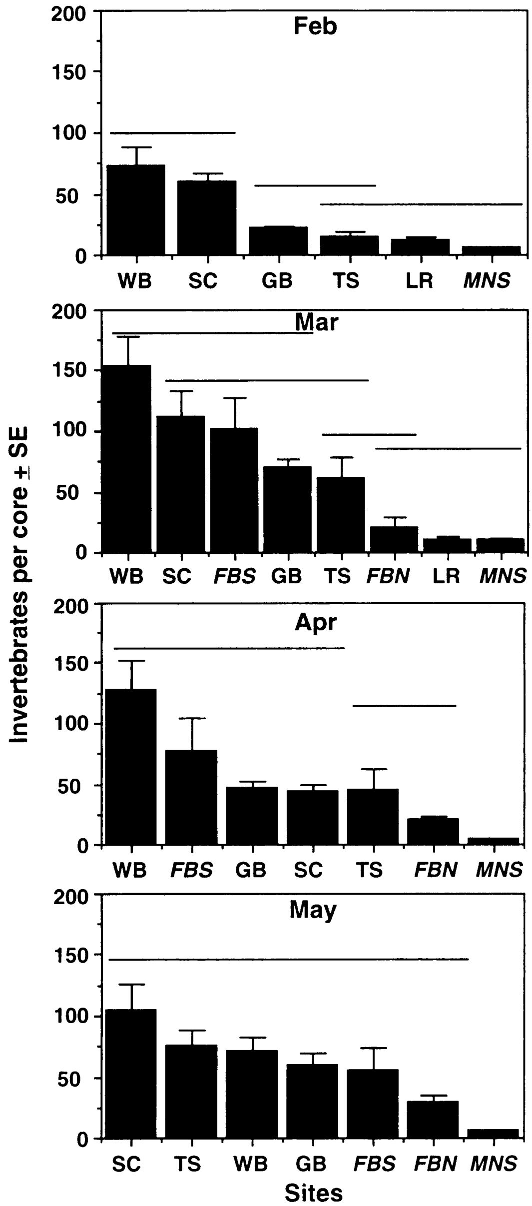

Fig. 4. Prey abundance/393 cm³ core sample in 1991 on South Island, South Carolina. Sites connected by a horizontal line above bars did not differ as tested by a Tukey test at $P < 0.05$. WB = Wheeler Basin, SC = Sand Creek, FBS = Front Beach South, GB = Gibson Pond, TS = Twin Sisters, FBN = Front Beach North, LR = Lower Reserve, MNS = Mother Norton Shoals.

small shorebirds seeking refuge from wind during any part of the tide cycle (Burger 1984).

Less predictable was the question of relative shorebird use of managed and natural sites at low tide. High shorebird use of managed wet-

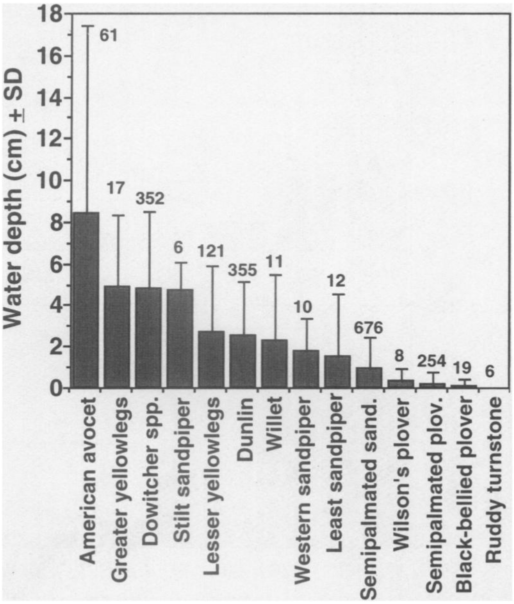

Fig. 5. Mean water depth (cm) used by shorebirds in managed wetlands on South Island, South Carolina. Numbers above bars are sample sizes. Species include stilt sandpiper (*Micropalama himantopus*) and Wilson's plover (*Charadrius wilsonia*).

