This document was produced by the United States Geological Survey, Patuxent Wildlife Research Center, at the request of Cape Hatteras National Seashore. The information and recommendations presented are the professional opinions of the scientists that analyzed and interpreted the scientific data associated with protected species at the Seashore. This information will be considered by the National Park Service (NPS), along with federal laws and mandates, NPS policies, other scientific information, and public input, in developing management plans and conservation strategies implemented at the Seashore.

MANAGEMENT AND PROTECTION PROTOCOLS FOR THE THREATENED PIPING PLOVER (*Charadrius melodus*) ON CAPE HATTERAS NATIONAL SEASHORE, NORTH CAROLINA

MANAGEMENT AND PROTECTION PROTOCOLS FOR THE THREATENED PIPING PLOVER (*Charadrius melodus*) ON CAPE HATTERAS NATIONAL SEASHORE, NORTH CAROLINA

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Executive Summary

1. The breeding population of the piping plover (*Charadrius melodus*), a federally-threatened shorebird, at Cape Hatteras National Seashore (CAHA) declined from 15 pairs/yr to 3 pairs/yr from 1989-2004. A population of this size may face immediate risk of extirpation from several sources. At several former breeding sites at CAHA, there have been no nesting pairs in recent years.

2. Only one plover chick has survived to fledging at CAHA, 2001-2004. While survival of eggs has often been moderate to high since 1989, survival of chicks has generally been low. Reproductive rate improved in 2005, with 6 chicks fledging from 2 pairs in conjunction with more actively managed closures in brood-rearing areas.

3. Inclement weather, predation, and recreational disturbance may negatively impact reproductive success of piping plovers at CAHA. Recreational disturbance and habitat loss caused by ORVs may discourage pairs from attempting to nest.

4. To recover the breeding plover population at CAHA, it will be necessary to create disturbance-free areas containing high-quality nesting and foraging habitat from the territory-establishment phase to the brood-rearing phase of the breeding cycle. We provide three management options to reduce risk of disturbance and mortality. They entail full closure of the seashore to recreation, closure of historical breeding sites to ORVs, or restriction of recreation to an oceanside corridor.

5. To reduce the risk of egg and chick mortality, we recommend continued efforts to trap and remove mammalian predators from all aforementioned sites and the continued use of predator exclosures around nests. We further recommend intensive monitoring and surveillance of protected areas to determine the extent and timing of threats to nests and broods, including nest overwash, predation, and disturbance or vandalism by humans.

6. Even if reproductive success improves under our recommendations, however, a population of this size will take several years to recover in the absence of immigrants from other sites, and there may not be a noticeable increase in population size in the short term. We recommend using an Adaptive Management approach, combining research, monitoring and management to assess the effectiveness of management actions in achieving our goals to recovery this threatened species at Cape Hatteras.

7. The size of nonbreeding flocks, their habitat use, their site tenacity, and sources of disturbance and mortality are not known with high precision. We recommend monitoring standards and research to address this problem, while at the same time restricting recreation adjacent to important migration and wintering sites to afford nonbreeding birds increased protection.

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Introduction

The Atlantic Coast population of the piping plover (*Charadrius melodus*) was federally listed in 1986 as threatened (Federal Register 1985). At that time approximately 790 pairs remained and the species was in decline (USFWS 1996). Habitat loss caused by human development and recreation, and low reproductive rates caused by human disturbance and predation were considered to be the primary causes of the decline (Haig 1992). Disturbance and predation were intensively managed after listing, and the population rebounded to 1676 pairs by 2003 (USFWS 2004), but was still short of the recovery goal of 2000 pairs (USFWS 1996). The population south of New Jersey was estimated at 203 pairs in 2003, well short of the regional goal for the southern Atlantic Coast (DE, MD, VA, NC, SC) of 400 pairs, and North Carolina itself experienced a >50% decline in breeding pairs from 1989 to 2003 (USFWS 2004).

No published accounts exist of breeding piping plovers in North Carolina from 1902 to 1960, when a pair was found on Ocracoke Island (Golder 1985). Four nests and one brood were discovered within the boundaries of Cape Hatteras National Seashore (CAHA) in 1984 incidental to monitoring of other species, and 5 chicks were known to have fledged that year (Golder 1985). Nine pairs were counted in 1986, again incidentally (Golder 1986), and 10 pairs were discovered in 1987 in specific surveys for the plover (Cooper 1990). The plover population reached a high of 15 pairs in 1989 and varied between 11 and 14 pairs until 1996, after which a sharp decline began. The population reached a low of 2 breeding pairs in 2002 and 2003 with only 3 breeding pairs reported in 2004 (Fig. 2, Lyons 2001, Lyons 2002, Lyons 2003, Lyons 2004, M. Lyons, National Park Service. unpublished data 2004), and 2 in 2005. Plovers breeding at CAHA have had to coexist with increasingly higher numbers of human visitors to the park. From 1986-2004, the number of recreational visitors to CAHA increased 44%, from 1.54 million/yr to 2.21

million/yr (NPS 2005). Specifically, there was a 29% increase in visitation in the plover nonbreeding months (Sept.-Feb.) from 0.57 million/yr to 0.73 million/yr, and a 52% increase in the plover breeding months (Mar. – Aug.) from 0.97 million/yr to 1.48 million/yr.

Small populations may face a risk of immediate extinction from several general sources. These include environmental stochasticity (i.e., random environmental variation, such as storm events), inbreeding depression, genetic stochasticity (i.e., random variation of genotypes, which may not be adapted to local conditions), demographic stochasticity (i.e., random variation in birth and death rates), and the Allee effect, in which organisms are unable to find mates (Lande 1988).

Given the vulnerability of the small plover population at CAHA to extinction due to random events, the persistence of the population will depend partly on controlling non-random sources of mortality to adults, eggs, and chicks. Predators, human disturbance, and access to foraging habitat have been identified in past research as limiting reproductive success at CAHA (Coutu 1990, Kuklinski 1996). There may be evidence for an Allee effect at CAHA, as plover monitoring reports from 2001-2003 and preliminary observations from 2005 indicate that unpaired birds displaying territorial behavior were observed in the pre-laying period at several sites (Lyons 2001, Lyons 2002, Lyons 2003). Thus, providing a disturbance-free environment early in the season may assist plovers attempting to establish territories and attract mates.

In addition to its declining breeding population, CAHA is used by migrating plovers and by wintering plovers from the threatened Atlantic Coast and Great Plains populations and the endangered Great Lakes population. The dynamics of the nonbreeding populations at CAHA are less-well documented than for the breeding populations. However, gathering information about

and protecting nonbreeding plovers and their habitat is a priority in the recovery plans for all three North American breeding populations (USFWS 1988, USFWS 1996, USFWS 2003).

The following management plan is intended to provide guidance for reducing risk of mortality and disturbance to breeding and nonbreeding birds and increasing breeding success. Even if reproductive success improves under our recommendations, however, a breeding population of this size will take several years to recover in the absence of immigrants from other sites, and there may not be a noticeable increase in population size in the short term. These protocols are based on current biological knowledge. It will be up to the NPS to decide how best to incorporate these protocols into a more comprehensive management plan, given the logistical and political realities faced by CAHA, and protocols for protection of other species. Finally, the protocols below provide site-specific recommendations and are intended to apply only to lands within the jurisdiction of CAHA.

The USGS Patuxent Wildlife Research Center developed these protocols, based on the best available scientific information, to guide management, monitoring and research activity at CAHA that would result in the protection and recovery of each species. These protocols do not attempt to balance the need for protection of these species with other activities that occur at CAHA, nor was NPS management policy considered in detail. A draft of the protocols was sent to species experts for scientific review; the final draft of protocols were reviewed by NPS personnel to ensure that description of recent management at CAHA was accurately represented and that the approach was consistent with our work agreement.

Distribution and Breeding Biology

The piping plover is a small (17-18 cm long, 43 – 63 g) sand-colored shorebird endemic to North America (Haig 1992). Breeding piping plovers occur in three distinct sub-populations:

the Atlantic Coast (from the Maritime Provinces of Canada to the Outer Banks of North Carolina), the Great Lakes (along Lake Superior and Lake Michigan), and the Great Plains (from southern prairie Canada to Iowa). Wintering populations occur on the Atlantic Coast from North Carolina to Florida, and the Gulf Coast from Florida to Mexico and the Carribean.

On the Atlantic Coast, breeding territory establishment and courtship generally begin in late March, the first nests are initiated in late April, and the brood-rearing period extends from late May to mid-August. In contrast, peak arrival in the Great Plains is the third week of April. Departure from the breeding grounds extends from mid-July to early September. Residency on the wintering grounds occurs from mid-July through early May, with the duration depending on the location.

The mating system is monogamous, although retention of the same mate between breeding seasons is variable. The nest consists of a shallow scrape in the substrate created by the male, often lined with shell fragments. Four is the modal clutch size, and one egg is laid every other day until the clutch is complete. Incubation typically commences the day of clutch completion, but sometimes when the penultimate egg is laid, and members of a pair share incubation duties. The eggs and chicks are cryptically-colored. Incubation time ranges from 25-29 days. A pair will renest multiple times if successive clutches are destroyed, but renesting after the chicks hatch is rare. Chicks leave the nest scrape within a few hours of hatching, and never return except where a nest hatches at night (Wolcott and Wolcott 1999). Members of a pair share brood-rearing duties (which comprise defending a brood-rearing habitat, brooding, giving alarm calls, and leading the chicks to foraging and roosting habitat), however females are known to desert their brood within the first week after hatch, a behavior observed frequently in one New York study (Cohen 2005) but infrequently elsewhere on the the Atlantic Coast.

Although chicks follow adults to foraging habitat, they forage for themselves. Fledging time ranges from 21-35 days (R. Boettcher, VA Dept. Game and Inland Fisheries, pers. comm.).

Breeding at CAHA

1989-2004.—The National Park Service began monitoring plovers at CAHA in 1989. Six primary nesting sites have been identified. These are Bodie Island Spit at the south end of Bodie Island, Cape Hatteras Point (Cape Point), South Beach, and Hatteras Spit on Hatteras Island, and the north and south tips of Ocracoke Island (NPS unpublished data 2004). Locally-breeding plovers arrive at CAHA in mid-March, begin courting and pairing in April, and begin to initiate nests the third week of April (Coutu 1990).

Bodie Island Spit had one pair of breeding plovers in 1996, 1997, 2001, 2002, and 2004. Mean nest survival (nests that hatched at least one egg/nests laid) was 40%, mean chick survival (chicks fledged/eggs hatched) was 0%, and mean reproductive rate (chicks fledged/pair) was 0.00.

Cape Point had 4-6 breeding pairs of plovers/yr from 1992-1996, after which the number of pairs declined to 1 pair/yr by 2001. No pairs were found at this site from 2002-2004. Mean nest survival was 64% and mean chick survival was 37%. Reproductive rate ranged from 0.00 in 2001 to 1.70 fledglings/pair in 1999, and averaged 0.85.

South Beach had 1 pair of plovers/yr from 1993-1999. Mean nest survival was 93% and mean chick survival was 36%. Reproductive rate ranged from 0.00 (in several years) to 2.0 fledglings/pair (in 1998 and 1999), and averaged 0.67.

At Hatteras Spit, 3-5 pairs nested/yr from 1992-1998, and 1-2 pairs nested from 1999-2004, including one pair in 2004. Mean nest survival was 40% and mean chick survival was

22%. Reproductive rate ranged from 0.00 (in several years including 2002-2004) to 2.00 fledglings/pair in 2001, and averaged 0.47.

North Ocracoke had 1-4 breeding pairs/yr from 1992-1996. Mean nest survival was 36% and mean chick survival was 43%. Reproductive rate ranged from 0.00 to 0.50 fledglings/pair and averaged 0.30. South Ocracoke had 1-2 breeding pairs from 1995-1999, and 1 breeding pair in 2003-2004. Mean nest survival was 67% and mean chick survival was 25%. Reproductive rate ranged from 0.00 (in several years) to 4.00 fledglings/pair in 1998, and averaged 0.70.

Mean nest survival at these CAHA sites was moderate to high when compared with nest survival at other breeding grounds, while chick survival was low (Mayer and Ryan 1991, Patterson et al. 1991, Loegering and Fraser 1995, Goldin and Regosin 1998). Except at South Beach, however, where nest survival was 100% in all years but one, nest survival varied greatly among years. Chick survival was highly variable at all sites. With all sites pooled, reproductive rate was correlated with chick survival ($r = 0.87$, $P < 0.001$, $n = 13$ yr), but not nest survival ($r = 0.16$, $P = 0.603$, $n = 13$ yr).

2005.—In 2005, there was evidence of territory prospecting by at least one pair at Bodie Island Spit, at least one pair at South Ocracoke, one pair at Hatteras Spit, and two pairs at Cape Point. Ultimately, nests were found for one pair at Hatteras Spit and one pair at Cape Point. Each pair fledged 3 chicks.

Nonbreeding Plovers at CAHA

North Carolina is currently the only state on the Atlantic Coast that has piping plovers during all phases of the annual cycle. Band sightings indicate that plovers from all three North American breeding populations use CAHA during migration and/or the winter, and plovers from the endangered Great Lakes population have been documented in fall and spring migration and

the wintering period. All plover breeding sites at CAHA were designated as critical habitat for wintering birds, as defined by the Endangered Species Act (Federal Register 2001) until 2004, when a court decision vacated the designation for Oregon Inlet, Cape Point, Hatteras Inlet, and Ocracoke Island (Cape Hatteras Access Preservation Alliance vs. U.S. Dept. of the Interior, 344 F. Supp. 2d 108 (D.D.C. 2004)).

From 2000-2005, the greatest number of nonbreeding plovers at CAHA occurred during fall migration, which begins in July and peaks between July and September (Table 1). The fall counts were highest at South Ocracoke, followed by Oregon Inlet (Bodie Island Spit, Pea Island National Wildlife Refuge, and formerly Green Island which is now largely unusable due to vegetation growth), then Hatteras Spit and Cape Point. Fall migration may last until November.

The first banded winter residents have appeared in August, although wintering birds may arrive in July. The nonbreeding population from Dec.-Jan. likely consists entirely of winter residents. The size of the resident wintering population is not precisely known, but it may be on the order of 20-35 birds (Table 1). Maximum numbers seen were about 50% of the recent norm in the winter of 2004-2005, but whether that was due to a difference in survey effort is unknown. The highest counts of wintering birds were at Oregon and Ocracoke Inlets. Rarely surveyed shoals, such as Clam Shoal (which is not part of CAHA) in Pamlico Sound, had up to 6-7 plovers when they were checked. Based on a sample of banded birds, winter residents can be present until April.

Spring migrant may appear in February or early March, and their numbers peak in late March or April (Table 1). Sites at Oregon Inlet have had the highest abundance of spring migrants, followed by Ocracoke Inlet, with lesser numbers at Hatteras Spit and Cape Point.

Ecological factors governing the distribution and size of the nonbreeding population at CAHA are unknown.

Habitat and Foraging Ecology

Breeding Habitat

Nesting.—On the Atlantic Coast, piping plovers nest in sand, gravel, or cobble substrates in backshore, dune, interdune blowout, overwash fan, and barrier flat zones of open or sparsely-vegetated beaches (Haig 1992). Nests sites may have little or no slope (Cairns 1982, Burger 1987), although nesting does occur on lower-elevation dunes (Cairns 1982). On wide beaches, plovers nest in the open to maintain a wide field of view, but on narrower beaches eggs can be laid in clumps of vegetation (Cairns 1982). On Assateague Island, Maryland, mean vegetative cover within 1 m of nest sites ranged up to 19.3% for depredated nests, and up to 14.8% for other nests (not significantly different, $P > 0.05$, Patterson et al. 1991). In New Jersey, substrate with 5-20% shell cover was preferred over sites with no shell cover (Burger 1987). Where beaches are wide enough, plovers nest far from the tide line to reduce risk of nest overwash, but this places nests closer to vegetated dunes where risk of predation is high (Burger 1987). In Virginia, Piping Plovers typically nest on the backside of overwash fans that have a minimum of 25% shell cover and offer unimpeded access to backside MOSH (R. Boettcher, VA Dept. Game and Inland Fisheries, pers. comm.).

Foraging.—Plovers prey mainly on terrestrial arthropods and benthic worms (Haig 1992). Adults forage both day and night (Staine and Burger 1994), but young chicks are brooded during the night (Wolcott and Wolcott 1999), although they are still vulnerable to nocturnal mortality due to weather, predation, or human activity. During territory establishment, foraging

adults exhibit a preference for low-wave energy moist substrate habitats (MOSH) for foraging, especially intertidal mudflats and sandflats (Keane et al. in press). Benthic invertebrates in MOSH provide prey at a time of year when terrestrial arthropods are scarce (Houghton et al. unpublished), and in Massachusetts were found to be more abundant than in the high-wave energy ocean intertidal zone (Hoopes 1993). Foraging broods exhibit a preference for wrack and MOSH, including mudflats, sandflats, and ephemeral pools (Goldin 1993, Hoopes 1993, Kuklinski et al. 1996, Elias et al. 2000). Such habitat has a higher abundance of terrestrial arthropods than drier zones (Hoopes 1993, Loegering and Fraser 1995, Kuklinski et al. 1996, Elias et al. 2000).

Breeding Habitat at CAHA.—In 1989, plovers at CAHA were observed to lay 50% of their nest attempts on the ocean beach, 37% on the dune toe, and 5% (1 nest) in an overwash (Coutu 1990). Broods foraged primarily on damp sand flats (Coutu 1990), where their percent time spent foraging, foraging rate (pecks/min), and prey abundance was much higher than in other habitats (Kuklinski 1996). Brood percent use of ocean fresh wrack, sparse vegetation, wet sand flat, and overwash was greater than expected based on the percent availability of those habitats (Kuklinski 1996).

Foraging Habitat Availability

Chicks with access to MOSH survived better than chicks without such access in Virginia (Loegering and Fraser 1995), Rhode Island (Goldin and Regosin 1998), and in some years in New York (Elias et al. 2000). Burger (1994) found that having a diversity of foraging habitat zones available to broods reduced the impact of human disturbance, because it provided opportunities for chicks to escape disturbance and still forage.

Winter

Wintering plovers on the Atlantic Coast select wide beaches in the vicinity of inlets that are associated with a high percent area of MOSH (Nicholls and Baldassarre 1990, Wilkinson and Spinks 1994). In coastal Alabama, MOSH was the primary foraging habitat, while sandy beaches served as roosting habitat (Johnson and Baldassarre 1988). Wintering plovers in Texas exhibited a preference for algal flats and sandflats (Drake et al. 2001). Because tide and weather variation often cause plovers to move among habitat patches, a complex of patches may be important to local wintering populations (Nicholls and Baldassarre 1990).

Threats to Survival and Reproductive Success

Weather and Tides

Direct effects.—Storm events lead to unusually high tides and flooding that can overwash plover nests (Haig 1992). Plovers may also nest close enough to the tide line to lose their nests on normal high tides. Storms can also result in widespread mortality of chicks (Houghton et al. unpublished). In New York, nest and chick survival were higher in warm, dry years than cool, wet years (Houghton et al. unpublished). Temperature, however, was not a factor limiting productivity in one study at CAHA (Kuklinsi et al. 1996). The effects of weather on winter survival are unknown for piping plovers, but high survival (100%) in a wintering population in Texas was speculated to be partly a function of a mild climate, as well as a lack of study sites adjacent to areas of human disturbance (Drake et al. 2001).

Indirect effects.—Flooding due to tides or weather may alter habitat enough to render it unsuitable for nesting. This may lead to territory abandonment within or among breeding seasons (Haig and Oring 1988).

Predation

Direct effects.—Predation is a primary factor limiting reproductive success of the piping plover (Haig 1992). Predators of eggs, chicks, and/or adults include mink (*Mustela vison*), red fox (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*), opossum (*Didelphis marsupilais*), domestic dogs, feral and domestic cats, crows (*Corvus* spp.), and gulls (*Larus* spp.) (Haig 1992), as well as raptors (Murphy et al. 2003a) and blackbirds (Icteridae) (Houghton et al. unpublished).

Ghost crabs (*Ocypode quadrata*) have occasionally been implicated in the loss of nests (Watts and Bradshaw 1995) and chicks (Loegering 1995). At Chincoteague National Wildlife Refuge in Virginia, however, interactions between crabs and plovers did not result in predation of eggs or chicks, even on beaches where crabs were very abundant (Wolcott and Wolcott 1999). Furthermore, ghost crabs could not be induced to prey on quail (*Coturnix japonicus* and *Colinus virginianus*) eggs and chicks in field and laboratory experiments, even when foraging behavior was elicited in the crabs with bait (Wolcott and Wolcott 1999). Anecdotal evidence indicates that ghost crabs may be more of a problem in North Carolina than at sites further north (D. Allen, North Carolina Wildlife Resources Commission, pers. comm..)

Indirect effects.—Reproductive failure due to predation apparently led to abandonment of territories within and between breeding seasons, specifically when population-level reproduction was poor (Cohen 2005). This effect was not demonstrated in the Great Plains (Haig and Oring 1988, Wiens and Cuthbert 1988). The consquences of site abandonment to adult survival and future reproductive success are unknown.

Human Activities

Direct Effects.— Human pedestrians and joggers occasionally destroy nests or kill chicks, either by intentional vandalism or by accident (Patterson et al. 1991, Houghton et al. unpublished). Furthermore, ORVs can run over adults, nests, and chicks, which may run or crouch in vehicle tracks in response to danger. Chicks are difficult to see in this situation due to their cryptic coloration (Melvin et al. 1994). Human development and recreation results in loss or degradation of breeding habitat (Haig 1992). Off-road vehicle (ORV) use has been demonstrated to destroy the wrack line (Goldin 1993), thereby degrading an important foraging habitat. Breeding and nonbreeding birds are subject to disturbance (disruption of normal activities) by ORVs and pedestrians.

Beach renourishment and artificial dune construction to protect human structures from storm damage may temporarily increase the size of nesting areas (Melvin et al. 1991). However, there are negative indirect effects associated with renourishment (see below).

Indirect Effects.—The impact of predation has been postulated to be greater on beaches with high human use, because the presence of pets and trash that may attract wild predators is correlated with the presence of humans (USFWS 1996). In some studies, beaches with high levels of human disturbance had lower reproductive rates than less-disturbed beaches (Cairns 1982, Flemming et al. 1988). At other sites, disturbance did not affect reproductive rate (Patterson et al. 1991, Hoopes 1993, Burger 1994), although pedestrians, kites, and ORVs caused a decrease in brood foraging behavior in Massachusetts (Hoopes 1993) and New Jersey (Burger 1994). It is important to note, however, that in the high-disturbance sites in the above studies, disturbance was being actively managed to protect plovers. In New York, the response of incubating adults to the presence of humans near the nest was found to be highly variable,

ranging from delayed laying schedules or nest abandonment to no effect. Average nest success, however, was unrelated to the number of disturbance sources observed within 100 m of nests during daily monitoring (Houghton et al. unpublished). Plovers may be more sensitive to disturbance in the Atlantic Coast southern recovery unit, as evidenced by longer flush distances in response to disturbance sources at Assateague National Seashore (Loegering 1992). In Texas, plovers avoided foraging on sandflats close to areas of high human use (Drake et al. 2001). Zonick (2000) found that the number of plovers was lower on disturbed bayside flats than undisturbed flats, and that plovers experienced lower foraging efficiency when disturbed. Other unpublished data support the assertion that winter habitat selection is negatively correlated with human activities and development.

ORV use affects the geomorphology of the beach through sand displacement and compaction, which may lead to steeper dune profiles (Anders and Leatherman 1987), which may be unsuitable for plover nesting. Destruction of the wrackline by ORVs may decrease reproductive success due to loss of important habitat used for foraging and cover (Goldin 1993).

Renourishment projects alter the profile of beaches causing increased erosion and habitat loss over longer periods (Leatherman and Allen 1995). Furthermore, beach stabilization prevents normal storm processes such as overwash fan formation, thereby leading to long-term loss of MOSH and accelerated vegetative succession in potential nesting habitat (Dolan et al. 1973). A cumulative effect of renourishment occurs when it is followed by human development. Construction of human structures on beaches eliminates breeding territories, and may result in an increased level of human disturbance of and predation on remaining pairs (Houghton et al. unpublished). Since wintering populations have been shown to prefer areas

around inlets, artificial closure of storm-created inlets may be expected to reduce local carrying capacity for nonbreeding birds.

Threats at CAHA

Predation, human disturbance, and inclement weather have been implicated as causes of low reproductive success at CAHA (Cooper 1990, Coutu et al. 1990, Kuklinski et al. 1996, Lyons 2002, Lyons 2003, Lyons 2004). Poor nutrition of broods without access to MOSH was also suspected as a source of mortality in one study (Kuklinski 1996).

In 1996, nest predation varied among sites and was most severe at Hatteras Spit. Nest abandonment increased from 2000-2002 compared to previous years, but no nests were lost in 2003, of the 2 laid. Abandonment was sometimes associated with predator trails circling nest exclosures (Lyons 2002, Lyons 2003, Lyons 2004). A nest was lost to flooding in 2002. In 2001-2003, sources of chick loss were unknown. Chick mortality, however, sometimes followed a rain event. After the disappearance of some chicks, predator trails were found where the brood was last seen, including red fox, domestic dog, and cat (Lyons 2002, Lyons 2003).