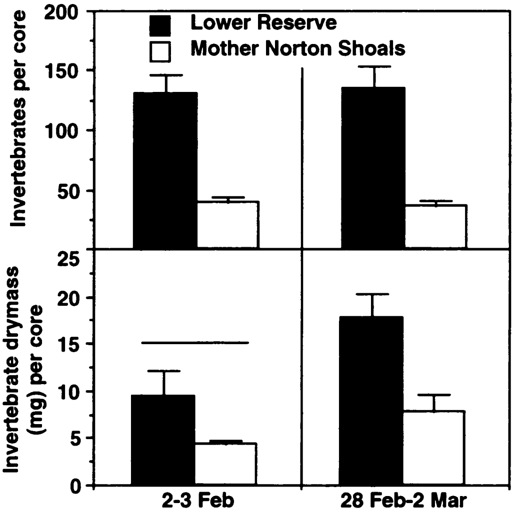

Fig. 6. Prey abundance and biomass/393 cm^3 core sample in 1993 on South Island, South Carolina. Treatments connected by a horizontal line did not differ as tested by *t*-test at $P <$ 0.05.

lands versus low use of Mother Norton Shoals from March to May, 1993 contrasted with the opposite pattern in February. Our March to May high shorebird numbers in managed wetlands are consistent with a preponderance of shorebirds generally found in managed compared to natural wetlands in New Jersey studies (Erwin et al. 1994, Burger et al. 1982). Results are also consistent with a simultaneous finding on South Island that American avocets occurred more frequently in managed wetlands than natural intertidal areas (Boettcher et al. 1995).

Greater invertebrate density in managed wetlands than in Mother Norton Shoals might explain results from March to May. Greater invertebrate density and biomass does not explain the pattern during February. Low February occurrence of shorebirds in Lower Reserve may be explained by firm substrate in that wetland compared to Mother Norton Shoals (Weber, pers. observ.). Shorebirds may have preferred Mother Norton Shoals despite lower invertebrate density because substrate was easier to penetrate with their bills. Managed wetlands drawn down from March to May had soft substrate like Mother Norton Shoals. With equal penetrability, shorebirds may have preferred managed wetlands from March to May because of higher prey density.

If shorebird density is a function of invertebrate density, organic content may ultimately determine shorebird distribution. In British diked wetlands, the major determinants of chironomid abundance were organic content in sediment, and water depth levels throughout the annual cycle (Rehfisch 1994). On South Island, managed wetlands are likely to have more organic content than intertidal areas due to sedimentation and the absence of tidal flushing. Therefore, high organic content in managed wetlands may ultimately account for higher shorebird density at low tide.

MANAGEMENT IMPLICATIONS

Despite greater shorebird use of managed wetlands than natural mudflats, we do not advocate the building of more diked wetlands to replace natural marsh. Not all species benefit from diked wetland management (Burger et al. 1982). We do recommend that the integrative shorebird-waterfowl management technique be used in existing diked wetlands now being managed solely for waterfowl. We also recommend that more shorebird density comparisons between managed and natural areas be conducted in other coastal sites because our results are based on only 3 natural sites.

In managing wetlands for shorebirds, we suggest there be an interspersion of depths throughout the managed wetland complex at a site to provide for a diversity of species. Depths should be a maximum 5 cm for non-avocet shorebirds, targeted at 2–3 cm if possible for peeps. For avocets, mean water depth should be higher ($\bar{x}$ = 8.4 cm, SD = 4.5), but because most avocets leave by 1 May, water levels could be dropped to <5 cm in May. We recommend staggered drawdown periods to provide habitat for a diversity of species. At our site, managing for sea purslane and widgeongrass made habitat available over a longer time than would be available by just 1 management strategy. Staggered drawdowns allow new areas to open late in the season that have not been exploited by shorebird foraging, important because shorebird predation can cause significant declines in invertebrate biomass (Weber 1994). An interspersion of depths and drawdown periods also provides habitat to other avian wetland species (Epstein and Joyner 1986, Breininger and Smith 1990).