In 1990, research indicated that enforcement levels at the time were not adequate to keep pedestrians, pets, and ORVs out of restricted plover breeding areas (Coutu et al. 1990). In 1996 potential disturbance sources remained apparently outside of protected areas, and predation rather than disturbance was considered the major direct threat to reproductive success (Kuklinski 1996), although fieldwork did not begin until May 30 and missed the first part of the nesting season. Documented violations of protected areas by pedestrians began to increase sharply after 2000, but this may have been due in part to more careful recording of incidents (Lyons 2002, Lyons 2003, Lyons 2004). Approximately 50-60 incidents of ORVs entering protected areas were recorded each year from 2000-2002, and in 2003 the symbolic fence was vandalized by an

ORV and several instances of ORVs within the protected area were observed (Lyons 2002, Lyons 2003, Lyons 2004).

Rates and sources of mortality and disturbance and responses of plovers to disturbance in the nonbreeding period have not been assessed at CAHA. Plover foraging and roosting habitat, however, is used by pedestrians and ORVs year round. The potential therefore exists for direct mortality of plovers due to ORVs (Melvin et al. 1994) and domestic pets, and disturbance to roosting and foraging birds which may reduce foraging efficiency or alter habitat use thereby increasing the risk of nutritional or thermal stress (Zonick 2000).

Protection Measures

Management of breeding populations on the Atlantic Coast has focused on predation control and reduction of human disturbance and risk of mortality due to pedestrians and ORVs (USFWS 1996, Erwin et al. 2002). Predator exclosure cages placed around nests have successfully reduced nest losses (Melvin et al. 1992, Erwin et al. 2002) and may contribute greatly to population recovery (Larson et al. 2002). Predators, however, may learn to hunt adult plovers at exclosures (Murphy et al. 2003a). Furthermore, the technique does not promote self-sustaining populations in the long term because it does not eliminate predators (Johnson and Oring 2002). Electric fences around nesting and brood-rearing areas have been used successfully to improve reproductive rate in the Great Plains (Mayer and Ryan 1991), but may provide little extra benefit over exclosures in places where chick survival is not limiting reproductive success (Murphy et al. 2003b). On the coast, electric fences may be difficult to maintain (USFWS 1996).

Reduction of human disturbance usually entails erection of a series of special "Bird Nesting" signs connected by string, termed "symbolic fence," around nests or nesting habitat (USFWS 1996, Erwin et al. 2002). Protection from disturbance also entails closure of beaches to

ORVs and pedestrian traffic during part or all of the breeding period, and restrictions on pets, kites, trash disposal, and other potential disturbances (USFWS 1996).

Recent Management at CAHA

Additional management needs for Hatteras Inlet were enumerated in the Atlantic Coast revised recovery plan as predator exclosures, additional predator control, vegetation control, monitoring of brood foraging and ORV impacts, additional enforcement of protective rules, intensified wardening, education and outreach, control of feral animals, pet restrictions, and clarification of signs (USFWS 1996).

At CAHA starting in 2004, ORV traffic is restricted year-round to a 150'-wide corridor parallel to the shoreline, bounded at one side by the average high water line. Vehicles may drive along or park within the corridor. Where there is a primary dune line, this corridor effectively extends to the dune toe in most places. Thus, little to no ocean intertidal zone, ocean wrack, or ocean backshore habitat is free of ORV use between breeding periods. With some exception at the inlets, the dunes, sound side shoreline, and interior features (such as sandflats, overwash fans, and ephemeral pools) are free from ORV use, but not pedestrian use, year round. Pedestrians, but not pets, are permitted outside the ORV corridor at the spits, except where there are specific "resource closures."

Historically-used breeding habitat has been closed to ORVs and pedestrians during the first week of April in most locales in most years (Lyons 2004), using symbolic fencing with interpretive signs. Such resource closures are off limits to all recreation, including pedestrians and pets. However, this policy is not consistently applied prior to the discovery of nests, and string is not always used to bar the gaps between the signposts until after eggs are laid. In 2003 violations of protected areas by pedestrians and ORVs were frequent, especially at Hatteras Spit,

prompting an increased presence of monitors and law enforcement. Breeding sites are sometimes closed to ORVs, to varying degrees, when a nest is expected to hatch (USDOI 2004).

Predator exclosures are erected around most nests. The effectiveness of exclosures in protecting nests, however, was lower in 2001 (33% of exclosed nests hatched) and 1999, 2000, and 2002 (50% of exclosed nests hatched) than in previous years (75-90% of exclosed nests hatched) due to nest abandonment associated with predator disturbance (Lyons 2002, Lyons 2003). From 2002-2005 the NPS undertook trapping to remove mammalian predators from Bodie Island and Hatteras Island. In 2002, 12 foxes were removed from Hatteras Island by U.S. Dept. of Agriculture (USDA) Wildlife Services personnel, and another 16 from Bodie Island. USDA officials believed there was still one fox left near South Beach, and a number of foxes on Bodie Island. In 2003, 15 foxes were removed from Bodie Island and 1 from Hatteras, as well as three opossums and one raccoon at Hatteras. CAHA staff removed one feral cat from near Hatteras Inlet. Although a number of foxes were still believed to be on Bodie Island, no fox tracks were seen in plover habitat after trapping began in 2002. Predator removal may enhance the success of exclosures.

CAHA has a leash law but it is loosely enforced. CAHA has no regulations regarding the flying of kites near endangered species areas (Lyons 2003). With over 70 miles (112 km) of beach to patrol, a limited staff size, and 24 hour public access, biological monitoring and law enforcement are challenging at CAHA.

There are no specific procedures for protection of nonbreeding plover habitat at CAHA. Migrants may currently benefit from nesting area closures (see below), which in some years were left up for an extended period to protect migrants. Furthermore, the current ORV corridor may provide some refuge from disturbance to nonbreeding birds.

In 2005, a 0.1-mile "passthrough only" section of the ORV corridor was enforced at Bodie Island spit, to reduce disturbance to plovers foraging at ephemeral pools close to the original corridor boundary. Pedestrians were not allowed in the passthrough zone. At Cape Point, a resource closure was created around a complex of ephemeral pools to protect an oystercatcher brood (the closure extended to approximately 50 feet from the edge of the pools). This closure was later used by a plover brood that hatched to the west. Cape Point was closed to ORVs after the plover brood moved to the ephemeral pool area. At Hatteras Spit, ORV traffic was only permitted in the ORV corridor once per hour in convoys escorted by bird monitors, to reduce the risk of mortality to an oystercatcher brood and to reduce disturbance to an incubating plover nest. ORVs were permitted to park at the tip of the spit, west of the escort corridor. The spit was closed to recreation at night. Once the plover eggs hatched, Hatteras Spit was closed to ORV traffic until the chicks fledged. At South Ocracoke, the ORV corridor was narrowed in one place to protect a section of ocean intertidal zone where a pair of adult plovers was observed foraging on several occasions. ORVs were permitted to drive past the protected area in the backshore, but were restricted from the shore of the Sound.

Effects of current management.—Current management at CAHA results in the presence of ORVs in oceanside and inlet habitat during the nonbreeding and territory establishment periods, and pedestrians in oceanside, inlet, and soundside habitat. Based on 2005 management, recreation is only restricted from plover habitat when broods of plovers or other species are present, although recreation is kept to a 50 m distance from incubating nests by resource closures. As detailed above (see "Threats to Survival and Reproduction"), the effects of this recreation may include the crushing of adult birds, destruction of the wrack line (leading to a decrease in foraging opportunities for adults and broods), alteration of the beach profile which

can affect suitability for nesting, disturbance to adult birds (with possible disruption of territory establishment or decrease in foraging efficiency), vandalism of nests, and an increased presence of domestic and wild predators, that may in turn decrease nest and chick survival or lead to territory abandonment.

Adaptive Resource Management

Monitoring of floral and fauna over large landscapes should always include three components: a research question(s) aimed at a desired goal, a management approach or experiment to try to determine causality, and a monitoring component to determine the resultant magnitude, duration, and latency of changes associated with the management action or experiment. As monitoring results are revealed, a feedback loop allows the manager to either continue the current management practice or technique, or modify it until the desired trajectory is achieved.

The recent rapid decline in breeding numbers and extremely low population size of breeding plovers at CAHA necessitates the immediate simultaneous management of as many conceivable threats as possible. The effectiveness of management, however, should be assessed in an ongoing manner to the extent possible. This will assist managers in choosing from among the management options recommended below. While improvement in demographic parameters may not be obvious at first regardless of which option is chosen for a particular site, changes in behavior, disturbance rates, and abundance of potential predators may be immediately detectable. The research questions detailed below are designed to allow managers to understand the effect of management, as well as to set more specific management goals.

Questions to Be Addressed by Research and Monitoring

1. What is the nesting population, where are nests located, and what is their hatching and fledging success?
2. What is the size of the wintering population, where are the flocks located, how site faithful are they, and how much movement is there between them?
3. What factors limit the size and distribution of breeding and nonbreeding populations?
4. How do young and adults use nesting and feeding habitat (breeding, migration, and winter seasons)? How much site fidelity is there?
5. What factors limit nesting success?
6. What are survival rates of young in nest, post-fledged, immatures, and adults?
7. How significant is this (e.g. CAHA) breeding or wintering population segment to the state, region (middle Atlantic coast), or Atlantic coast wide population changes and trends?
8. What is the current level of ORV, pedestrian traffic, and leashed and unleashed pets in piping plover habitat?

Adaptive Management Protocols

Objective 1: To attain a nest exclosure design that protects eggs from predation and prevents harrassment and mortality of incubating adults by predators in accordance with the "Guidelines for the Use of Predator Exclosures to Protect Piping Plover Nests" in the Atlantic Coast revised recovery plan (USFWS 1996).

Proposal: Several treatments may be tested for the same nest over time, as the purpose is to modify the exclosure design until the risk of mortality of eggs and adults is minimized, rather than to stick to one treatment until the nest is lost. The stewards will have to decide which designs make sense to try, based on the risk and the circumstances, and some plovers may refuse to incubate inside an exclosure of any design. Pre-construction evaluation, construction, and post-construction monitoring should be performed according the the Atlantic Coast revised recovery plan guidelines (USFWS 1996). There are many exclosure designs in the literature, but the treatments we propose are

a) standard 3 m diameter circular exclosure of 5-cm welded wire fencing, staked with steel fence posts and roofed with bird netting (Fig. 3).

b) Design *a*, but with 3 m long straight wings of exclosure fencing attached to opposite sides of the circle, to prevent predators from circling the exclosure (Fig. 3).

c) Design *a* or *b*, with a battery-powered electrified wire girdling the exclosure approximately 0.3-0.6 m from the ground, to deter predators.

d) No exclosure

A fifth "treatment" would be to remove a particular predator through hunting or trapping if it appears to be causing a problem. This treatment can be added to any of the above exclosure designs, and should be used with treatment *d* if an exclosure has to be removed due to a nuisance predator.

Exclosures should be monitored with infrared 24 h time lapse videography, to determine number of predator encounters, predator response to the exclosure (including time spent at the exclosure, or near the nest if there is no exclosure), response of the adult plovers to the predator, and outcome of the encounter (survival of nest or adult). However, care must be taken to ensure

the camera and its foundation does not serve as a perch for avian predators. If resources are an issue, the exclosure can be checked each day for signs of disturbance, and the camera only used if a problem becomes evident (but it should be used in any case when the expected hatch date is imminent). Qualitative results of changing the design can be inspected at first, but quantitative analyses may be conducted after several years of data are gathered (or the population size grows enough to permit it.

Objective 2: To compare disturbance rates, habitat availability and use, and the presence of potential predators among sites where different management options are being employed. Note that the decision about which management option to use should be based on providing the most protection possible to the population at a site. Reducing the protection to any degree below 100% should be a matter of discussion between the Park Service and the USFWS, and the NCWRC. The proposal below is therefore a protocol for data collection, rather than experimentation, and should be followed even if the same level of protection is used at all sites. If the protection level is ever changed, managers will then be prepared to guage the effect of the change.

Proposal: Collect the following data at each site:

1) Recreation management strategy employed at the site
2) Number of territorial pairs
3) Number of pairs for which at least one nest was found
4) Number of eggs hatched/nest, number of chicks fledged/brood and chicks fledged/pair
5) Causes of egg, nest, chick, or adult loss, if apparent

6) Habitat use and activity budgets of adults (migratory, wintering, territorial establishment, and breeding periods) in 5 or 10 min periods, using a focal animal method (Altman 1974).
7) Habitat use and activity budgets of chicks in 5 or 10 min periods, using a focal animal method (Altman 1974)
8) Habitat availability, using aerial photos and transects
9) Terrestrial and benthic prey abundance and biomass
10) Number of potential predators and disturbance sources within 100 m of adults, nests, and broods

Habitat use should be measured both as:

a. Proportion of daily surveys in which an adult or brood was in a particular habitat when first located
b. % time spent in a particular habitat during 5-minute behavioral observations, where habitat use is recorded on a tape and later sampled every 10 seconds. Disturbance events, including disturbance source, and duration of the disruption of normal activity should be recorded during these observations.

Weather and tidal stage should be recorded whenever behavior is measured.

When measuring habitat availability, large-scale features (such as MOSH and non-MOSH "upland" habitat) can be classified from aerial photos taken during the relevant time of year, and smaller-scale features can be measured as % width along randomly-placed transects perpendicular to the shoreline. These transects can be measured once/month, except wrack should be measured once/week due to the variability in its availability.

Terrestrial prey can be sampled by placing sticky traps in different beach zones. Benthic prey can be sampled with cores.

Objective 3: To determine the necessary buffer distances to prevent disturbance to breeding and non-breeding birds by pedestrians, ORVs, kites, dogs, and boats.

Proposal: As with objective 2 above, this is a protocol for data collection that will assist managers in assessing the effects of changing buffer distances, if a management option involving buffer zones around habitat and/or nests (as opposed to site closure) is employed. Collect data as per Objective 2, but record the buffer distance being employed around whatever feature is relevant to the focal animal at the time of the observation, the type of feature buffered (e.g., MOSH for foraging adults, nests for incubating adults, center of brood territory for chicks), the distance from the focal animal to the nearest buffer zone boundary, and a code to indicate if the bird was outside of a protected area. Recommendations for initial buffer sizes and protocol for changing them are given below (see "Management Recommendations").

Objective 4: To determine the effectiveness of predator removal on nest success, breeding success, and site fidelity.

Proposal: Attempt to remove all potential mammalian nest and brood predators from all plover habitat prior to the breeding season using various trapping methods, recording catch/unit effort

for each method. Remove problem avian predators as they occur. Set up 24 hour predator bait stations near (but not in) plover habitat, with motion sensitive cameras to monitor encounters with predators. In addition, record number of potential predators within 100 m of nests or broods during daily monitoring. Count predator tracks along randomly-placed transects perpendicular to the shoreline in plover habitat. Determine the relationship between trapping success and predator abundance indices, and between predator abundance indices and proportion of nests lost to predators, breeding success, and adult movements within the breeding season (especially between nest attempts).

Additional Research to Address Management Goals

Question 1: What are the vital rates of the breeding population of plovers, which one (if any) currently regulates the population?

Proposal: Catch and individually color-mark all adults and chicks at CAHA, over several years. Attach radio-tags to nearly-fledged chicks so that survival and movement during post-fledging can be monitored. Calculate annual survival of adults and young, as well as emigration and immigration rates, and population growth rate. This study will only be informative if the protections recommended in these protocols are enacted. Without such protection, we do not predict an appreciable change in vital rates or population growth.

Question 2: How different are day and night behaviors and habitat use?

Proposal: Repeat the behavioral observations detailed above under objective 2, using night-vision optics. If habitat areas are closed at night to recreation as per our recommendations below this should be noted during data collection.

Question 3: How significant is ghost crab predation, and how may it interact with predation by other animals?

Proposal: Use the infrared videography technique detailed above to record encounters of ghost crabs with nests. Record frequency of ghost crab encounters with adults and chicks during behavioral observations. If ghost crabs are observed to take eggs or create a burrow near a nest, record whether the nest was first disturbed by another predator.

Question 4: What is the carrying capacity of Cape Hatteras National Seashore for piping plovers in the breeding period, and how is the estimate affected by recreational use of the beaches, and by overwash?

Proposal: Collect aerial photos and ground truth points in plover habitat during the territory-establishment period (late April to early May). Classify nesting and foraging habitat, and delineate ORV-use zones and overwashes. Calculate expected carrying capacity based on values of birds/ha nesting habitat from Cohen 2005. Further estimate carrying capacity as if ORV-zones were unusable, or less usable, and without overwash areas.

Question 5: How much site tenacity is there for nonbreeding birds, and how much movement is there among subpopulations in the winter?

Proposal: The first question can be addressed simply by monitoring use of locations using GPS devices and applying modifications of Markov models (see Erwin *et al*. 1998). The

second should be addressed by color-marking or radio-marking plovers during the wintering period (late Nov – Feb) and following their movements.

Management Recommendations

We provide three management options for piping plovers and their habitat, presented in order of increasing predicted negative effect. The protections described herein are based on the recommendations in the recovery plan (USFWS 1996), but are intended to be applied in addition to the protections recommended in the recovery plan, wherever this document provides stronger protection or more intensive monitoring (Table 1). Since the plover habitat at CAHA is dynamic and subject to change given weather, tides, and the continuous coastal processes of sediment erosion and accretion, some of the recommendations may become inapplicable for certain sites, or new sites may form that provide suitable plover habitat.

Option A: Highest Degree of Protection

Recommendations:

1) Close all potential piping plover nesting, roosting, and foraging habitat (ocean and soundside intertidal zone and other MOSH, ocean backshore, dunes, dry sand flats, overwashes and blowouts) to all recreation, 24 h/day year round, at Bodie Island Spit, Cape Point, South Beach, Hatteras Spit, North Ocracoke, South Ocracoke (Fig. 4-8).
2) Throughout the remainder of CAHA, protect a zone of ocean backshore at least 10 m wide and running the length of the site from recreation. This zone should be

adjacent to the toe of the primary dune wherever a primary dune exists (i.e., recreation should be restricted to a corridor between the mean high tide line and the edge of the zone of protected backshore). This will reduce the effects of recreation on nesting habitat throughout CAHA and increase the likelihood that plovers will colonize sites outside of the spits, once the carrying capacities of the spits have been attained. Management should revert to Option A item 1 if plovers are documented in an area.

3) A 50-m buffer zone of signed, stringed symbolic fencing should be placed around all nests to reduce the risk of damage by essential vehicles or monitors. CAHA should coordinate with agencies that have jurisdiction over the water to keep boats outside of this buffer zone, where applicable (the Park boundary is approximately 50 m from the shoreline on the Sound side).
4) Essential vehicles should only enter restricted areas subject to guidelines in the Essential Vehicles section of Appendix G of the Revised Recovery Plan for the piping plover (USFWS 1996). Essential vehicles should drive in the intertidal zone at speeds not to exceed 10 mph, whenever possible. Essential vehicles should be accompanied by a plover monitor whenever possible.
5) In the nonbreeding season, and prior to nest-hatching in the breeding season, plover monitors may conduct their activities by ORV. They should drive only in the ocean intertidal zone, but avoid the wrackline, at speeds not to exceed 10 mph. If this is not possible, monitoring by ORV should not be conducted at that time. When a courting pair or a set of courtship scrapes has been located, the monitoring vehicle should not pass through the prospective territory until the nest

has been discovered. The vehicle should be parked at least 200 m from the suspected center of territorial activity (farther away if the area of scraping is more extensive), and the rest of the monitoring in that area should be conducted by foot. Once the nest is discovered, ORV-based monitoring may resume until the nest is lost and the pair begins attempting to renest, or the nest hatches. In case of hatch, if an ORV is used it should be parked at least 1000 m from the last known brood location, and the rest of the monitoring conducted on foot until the brood is at least 35 days old.

6) Continue trapping of potential nest and brood predators prior to the onset of the breeding season with the goal of removing all potential mammalian predators from the site, including the removal of all foxes from Hatteras Island and the prevention of their spread to Ocracoke Island. Removal of avian predators should be done by targeting problem individuals (Boarman 2003) within plover breeding habitat in the presence of a trained monitor, and avian predation can be further controlled by enforcing proper trash disposal and anti-feeding regulations throughout CAHA (Boarman 2003). Consult with a plover monitor familiar with nest and/or brood locations when trapping during the breeding period, to avoid disturbing nests or broods. Trapping should be done by USDA Wildlife Services or trappers approved by USDA who have experience with the species being trapped, under the guidance of Department of the Interior Animal Care and Use guidelines.

7) Protect nests with exclosures according to the adaptive management protocols detailed above. Monitor the exclosures for sign of harassment of adults by predators, or evidence of adult mortality.

Predicted effects:

There will be almost no risk of direct recreation-related injury, mortality, or disturbance to piping plovers within the focal sites mentioned, and no recreation-related habitat loss at those sites under this management option. The risk of mortality or disturbance to adults, nests, or broods, attraction of predators to plover habitat, degradation of the wrack line, and alteration of the beach profile is very high outside of the focal sites, although we don't predict breeding plovers to use the rest of CAHA until the populations at the focal sites increase. Visitation to other areas of CAHA may attract potential plover predators such as gulls that may then enter plover habitat at the focal sites. Essential vehicle use of plover habitat and ORV-based monitoring entail slight risks of a nest being crushed if it is laid in a previously unsuspected location, and death or injury to an adult bird or chick. Predator trapping may result in disturbance to adult plovers or broods, or loss of chicks if the trappers are not cognizant of the location of the birds. Nest exclosures will cause disturbance to adults during placement, entail a slight risk of damaging eggs during placement, and may result in adult mortality or nest losses if a particular predator learns to hunt at them.

Option B: Moderate Protection

Recommendations:

1) Close all potential piping plover nesting, roosting, and foraging habitat (ocean and soundside intertidal zone and other MOSH, ocean backshore, dunes, dry sand flats, overwashes and blowouts) to ORV traffic, 24 h/day year round, at Bodie Island Spit, Cape Point, South Beach, Hatteras Spit, North Ocracoke, South Ocracoke (Fig. 4-8).
2) CAHA should coordinate with agencies that have jurisdiction over the water to keep boats outside of 50 m from the habitat at the above sites, where applicable.
3) Pedestrians may be permitted within a narrow walking and sunbathing corridor extending landward from the mean high tide line, from sunrise to sunset, on the oceanside only. Prohibit recreation at these sites from sundown to sunrise. Pets, kite-flying, frisbee and ball-playing, fireworks, wildlife feeding and trash disposal should be prohibited. This corridor should be narrowed or eliminated over all or part of its length if necessary to prevent disturbance to plovers. The pedestrian corridor should be narrowed or closed to provide a recreation-free buffer zone 50 m wide (or the distance recommended for other avian species using the area, whichever is greatest) around all areas of MOSH, all overwash corridors, and any place that courtship behavior or scrapes are observed. The buffer zones should immediately be widened to 100 m any place that disturbance of plovers by recreation is observed, then to 200 m if disturbance persists. Furthermore, the corridor should be narrowed or closed to provide a recreation-free zone in the ocean backshore at least 10 m wide and running the length of the site, wherever

backshore habitat occurs. Once narrowed or closed, the recreation corridor should not be widened or reopened without the approval of the USFWS and North Carolina Wildlife Resources Commision (NCWRC) on a case by case basis.

4) Throughout the remainder of CAHA, narrow the current 50-m ORV corridor such that a zone of ocean backshore at least 10 m wide and running the length of the site is free of ORV traffic. This zone should be adjacent to the toe of the primary dune wherever a primary dune exists (i.e., recreation should be restricted to a corridor between the average high tide line and the edge of the zone of protected backshore). This will reduce the effects of recreation on nesting habitat throughout CAHA and increase the likelihood that plovers will colonize sites outside of the spits, once the carrying capacities of the spits have been attained. Management should revert to items 1 and 2 of Option B if plovers are documented in an area.

5) When a nest is discovered, prohibit pedestrians from approaching within 50 m of the nest (USFWS 1996), or the distance recommended for other avian species if any of them are nesting nearby (whichever is greatest), using stringed symbolic fencing. Adjustments of the fencing should be limited to those needed to protect the incubating adults from disturbance. This buffer zone should be expanded on a nest-by-nest basis if monitors determine 50 m to be inadequate to prevent disturbance to a particular pair. The first time disturbance is observed, the buffer zone should be expanded to 100m, then to 200 m. If an experienced monitor is unavailable to alter the buffer area, the beach should be closed for 200 m around the nest until the fence can be restructured. If the tide line is within the buffer

zone, close the beach to recreation 50 m on either side of the nest, expanding this distance if disturbance is observed, as above.

6) Within one week of the expected hatch date of a nest, prohibit ORVs and boat landings in all plover habitat within 1000 m of the nest. After hatch, the closed area should be 1000 m on either side of the brood's center of activity. Within this zone, at the Park's option pedestrians can pass below the tide line at a walking pace and not stop, if a trained monitor is observing the brood. Alternatively, the brood zone can be shut down to all recreation. We recommend the latter until the plover population size has increased to at least 10 pairs. Maintain this protection until it is certain that all chicks have fledged or are 35 days of age.
7) Enact recommendations 3-6 detailed above under Option A.
8) Buffer zones that were expanded to protect nests may be returned to their pre-nest size after the nest is lost if, after 1 week of monitoring, it is determined that the pair is not attempting to renest in the area and that no breeding colonial waterbirds, oystercatchers, sea turtles, or seabeach amaranth occurs within the expanded buffer zone. Such modifications should be made only with the consent of the USFWS and NCWRC, on a case by case basis.
9) Portions of the pedestrian corridor that were narrowed or closed according to Option B item 3 during any part of the year may be reopened to recreation, once piping plovers have left the area, provided that no colonial waterbirds, oystercatchers, sea turtles, or seabeach amaranth occur in the closure and CAHA obtains permission from the USFWS and NCWRC on a case by case basis.