Shorebird and waterfowl management strategies on South Island integrated well because peak waterfowl and shorebird migration periods did not overlap. Waterfowl numbers over the years appeared to be maintained despite the extended drawdown. However, the drawdown period was longer (for the sake of shorebirds) than traditional waterfowl management in the South Carolina coastal region. The main cost of this extended drawdown might be increased growth of unwanted emergent vegetation toward the perimeter and shallowest areas of each managed wetland (R. Joyner, pers. commun.), but this hypothesis has not been adequately tested. Eradication of emergents is achieved at the Yawkey Center through year-round flooding (no drawdown) or prescribed burning. Thus, the cost of shorebird management might be more frequent year-round flooding or other emergent vegetation control management than under traditional waterfowl management.

In conclusion, the integrative shorebird-waterfowl impoundment management technique provided habitat in managed wetlands for migrating and wintering shorebirds. Shorebird density was higher in managed wetlands than natural mudflats not only at high tide, but even at low tide during most of the season. This strategy may help alleviate effects of decreasing quality and quantity of natural shorebird habitat.

LITERATURE CITED

ALTMANN, J. 1974. Observational study of behavior: sampling methods. Behaviour 49:227–267.

BOETTCHER, R., S. M. HAIG, AND W. C. BRIDGES, JR. 1995. Habitat-related factors affecting the distribution of nonbreeding American avocets in coastal South Carolina. Condor 97:68–82.

BREININGER, D. R., AND R. B. SMITH. 1990. Waterbird use of coastal impoundments and management implications in east-central Florida. Wetlands 10:223–241.

BURGER, J. 1984. Abiotic factors affecting migrant shorebirds. Pages 1–72 *in* J. Burger and B. L. Olla, eds. Shorebirds: migration and foraging behavior. Plenum Press, New York, N.Y.

———, J. SHISLER, AND F. H. LESSER. 1982. Avian utilization on six salt marshes in New Jersey. Biol. Conserv. 23:187–212.

DAVIDSON, N. C., AND P. R. EVANS. 1986. The role and potential of man-made and man-modified wetlands in the enhancement of the survival of overwintering shorebirds. Colonial Waterbirds 9:176–188.

DEVOE, M. R., AND D. S. BAUGHMAN. 1986. Coastal wetland impoundment project: problem identification and project description. Pages 13–27 *in* M. R. DeVoe and D. S. Baughman, eds. South Carolina coastal wetland managed wetlands: ecological characterization, management, status, and use. Vol. 2: tech. synthesis. Publication SC-SG-TR-86-2. South Carolina Sea Grant Consortium, Charleston.

ELDRIDGE, J. L. 1992. Management of habitat for breeding and migrating shorebirds in the Midwest. U.S. Fish and Wildl. Serv. Leafl. 13.2.14. U.S. Fish and Wildl. Serv., Twin Cities, Minn. 5pp.

EPSTEIN, M. B., AND R. L. JOYNER. 1986. Use of managed and open tidal marsh by waterbirds and alligators. Pages 529–579 *in* M. R. DeVoe and D. S. Baughman, eds. South Carolina coastal wetland impoundments: ecological characterization, management, status, and use. Vol. 2: tech. synthesis. Publication SC-SG-TR-86-2. South Carolina Sea Grant Consortium, Charleston.

ERWIN, R. M., J. S. HATFIELD, M. A. HOWE, AND S. KLUGMAN. 1994. Waterbird use of saltmarsh wetlands created for open marsh water management. J. Wildl. Manage. 58:516–524.

GILMORE, R. G. 1987. Fish, macrocrustacean, and avian population dynamics and cohabitation in tidally influenced impounded subtropical wetlands. Pages 372–395 *in* W. R. Whitman and W. H. Meredith, eds. Proc. of a symposium on waterfowl and wetlands management in the coastal zone of the Atlantic flyway. Delaware Dep. of Nat. Res. and Environ. Control, Dover.

HAIG, S. M., AND J. H. PLISSNER. 1993. Distribution and abundance of piping plovers: results and implications of the 1991 International Census. Condor 45:145–156.

HANDS, H. M., M. R. RYAN, AND J. W. SMITH. 1991. Migrant shorebird use of marsh, moist-soil, and flooded agricultural habitats. Wildl. Soc. Bull. 19: 457–464.

HELMERS, D. L. 1992. Shorebird management manual. Western Hemisphere Shorebird Reserve Network, Manomet, Mass. 58pp.

HOPKINS-MURPHY, S. 1989. The Santee Delta-Cape Romain Unit of the Carolinian–South Atlantic Biosphere Reserve. Pages 79–91 *in* W. P. Gregg, S. L. Krugram, and J. D. Wood, eds. Proc. of the symposium on biosphere reserves. U.S. Dep. of the Inter., National Park Service, Atlanta, Ga. 291pp.

HOWE, M. A., P. H. GEISSLER, AND B. A. HARRINGTON. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biol. Conserv. 49:185–199.

MARSH, C. P., AND P. M. WILKINSON. 1991. The significance of the Central Coast of South Carolina as critical shorebird habitat. Chat 54:69–91.

MCGOVERN, J. C., AND C. A. WENNER. 1990. Seasonal recruitment of larval and juvenile fishes into impounded and non-impounded marshes. Wetlands 10:203–221.

MIGLARESE, J. V., AND P. A. SANDIFER. 1982. An ecological characterization of South Carolina wetland impoundments. South Carolina Marine Resources Center. Tech. Rep. No. 51. South Carolina Dep. of Nat. Res. Charleston, S.C. 131pp.

MONTAGUE, C. L., A. V. ZALE, AND H. F. PERCIVAL. 1987. Ecological effects of coastal marsh impoundments: a review. Environ. Manage. 11:743–756.

MORRISON, R. I. G., C. DOWNES, AND B. COLLINS. 1994. Population trends of shorebirds on fall migration in eastern Canada 1974–1991. Wilson Bull. 106:431-447.

MYERS, J. P., R. I. G. MORRISON, P. Z. ANTAS, B. A. HARRINGTON, T. E. LOVEJOY, M. SALLABERRY, S. E. SENNER, AND A. TARAK. 1987. Conservation strategy for migratory species. Am. Scientist 75:19–26.

PAGE, G. W., AND R. E. GILL. 1994. Shorebirds in western North America: late 1800s to late 1900s. Stud. in Avian Biol. 15:147–160.

REHFISCH, M. M. 1994. Man-made lagoons and how their attractiveness to waders might be increased by manipulating the biomass of an insect benthos. J. Appl. Ecol. 31:383–401.

ROGERS, D. R., B. D. ROGERS, AND W. H. HERKE. 1994. Structural marsh management effects on coastal fishes and crustaceans. Environ. Manage. 18:351–369.

SENNER, S. E., AND M. A. HOWE. 1984. Conservation of nearctic shorebirds. Pages 329–421 *in* J. Burger and B. L. Olla, eds. Behavior of marine animals. Vol. 5. Shorebirds. Plenum, New York, N.Y.

SWIDEREK, P. K., A. S. JOHNSON, P. E. HALE, AND R. L. JOYNER. 1988. Production, management, and waterfowl use of sea purslane, Gulf Coast muskgrass, and widgeongrass in brackish impoundments. Pages 441–457 *in* M. W. Weller, ed. Waterfowl in winter. Univ. of Minnesota Press, Minneapolis.

TOMPKINS, M. E. 1986. Scope and status of coastal wetland managed wetlands in South Carolina. Pages 31–57 *in* M. R. DeVoe and D. S. Baughman, eds. South Carolina coastal wetland impoundments: ecological characterization, management, status, and use. Vol. 2: tech. synthesis. Publ. SC–SG–TR–86–2. South Carolina Sea Grant Consortium, Charleston.

———. 1987. South Carolina's diked tidal wetlands: the persisting dilemmas. Coastal Manage. 15:135–155.

WEBER, L. M. 1994. Foraging ecology and conservation of shorebirds in South Carolina coastal wetlands. Ph.D. Thesis, Clemson University, S.C. 126pp.

WILLIAMS, K. R. 1987. Construction, maintenance and water control structures of tidal impoundments in South Carolina. Pages 139–166 *in* W. R. Whitman and W. H. Meredith, eds. Proc. of a symposium on waterfowl and wetlands management in the coastal zone of the Atlantic flyway. Delaware Dep. of Nat. Res. and Environ. Control, Dover.

Received 16 December 1994.
Accepted 21 July 1995.
Associate Editor: Ryan.