Predicted effects:

Adults are likely to be disturbed at a low level by pedestrians at the focal sites, and with less probability adults or nests may be harmed. Nests may be vandalized or otherwise damaged before they can be found and protected. The risk of all of these effects occurring is very high outside of the focal sites, although we don't predict plovers to use the rest of CAHA until the populations at the focal sites increase. Potential predators such as gulls may be attracted to the focal sites by the presence of pedestrians, but this effect is likely to be stronger outside the focal sites. Outside of the focal sites, ORV traffic may lead to destruction of the wrackline and alteration of the beach profile. Outside of the focal sites pets may harrass or harm plovers or their nests before management is put into place. Chicks are at risk of being crushed by pedestrians if they move to a previously unsuspected location, or if CAHA opts to allow pedestrians to walk through the brood zone. A benefit of allowing some pedestrian recreation adjacent to piping plovers is that there will be more opportunity to foster positive public attitudes toward plovers and plover management through outreach and education. Potential negative effects of essential vehicles, ORV-based monitoring, trapping, and exclosures are the same as for Option A.

Option C: Minimum Protection

Recommendations:

1) Restrict all recreation to a 50 m corridor on the ocean side, from the mean high tide line landward, from sunrise to sunset, 24 hr/day year round at Bodie Island Spit, Cape Point, South Beach, Hatteras Spit, North Ocracoke, South Ocracoke.

This corridor will be narrow enough to provide adequate nesting, foraging, and roosting habitat for piping plovers given the size and configuration of the habitat at these sites in 2005. Alteration of the habitat by storms or other natural processes may require a narrowing of the corridor, and at a minimum no recreation should be permitted in bay intertidal zone or other MOSH (except ocean intertidal zone), dunes, dry sand flats, overwashes and blowouts, and a 10-m wide strip of ocean backshore. Closure or narrowing of the corridor should occur as per the recommendations in Option B, item 2. Once narrowed or closed, it should not be widened or reopened without the approval of the USFWS and NCWRC, on a case by case basis. At the Park's option, ORVs may be allowed into the corridor only in escorted convoys, similar to the Hatteras Spit experiment in 2005. Prohibit recreation at these sites from sundown to sunrise.

2) CAHA should coordinate with agencies that have jurisdiction over the water to keep boats outside of 50 m from the habitat at the above sites, where applicable.
3) At the aforementioned sites, pets, kite-flying, frisbee and ball-playing, fireworks, and wildlife feeding and trash disposal should be prohibited. The speed limit should not exceed 10 mph.
4) Enact recommendations 4-9 under Option B above.

Predicted effects:

Adults are at risk of disturbance by pedestrians and recreational ORVs and boats at the focal sites, although this risk is lower than under current management

because the closures are more extensive. Adults are at risk of being harmed, and nests may be damaged before they are found and protected. These effects would be reduced with the escort option. The wrackline is likely to be degraded by ORV traffic and the beach profile altered by vehicle passage, even with an escort option. Enforcement of restrictions on pets and other activities will be more difficult than under Option B, increasing the risk of harrassment or harm to plovers. Young chicks may become trapped in ORV ruts. Attraction of potential predators such as gulls to breeding areas would be less than under current management to the extent that trash disposal and wildlife-feeding rules are enforced. Effects of recreation outside the focal areas and potential effects of essential vehicle use, ORV-based monitoring, trapping, and exclosures are the same as for Options A and B.

Additional Recommendations:

Green Island

Close Green Island to all human activities, including boat landings, after April 1st. This closure is intended to increase the chances that plovers will colonize the site. After breeding activity for piping plovers and other waterbird species has ceased, restrictions can be lifted, except habitat such as MOSH used by protected species in the nonbreeding period should be protected from recreational use by a 50 m buffer zone.

Protection of Habitat Created as a Result of Storms and Other Natural Coastal Process

Overwash and breach-created landscape features are a normal part of the barrier-island system, but armoring or renourishing the shoreline and filling or stabilizing inlets to protect human structures is a common practice that prevents such features from forming and alters patterns of vegetative succession (Dolan *et al*. 1973). Piping plovers and other species may exhibit preference for such dynamic features for roosting, nesting, and foraging, and hindering their formation may indirectly effect a local population by decreasing the carrying capacity of the landscape for these animals (Goldin and Regosin 1998, Nicholls and Baldassarre 1990, Elias *et al*. 2000, Cohen 2005). Thus, we recommend allowing natural processes to occur unimpeded whenever feasible. Newly-created inlets and overwash areas should be afforded the same level of protection from disturbance that we detailed above for historical plover breeding sites at CAHA, at least until their use by plovers and other species can be assessed and the USFWS can determine whether alteration of the habitat would lead to effects on plovers or their prey in the present or future.

Monitoring

The first goal of monitoring pertains to collecting information on population size and reproduction. Managers can use this information to protect birds and habitat to further the ultimate goal of recovering the population. The specific objectives are to determine the number and location of territorial pairs, the number and location of nesting pairs, the number of nest attempts, reproductive rate (chicks fledged/nesting pair), sources of nest and chick mortality, and size and location of nonbreeding flocks. The second goal of monitoring is to provide immediate

information on potential threats to flocks, pairs, nests, or broods so that managers can act quickly to protect the plovers.

Nest and Chick Survival

Except at Green Island, search sites for plover pairs at least three times/week from March 15 until the first nest is laid. Record locations where territorial behavior, courtship, and mating behavior are observed on a map, with the date of observation. Enlarge protected areas where plovers are observed prospecting for territories outside of the symbolic fence.

After April 20th, search for nests at least once every two days, except at Green Island where monitoring should occur as logistics permit. Keep a small disposable camera on hand in case evidence of a take is encountered (do not leave the camera in a truck for days or the film may be ruined by hot weather). Check known nests at least once every two days. Prior to incubation the nest may be approached so that the eggs can be counted, and potential disturbances to the laying schedule can be assessed. After incubation commences, observe the incubating bird with optical equipment from outside the symbolic fence. If the bird cannot be seen on the nest, the nest may be approached. Whenever a nest is checked, we recommend that a minimum of the following information be recorded:

1. Date and time of nest check
2. Nest number
3. Geographic coordinates of the nest location when it's first found, recorded with a GPS unit in UTM coordinates and NAD 83. You should be able to locate the nest in open beach with a GPS even if markers are gone or not used. Colored flagging may be tied to the symbolic fence, 50 m if possible but at

least 10 m from the nest (for closures truncated at the tide line), to assist other stewards in relocating the nest. Nest markers should not be placed in the sand.

4. Habitat (see glossary)
5. Number of eggs (if the bird is not flushed, record that the bird was incubating and the number of eggs was not observed)
6. Status of the nest (laying, incubating, lost, abandoned, hatching, hatched)
7. The presence and behavior of the adults [incubating eggs, shading eggs, resting, foraging, disturbed (record source), territorial flight, territorial encounter, distraction display or other defensive behavior toward predator or pedestrian, courtship, other behavior (describe)]
8. The presence of potential predators, humans, pets, or ORVs within 100 m and locations relative to the nest
9. Evidence (i.e., trails) of potential predators, humans, or ORVs within the posted areas, including distance to the nest.
10. Approximate distance to tide line, in meters
11. Suspected cause of nest loss, if apparent

Items 7-10 can help managers to assess threats to the nest. Once a nest hatches, observe the brood at least once every two days. Broods should be observed with optics from a distance unlikely to cause disturbance (20 m greater than the maximum distance at which monitoring activities are found to disturb broods at CAHA). Unlike other species where banding and marking of young is permitted and recapture allows for robust statistical models to be applied, piping plover marking is generally not permitted by the Region 5 USFWS Recovery Plan. Therefore, "probability of fledging" is always more uncertain for a nest in this species than in

many others. We recommend a minimum of the following information be recorded at each brood check:

1. Date and time of brood check
2. Nest/brood number
3. Location of brood (mark on a map or record with a GPS unit)
4. Habitat (see glossary)
5. Number of chicks
6. Brood age (this is known from other data on hatch date)
7. Brood behavior [foraging, resting/brooding, disturbed (record source), other]
8. The presence and behavior of the adults [foraging, brooding, resting, disturbed (record source), territorial flight, territorial encounter, distraction display or other defensive behavior toward predator or pedestrian, courtship, other behavior (describe)]
9. The presence or evidence of potential predators, humans, or ORVs within 100 m and their location relative to the brood
10. Cause of chick loss, if carcass is found and source of mortality is apparent

A nest or brood that appears to be at risk should be reported to a manager from the field if possible, but otherwise upon return from the field. All data from the nest or brood monitoring sheet should be provided to the manager.

Nonbreeding Plovers

Monitoring of nonbreeding plovers should be aimed at estimating the size and distribution of the population at CAHA during migration and wintering, determining the types of habitats used by nonbreeding plovers, and identifying sources and rates of mortality and

disturbance to nonbreeding plovers. Bodie Island Spit, Cape Point and South Beach, Hatteras Spit, North Ocracoke, and South Ocracoke should be surveyed at least 3 times per week from July 1 to May 30 for nonbreeding plovers. All sites should be surveyed on the same day to the extent possible, to reduce double-counting of individual. Green Island and other shoal islands should be surveyed when practicable, especially when no birds are apparent at the barrier island sites. CAHA should coordinate with Cape Lookout National Seashore to conduct simultaneous surveys or receive survey data from Portsmouth Island during the winter, especially when no plovers are seen at South Ocracoke, since based on past banding data wintering birds may move across Ocracoke Inlet. Additionally, CAHA should coordinate monitoring of winter birds with NCWRC nonbreeding surveys. The following data should be collected during nonbreeding bird surveys:

1. Date
2. Start and end time of survey at each site
3. Weather variables [air temperature, wind speed and direction, visibility, % cloud cover (estimated by eye), precipitation (0=none, 1=light, 2=heavy)]
4. Tidal stage (hours after high tide)
5. Number of birds
6. Habitat (see glossary)
7. Site management where the birds are seen (e.g., ORV Closure
8. Behavior of the majority of birds in the flock [foraging, resting, disturbed (record source), other]
9. Whether territorial (T) or courtship (C) behavior is observed, or not (0)

10. If the bird/flock moves during a survey, record distance moved in meters, and cause of move if apparent
11. Number of pedestrians, pets, ORVS, gulls, other potential disturbances within 100 m (estimated by eye) of the bird or flock
12. Band combination of any banded birds, using the reporting protocols already developed by CAHA staff for band color and location.

If there appear to be multiple distinct flocks at a particular site, the observer should record data for each flock on a separate line on the data sheet, since flocks may often use different habitats or exhibit different behaviors. The above data will assist managers in determining the abundance and distribution of nonbreeding birds. Furthermore, it will help to answer questions about the prevalence of threats to wintering birds and the response of the birds to those potential threats.

Law Enforcement

Nests or broods deemed to be at particular risk of vandalism should not be left unattended. Lay volunteers may be used to sit within viewing distance of a nest or brood during daylight hours, to report problems. Monitors should carry radios or cellular phones. If a monitor observes a potential infraction of the law that threatens a plover adult, nest, or brood, the relevant law enforcement personnel should be immediately contacted from the field, if possible, and the monitor should maintain visual contact with the nest or brood in danger. This will allow the monitor to provide the most accurate description possible. If the monitor is not able to contact enforcement immediately, or if the monitor risks endangering him or herself by remaining at the site, the monitor should leave the field as soon as possible and contact law enforcement.

If the scene of a past violation is discovered (such as a nest destroyed by a pedestrian), the scene should be left intact and the following information should be recorded:

- Date and time
- Weather and tide conditions
- Location (Use a GPS unit to record the location). Plant a survey flag or other marker to assist in relocating the site. This should be a colored, easy to see marker.
- Nest number if given
- Number of adults, eggs, and/or chicks involved
- Behavior of adults and/or chicks
- Condition of adults, eggs, and/or chicks
- Hand-drawn map showing adult , nest, and/or brood, symbolic fence line, predator, pedestrian, and/or ORV trails, other evidence, and nearby landscape features (e.g., tide line, dune line). If possible, use gridded paper so map scale can be indicated.
- Photographs of the evidence

The relevant law enforcement personnel should be contacted as soon as possible and provided with a copy of the incident record. While gathering of information by a lay person may compromise the scene to some degree, the ephemeral nature of evidence in beach environments requires immediate collection of some basic data.

Reporting Procedures

The data collected in the field have many potential uses and applications. For nesting location data, GPS locational information needs to be conveyed as quickly as possible to Resource Management staff in order to implement protection measures. Similarly, witnessing violations of closure areas or other illegal activities needs to be conveyed to Law Enforcement staff as soon as possible. If violations of federal or state regulations are confirmed, notification needs to be made to the U.S. Fish and Wildlife Service – Raleigh Field Office, the National Marine Fisheries Service, and the North Carolina Wildlife Resources Commission as appropriate.

The field data should be collected in two forms: in field books as narrative accounts, and on field data forms developed in conjunction with other partner agencies, scientists and managers. Field forms should be quality checked by an independent reader, comparing field notebooks and forms where appropriate (see section below). When verified, the data should be electronically entered, analyzed where needed, summarized in reports in text, tabular and graphic form, and submitted to both CAHA administrative personnel and other cooperating agency personnel and other scientists and managers as requested. Reports should be available both in electronic form (pdf preferred) and in limited numbers of hard copy.

Data Management

Raw data collection

Field data sheets should include, at a minimum, the date, the reference location (GPS and usually a code number), a point or specific area, and observer name or initials. Because of the large amount of data included in these different data collection efforts, we strongly urge that all individuals engaged in data collection be trained in advance of the actual data collection period. Regardless of how clear a field form appears to be, questions always arise about how to record certain types of data. In addition, where counts of birds are recorded, we strongly urge that two observers keep independent records. Variation due to observer differences has been shown to be a major source of error (Sauer et al. 1994).

Data entry

Because the National Park Service (as well as other agencies) has determined that Microsoft Access will be the official database management software in the monitoring programs, we recommend it as the primary management tool. In some cases, Excel spreadsheets may be used since this is what the cooperators/contractors often provide. However, conversion of Excel to Access is not difficult and the structure of the tables is quite similar.

For the majority of the bird data sets, the data are entered directly from field forms into Microsoft Access, a relational database. One advantage of Access includes efficiency, because many fields of data (location, physical parameters) need not be reentered on each successive survey, and flexibility in presentation. Links can be made among tables of physical parameters, nesting rate estimate, hatching success, etc.

Metadata

The metadata are best structured as separate components as the resource and scientific community needing different aspects of the data are quite different. Quality assurance and quality control are best maintained by having the field data reviewed and entered into the database on the same day it is collected. Two individuals should first review the data to reduce error propagation. Generally it is best to have the person collecting the data also doing the data entry, followed by having a second person compare the computer printout with the original field sheets. This second step can be done at a later date to reduce fatigue on field days.

Data storage

Field data sheets should be stored in a safe, low-fire-risk location in or near the NPS Headquarters in Manteo. Upon entry into a PC's electronic Access database, an extra copy of the database should be generated on a separate portable hard drive, or on CDs which then should be maintained in a separate building. If a computer network is available at the site, the files can be more easily transferred electronically to other PC sites, rather than having to physically transfer media between locations. Security demands by the NPS may require extra steps in the data management outlined here.

Data analysis techniques

The methods for analyzing the data will vary greatly depending upon the question and the level of analysis of interest. Excellent statistical support and advice is available both at the USGS Patuxent Wildlife Research Center (Drs. Jim Nichols, James Hines, John Sauer, William

Kendall, Michael Runge, and Jeff Hatfield) and at NC State University (Dr. K. Pollock associated with the NC Cooperative Wildlife Research Center). Biologists at CAHA should consult with one or more statisticians whenever statistical analyses are to be conducted. Many population and metapopulation models are already available online from Patuxent (see http://www.pwrc.usgs.gov), but usually these require some discussion with statisticians beforehand.

Education and Outreach

Public Education.—While the strict protections detailed above are necessary to recover the plover population at CAHA, it will be important to engage the public at all times while implementing these protocols. Long-term sustainability of plover recovery at CAHA will depend on the cooperation of the public that uses CAHA. Area closures and restrictions, and the reasons for each of them, need to be made plain. Continue posting all symbolic fence lines with signs that clearly indicate the species being protected. Post signs detailing plover biology and the reasons for protecting the species at points where visitors are likely to first encounter restricted areas.

Provide visitors with postcards and informational brochures that contain information on plovers and the biological and legal reasons for their protection at CAHA, as well as details on how closures will be used to better inform management in the future such that restrictions may possibly be eased. Interpretive walks in which visitors are guided to places to watch breeding and nonbreeding adults and broods through a spotting scope can also be a useful outreach mechanism, since untrained visitors will likely never otherwise see this species due to its cryptic coloration and inconspicuous behavior. Teaching the public to value plovers as part of the beach-going experience is the most important management activity that CAHA can undertake.

Advertise plover protection efforts and management successes in local papers and magazines and write educational articles for these outlets. Gain the confidence of a skilled writer/reporter in what you are doing. Ask that all articles that reporters write be checked by a manager or biologist so that corrections can be made if errors are found. Issue press releases detailing closures and other restrictions during both the breeding and nonbreeding seasons. Provide these press releases to local officials, the local press, local marinas, shops, special interest groups, etc.

Staff training.—Provide training to all CAHA staff including sign crew, patrol, maintenance crews, etc. on behavior and monitoring techniques for both nesting and wintering plovers. This training should also include plover identification, safe vehicle operations within plover habitat and limiting activities in habitat.

Plover monitors themselves need to have a subset of skills and knowledge before entering the field independently. These ideally include:

1) Ability to identify the adults, nests, and young of all protected species by sight, sound, and track evidence
2) Ability to identify breeding and nonbreeding behaviors by sight, sound, and other sign (e.g., nest scrapes, distraction displays)
3) Ability to observe adults, nests, and young of each species through optics and to record data without causing disturbance
4) Familiarity with the CAHA protocols for management and protection of each species
5) Basic knowledge of the laws protecting each species

6) Understanding of the process for dealing with and reporting legal infractions and injured wildlife
7) Clear understanding of Park policies for interacting with members of the public, the press, etc., and enough basic knowledge of the biology of each species to permit such interactions to be positive and informative.

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Literature Cited

ALTMAN, J. 1974. Observational study of behavior sampling methods. Behaviour. 49: 227-267.

ANDERS, F. AND S. LEATHERMAN. 1987. Disturbance of beach sediment by off-road vehicles. Environmental Geology and Water Sciences 9:183-189.

BOARMAN, W. I. 2003. Managing a subsidized predator population: reducing common raven predation on desert tortoises. Environmental Management 32:205-217.

BURGER, J. 1987. Physical and social determinants of nest site selection in piping plover in New Jersey. Condor 98: 811-818.

_____. 1994. The effect of human disturbance on foraging behavior and habitat use in piping plover (*Charadrius melodus*). Estuaries 17: 695-701.

CAIRNS, W.E. 1982. Biology and behavior of breeding Piping Plovers. Wilson Bull. 94: 531-545.

COOPER, S. 1990. Notes on piping plovers nesting at Cape Hatteras National Seashore during 1987. Chat 54:1-6.

COHEN, J. 2005. Factors limiting piping plover nesting pair density and reproductive output on Long Island, New York. Ph.D. dissertation, Virginia Tech University, Blacksburg, VA. 256 pp.

COUTU, S., J.D. FRASER, J. MCONNAUGHEY, AND J. LOEGERING. 1990. Piping plover distribution and reproductive success on Cape Hatteras National Seashore. Dept. of Fisheries and Wildlife Sciences, Virginia Tech University, Blacksburg, VA. 67 pp.

DOLAN, R., P.J. GODFREY, AND W.E. ODUM. 1973. Man's impact on the barrier islands of North Carolina. Amer. Sci. 61:152-162.

DRAKE, K.R., J.E. THOMPSON, AND K.L. DRAKE. 2001. Movement, habitat use, and survival of nonbreeding piping plovers. Condor 103: 259-267.

ELIAS, S.P., J.D. FRASER, AND P.A. BUCKLEY. 2000. Piping plover brood foraging ecology on New York barrier island ecology. J. Wildl. Manage. 64: 346-354.

ERWIN, R. M., J. D. NICHOLS, T. B. EYLER, D. B. STOTTS, AND B. R. TRUITT. 1998. Modeling colony-site dynamics: A case study of gull-billed terns (*Sterna nilotica*) in coastal Virginia. Auk 115: 970-978.

_____., C.J. CONWAY, S.W. HADDEN, J. HATFIELD, AND S.M. MELVIN. 2002. Waterbird monitoring protocol for Cape Cod National Seashore and other coastal parks, refuges and protected areas. USGS report to the National Park Service. 44 pp.

FEDERAL REGISTER. 1985. Endangered and threatened wildlife and plants; final determinations of critical habitat for wintering Piping Plovers; final rule. Federal Register 50:50 FR 50726-50734.

_____. 2001. Endangered and threatened wildlife and plants; determination of endangered and threatened status for the Piping Plover; final rule. Federal Register 66:50 CFR 360378-36143.

FLEMMING, S.P., R.D. CHIASSON, P.C. SMITH, P.J. AUSTIN-SMITH, AND R.P. BANCROFT. 1988. Piping plover status in Nova Scotia related to its reproductive and behavioral responses to human disturbance. J. Field Ornithol. 59: 321-330.

GOLDER, W.W. 1985. Piping plovers nesting at Cape Hatteras, N.C. Chat 49:69-70.

_____. 1986. Piping plovers nesting at Cape Hatteras, N.C., in 1985. Chat 50:51-53.

GOLDIN, M.R. 1993. Effects of human disturbance and off-road vehicles on piping plover reproductive success and behavior at Breezy Point, Gateway National Recreation Area, New York. M.S. Thesis. University of Massachusetts, Amherst, Massachusetts. 128 pp.

_____ AND J.V. REGOSIN. 1998. Chick behavior, habitat use, and reproductive success of piping plovers at Goosewing Beach, Rhode Island. J. Field Ornithol. 69(2):228-234.

HAIG, S.M. 1992. No. 2: Piping Plover. In Poole, A., P. Stettenheim, and F. Gill (eds). Birds of North America. American Ornithologists Union. Philadelphia, PA. 18 pp.

HOOPES, E.M. 1993. Relationships between human recreation and piping plover foraging ecology and chick survival. M.S. Thesis. University of Massachusetts, Amherst, Massachusetts. 106 pp.

HOUGHTON L.M., J.D. FRASER, AND J.B. COHEN. In prep. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island. Final Report to The U.S. Army Corps of Engineers New York District.

JOHNSON, C.M. AND G.A. BALDASSARRE. 1988. Aspects of the wintering ecology of piping plovers in coastal Alabama. Wilson Bull. 100: 214-233.

JOHNSON, M. AND L. W. ORING. 2002. Are nest exclosures an effective tool in plover conservation? Waterbirds 24:184-190.

KEANE, S.E., J.D. FRASER, AND P.A. BUCKLEY. In press. Prenesting use of intertidal habitats by piping plovers on South Monomoy Island, Massachusetts. J Wildl. Manage.

KUKLINSKI, M.L., L.M. HOUGHTON, AND J.D. FRASER. 1996. Piping plover breeding ecology on Cape Hatteras National Seashore with special reference to the effect of temperature on productivity. Dept. of Fisheries and Wildlife Sciences, Virginia Tech University, Blacksburg, VA. 71 pp.

LANDE, R. 1988. Genetics and demography in biological conservation. Science 241:1455-1460.

LARSON, M.A., M.R. RYAN, AND B.G. ROOT. 2000. Piping plover survival in the Great Plains, an updated analysis. J. Field Ornithol. 71: 721-729

_____, M.R. RYAN, AND R.K. MURPHY. 2002. Population viability of Piping Plovers: effects of predator exclusion. J. of Wildl.Manage. 66:361-371.

LEATHERMAN, S. P., AND J. R. ALLEN, eds. 1985. Geomorphic analysis, Fire Island Inlet to Montauk Point, Long Island, New York. Reformulation study submitted to the U.S. Army Corps of Engineers, New York District.

LOEGERING, J.P. 1992. Piping plover breeding biology, foraging ecology and behavior on Assateague Island National Seashore, Maryland. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 247 pp.

_____, AND J.D. FRASER. 1995. Factors affecting piping plover chick survival in different brood-rearing habitats. J. Wildl. Manage. 59(4): 646-655.

_____, J.D. FRASER, AND L.L. LOEGERING. 1995. Ghost crabs prey on a piping plover chick. Wilson Bull. 107: 768-769.

LYONS, M. 2001. 2000 Piping plover breeding activities, Cape Hatteras National Seashore. Unpublished annual report. National Park Service. Buxton, NC. 10 pp.

LYONS, M. 2002. 2001 Piping plover breeding activities, Cape Hatteras National Seashore. Unpublished annual report. National Park Service. Buxton, NC. 13 pp.

LYONS, M. 2003. 2002 Piping plover breeding activities, Cape Hatteras National Seashore. Unpublished annual report. National Park Service. Buxton, NC. 15 pp.

LYONS, M. 2004. 2003 Piping plover breeding activities, Cape Hatteras National Seashore. Unpublished annual report. National Park Service. Buxton, NC. 18pp.

MAYER, P.M., AND M.R. RYAN. 1991. Electric fences reduce mammalian predation on piping plover nests and chicks. Wildl.Society Bull. 19: 59-63.

MELVIN, S.M., C.R. GRIFFIN, AND L.H. MACIVOR. 1991. Recovery strategies for piping plovers in managed coastal landscapes. Coastal Manage. 19:21-34.

_____, L.H. MACIVOR, AND C.R. GRIFFIN. 1992. Predator exclosures: A technique to reduce predation of piping plover nests. Wildlife Society Bulletin 20: 143-148.

_____, A. HECHT, AND C.R. GRIFFIN. 1994. Piping plover mortalities caused by off-road vehicles on Atlantic coast beaches. Wildl. Society Bull. 22: 409-414.

MURPHY, R.K., I.M.G. MICHAUD, D.R.C. PRESCOTT, J.S. IVAN, B.J. ANDERSON, AND M.L. FRENCH-POMBIER. 2003a. Predation on adult piping plovers at predator exclosure cages. Waterbirds 26:150-155.

MURPHY, R.K., R.J. GREENWOOD, J.S. IVAN, AND K.A. SMITH. 2003b. Predator exclusion methods for managing endangered shorebirds: are two barriers better than one? Waterbirds 26:156-159.

NICHOLLS, J.L. AND G.A. BALDASSARRE. 1990. Habitat selection and interspecific associations of piping plovers along the Atlantic and Gulf Coasts of the United States. Wilson Bull. 102: 581-590.

(USDOI) U.S. DEPARTMENT OF THE INTERIOR. 2004. Tip of Hatteras Spit to be temporarily closed. U.S. Dept. of the Interior Press Release, National Parks Service, Outer Banks Group, Manteo, NC. World Wide Web site http://www.nps.gov/caha/052604%20PR%20CAHA.htm

(NPS) NATIONAL PARK SERVICE. 2005. Park Visitation Report. National Park Service. Public Use Statistics Office. Denver, CO. World Wide Web site http://www2.nature.nps.gov/stats/

PATTERSON, M.E., J.D. FRASER, AND J.W. ROGGENBUCK. 1991. Factors affecting piping plover productivity on Assateague Island. J. of Wildl. Manage. 55: 525-531.

STAINE, K.J. AND J. BURGER. 1994. Nocturnal foraging behavior of breeding piping plovers (*Charadrius melodus*) in New Jersey. Auk 111(3): 579-587.

SAUER, J. R., B. PETERJOHN, AND W. LINK. 1994. Observer differences in the North American Breeding Bird Survey. Auk 111: 50-62.

[USFWS] U.S. Fish and Wildlife Service. 1988. Great Lakes and northern Great Plains piping plover recovery plan. 160 pp.

_____. 1996. Piping Plover *(Charadrius melodus)*, Atlantic Coast Population, Revised Recovery Plan. Hadley, Massachusetts. 258 pp.

_____. 2003. Recovery plan for the Great Lakes piping plover (*Charadrius melodus*), Ft. Snelling, MN 149 pp.

_____. 2004. 2002-2003 status update: U.S. Atlantic Coast piping plover population. Sudbury, MA. 8 pp.

WATTS, B.D., AND D.S. BRADSHAW. 1995. Ghost crabs prey on Piping Plover eggs. Wilson Bull. 107:767-768,

WILKINSON, P.M. AND M. SPINKS. 1994. Winter distribution and habitat utilization of piping plovers in South Carolina. Chat 58:33-37.

WOLCOTT, D.L. AND T.G. WOLCOTT. 1999. High mortality of piping plovers on beaches with abundant ghost crabs: correlation not causation. Wilson Bulletin 111:321-329.

ZONICK, C.A. 2000. The winter ecology of piping plovers (*Charadrius melodus*) along the Texas Gulf Coast. Ph.D. Dissertation, University of Missouri – Columbia.169 pp.

Table 1. Median and maximum nonbreeding birds seen/daily survey during fall, winter, and spring, selected sites at Cape Hatteras National Seashore, 2000-2005. Not all sites were surveyed each day (typically only one or two were surveyed), so these numbers provide only a rough idea of the total size of the nonbreeding population.

	Month	Oregon Inlet	Cape Point/ S. Beach	Hatteras Inlet	Ocracoke Inlet	All Sites
Median	Jul	0.49	0.18	0.45	2.21	5.67
	Aug	0.68	0.31	0.13	3.76	6.43
	Sept	0.66	0.07	0.38	4.22	5.67
	Oct	0.36	0.00	0.86	1.81	3.33
	Nov	0.82	0.00	0.07	1.00	4.21
	Dec	0.77	0.00	0.00	2.07	2.88
	Jan	0.25	0.00	0.00	1.00	1.18
	Feb	3.33	0.00	0.00	1.00	4.33
	Mar	1.25	0.00	0.00	0.75	2.75
	Apr	1.89	0.00	0.62	1.31	3.60
Maximum	Jul	32	5	21	56	56
	Aug	34	6	14	72	72
	Sept	16	5	4	37	37
	Oct	12	1	28	31	31
	Nov	15	0	8	12	15
	Dec	17	0	7	15	17
	Jan	18	0	1	11	18
	Feb	14	0	0	18	18
	Mar	12	3	4	8	12
	Apr	25	3	7	11	25

Table 2. Comparision of recommendations in the Atlantic Coast piping plover revised recovery plan (1996) and this Protocol.

Recovery Plan Recommendation	Protocol Recommendation
Symbolically fence areas on April 1 that receive high levels of human disturbance. Allow vehicles to pass through an ORV corridor between nesting habitat and the tide line if conditions permit.	Close or enact buffer zones around habitat by March 15, or sooner for nonbreeders. Allow pedestrians and/or ORVs in a corridor between the nesting habitat and the tide line if conditions permit
Keep pets on a leash and outside of fenced areas. Prohibit pets if leash laws are difficult to enforce. Prohibit kite-flying within 200m of breeding plovers. Prohibit fireworks on breeding beaches after April 1.	Prohibit pets, kites, ball playing, trash-disposal, wildlfe-feeding, kites, and fireworks from all sites being used by plovers, during any part of the year
Prohibit ORVs within 1000 m of broods, to be modified based on historical or current data of brood movements, provided the buffer is >100 m and all broods are monitored at a frequency to be agreed upon by the USFWS and state management agencies	Maintain 1000-m recreation free zones around brood, except pedestrians may be permitted to walk through a brood territory below the tideline under the supervision of a trained plover monitor
Monitoring of habitat twice per week prior to May 1, and at least 3 time/week thereafter. Monitor once/week during the nonbreeding period in each of 3 months (one month in the fall migration, wintering, and spring migration periods)	Monitor 3 times/week after April 1st, for breeding birds. Monitor nonbreeding birds 3 times/week from July 1 to May 30, also recording the onset of breeding behaviors.

Symbolically fence 50 m buffer zones around all nests, increasing the distance if it appears necessary. Truncate the buffer zone at the tide line, but monitor to ensure that this provides adequate protection from disturbance.	Follow recovery plan guidelines, except close areas to recreation if the nest is near the tide line. Increase the buffer distance to 100 m the first time recreational disturbance is noted, then to 200 m if necessary.
Use nest exclosures whenever predation is perceived to be a problem, but modify or remove the exclosure if it seems to be increasing the risk of nest loss.	Follow recovery plan guidelines, modified by adaptive management protocols to examine the effect of exclosure design. Remove all mammalian predators from plover habitat and all foxes from Hatteras Island. Remove individual avian predators from plover habitat as they become a problem. Monitor the effect of ghost crabs on nest and chick survival.

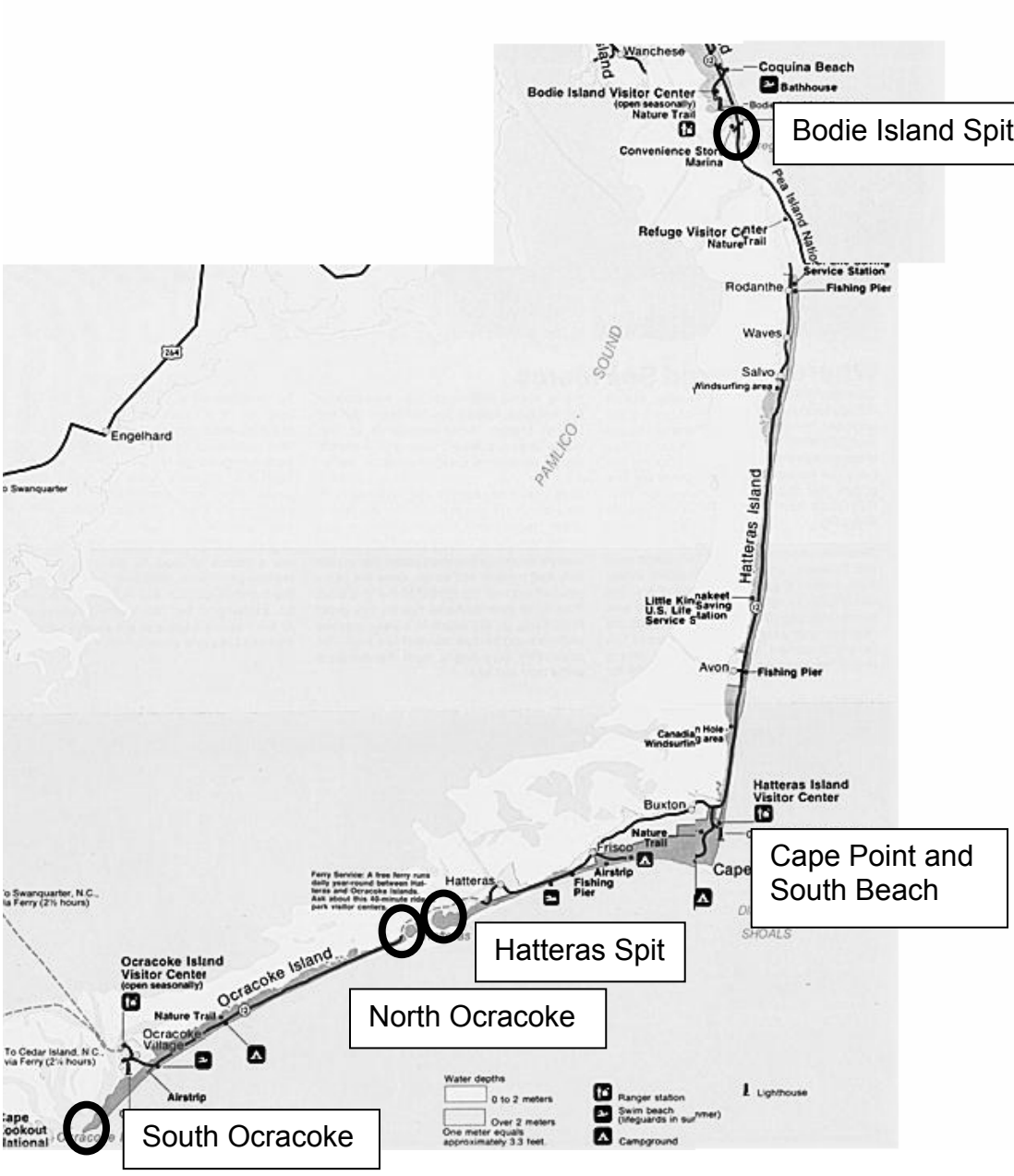

Fig. 1. Map of Cape Hatteras National Seashore. Ovals and labels indicate recent plover breeding areas. Map courtesy of the National Park Service.

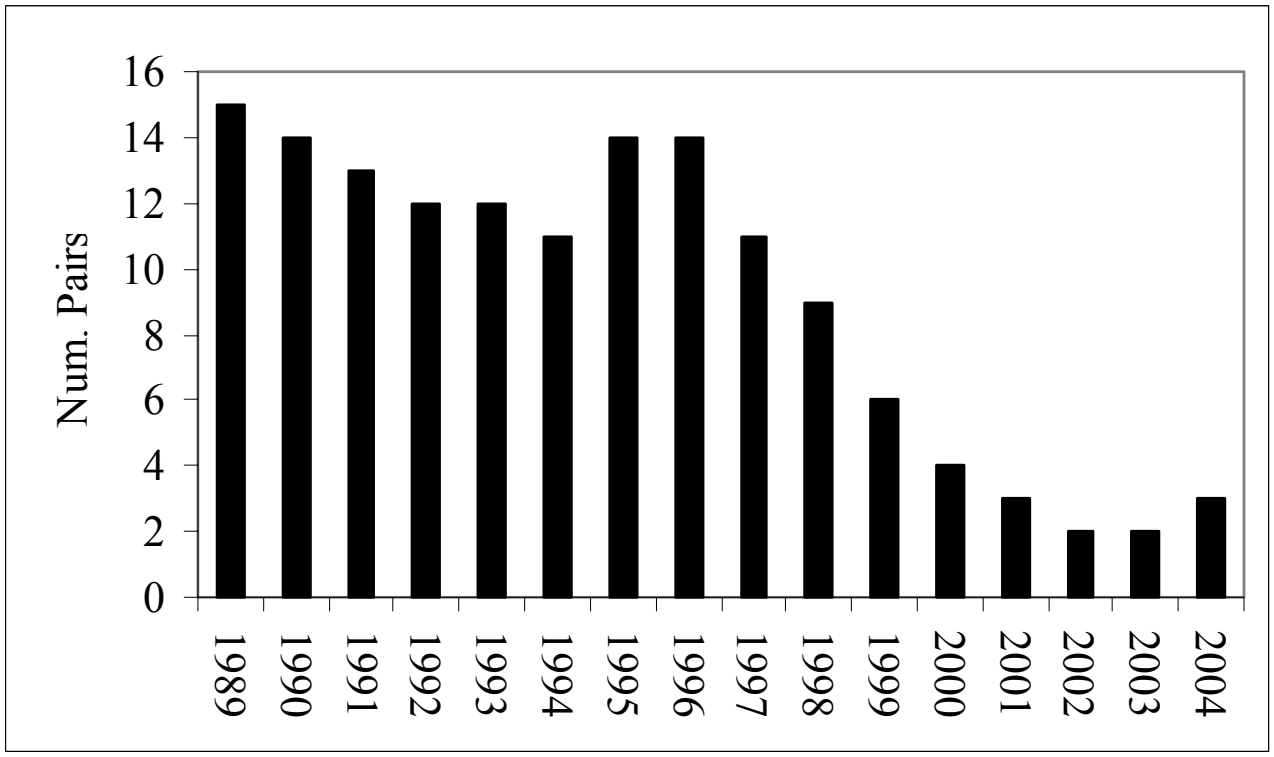

Fig. 2. Number of piping plover nesting pairs, Cape Hatteras National Seashore, 1989-2004

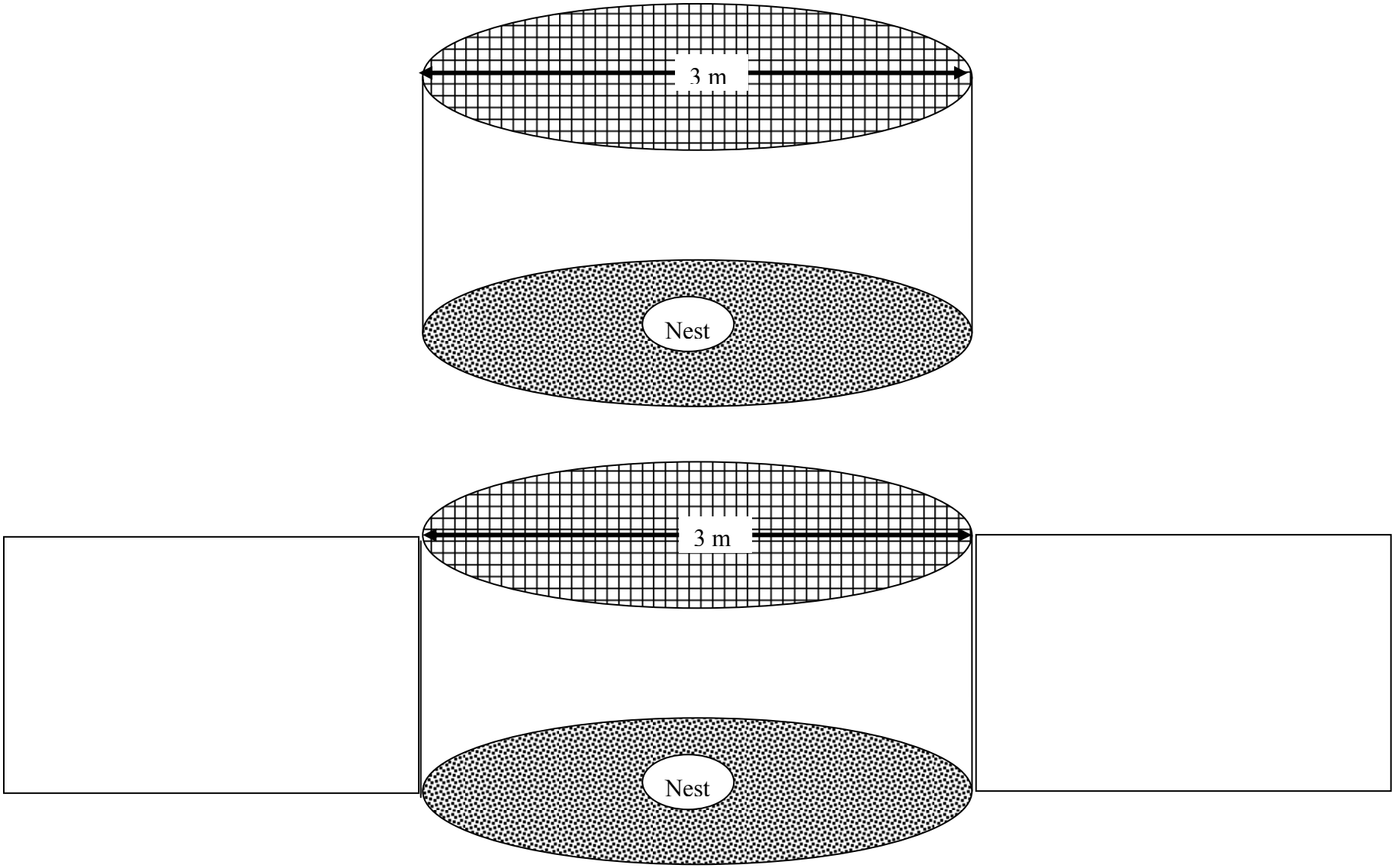

Fig. 3. Proposed exclosure designs for piping plove nests at Cape Hatteras National Seashore. White areas represent welded wire. Hatched areas represent bird netting. Stippled areas represent sand. a) Standard design b) Standard design plus 3 m wings.

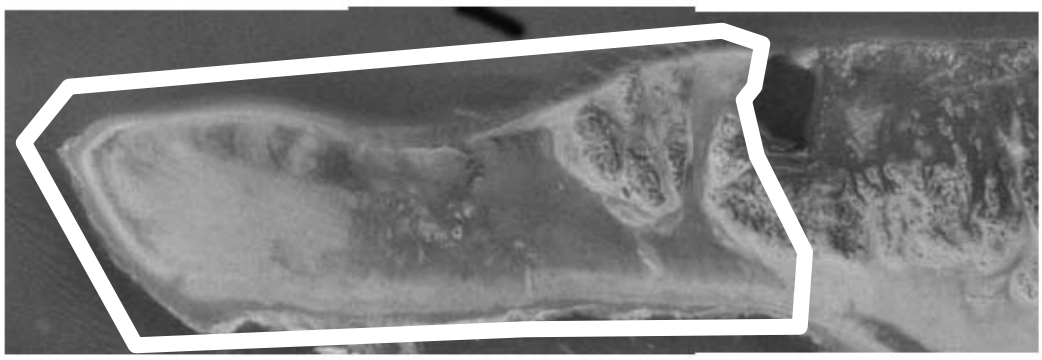

Fig. 4. Hatteras spit. White line indicates area within which recommended closures and restrictions should occur under management options A, B and C.

Fig. 5. South Ocracoke. White line indicates area within which recommended closures and restrictions should occur under management options A, B and C.

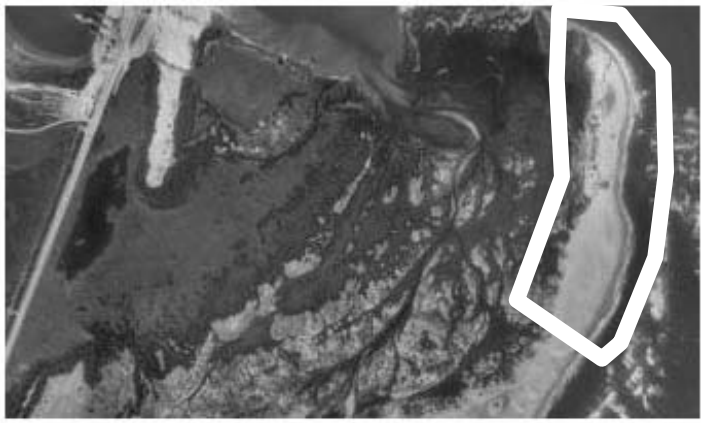

Fig. 6. North Ocracoke. White line indicates area within which recommended closures and restrictions should occur under management options A, B and C.

Fig. 7. Cape Point and South Beach. White line indicates area within which recommended closures and restrictions should occur under management options A, B and C.

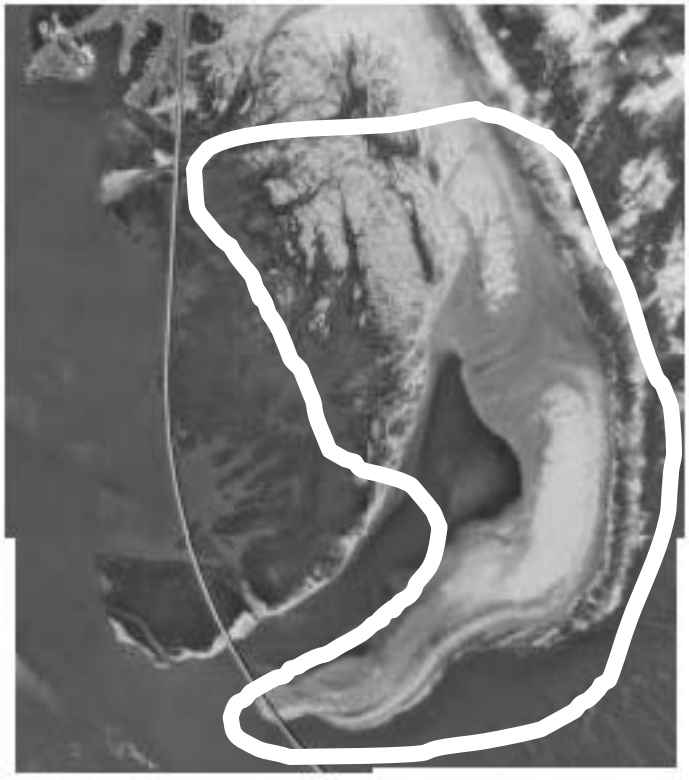

Fig. 8. Bodie Island Spit. White line indicates area within which recommended closures and restrictions should occur under management options A, B and C.

Appendix: Glossary of Terms

Backshore[a] - The upper part of the beach above the normal reach of the tides (high water), but affected by large waves occurring during a high.

Berm[a] – A nearly horizontal plateau on the backshore, formed by the deposition of beach material by wave action.

Dune[a] - Accumulations of windblown sand on the backshore, usually in the form of small hills or ridges.

Fledge – For piping plovers chicks, achievement of independence from parents. Often considered to be 35 days of age or when able to sustain flight for 15 m.

Foraging – Searching for, acquiring, and ingesting prey.

Foredune – Small dune seaward of the primary dune system, often accumulating around clumps of wrack or vegetation.

Intertidal zone[a] - The zone between the high and low water marks.

MOSH - Moist substrate habitat, excluding high-wave energy intertidal zone. Particularly mud flats, sand flats, ephemeral pools, and shores of brackish ponds.

Mudflat[a] or sandflat - A muddy or sandy low-lying strip of ground by the shore, or an island, usually submerged more or less completely by the rise of the tide.

Overwash[a] – (1) The part of the wave uprush that runs over the crest of a berm or structure and does not flow directly back to the ocean or bay. (2) the effect of waves overtopping a dune

Preyed upon (or depredated) – Killed or destroyed by a predator.

Reproductive rate – For piping plovers, no. of chicks fledged / no. of breeding pairs.

Sparse Vegetation – In piping plover habitat, any zone where vegetation is penetrable by adults and broods (typically < 90% cover)

Swash zone[a] - The zone of wave action on the beach, which moves as water levels vary

Wrack – (1) Lines of organic material (usually vegetation and algae) deposited on the edge of the swash zone (2) lines or clumps of organic material, usually vegetation or algae, deposited in the backshore during spring or storm tides, and often partially buried by sand.

[a]Voigt, B. 1998. Glossary of coastal terms. National Oceanographic and Atmospheric Administration. http://www.csc.noaa.gov/text/glossary.html#glossary.