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Population Trends of Atlantic Coast Piping Plovers, 1986-2006

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Abstract.—The Atlantic Coast population of Piping Plovers (*Charadrius melodus*) has been the focus of range-wide monitoring and recovery efforts since it was listed as *Threatened* in 1986 pursuant to the U.S. Endangered Species Act. Breeding pairs in the U.S. and Eastern Canada were censused annually from 1986 through 2006, and productivity (chicks fledged per breeding pair) was reported annually for varying proportions of the population. Census totals more than doubled, from 790 pairs in 1986 to 1,749 pairs in 2006, concomitant with sustained intensive management. Population growth was greatest and most rapid in the New England and New York-New Jersey recovery units, while increases were more modest in the Southern and Eastern Canada units. Periodic rapid declines in the Southern and Eastern Canada units raise concerns about long-term risks of extirpation. The Atlantic Coast population became less evenly distributed between 1989 and 2006, with the percentage of the population breeding in New England increasing from 21.5% to 36.2% while declining proportionately in the other three recovery units. Overall productivity for the Atlantic Coast population 1989-2006 was 1.35 chicks fledged per pair (annual range = 1.16-1.54), and overall productivity within recovery units decreased with decreasing latitude: Eastern Canada = 1.61, New England = 1.44, New York-New Jersey = 1.18, and Southern = 1.19. Within recovery units, annual productivity was variable and showed no sustained trends. There were significant, positive relationships between productivity and population growth in the subsequent year for each of the three U.S. recovery units, but not for Eastern Canada. There was a latitudinal trend in predictions of annual productivity needed to support stationary populations (λ = 1.0) within recovery units, increasing from 0.93 chicks fledged per pair in the Southern unit to 1.44 in Eastern Canada. These results are consistent with the hypothesis that survival rates of Atlantic Coast Piping Plovers decline with increasing latitude of breeding sites, and suggest that modified productivity objectives that are specific to individual recovery units may be appropriate. *Received 11 October 2007, accepted 11 September 2008.*

Key words.—Piping Plover, *Charadrius melodus*, endangered species, census, shorebird, conservation, demographics, population, Atlantic Coast.

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In 1986 the Piping Plover (*Charadrius melodus*) was listed as *Endangered* (Great Lakes breeding population) and *Threatened* (Atlantic Coast and Northern Great Plains populations in both the U.S. and Canada) pursuant to the U.S. Endangered Species Act (ESA) (U. S. Fish and Wildlife Service 1985). The U.S. Fish and Wildlife Service (USFWS) has approved separate recovery plans for populations breeding on the Atlantic Coast (USFWS 1988a, 1996), Great Lakes (USFWS 2003), and Northern Great Plains (USFWS 1988b). In Canada, two subspecies of Piping Plover are recognized, *C. m. melodus* in Eastern Canada and *C. m. circumcinctus* in Ontario and Prairie Canada, and each is listed as *Endangered* under the Species at Risk Act (Department of Justice Canada 2002).

Recovery criteria established in the Atlantic Coast Piping Plover recovery plan (USFWS 1996) include: (1) Achieve and maintain for five yrs, 2,000 breeding pairs distributed among four recovery units: *Atlantic* (Eastern) *Canada* (Newfoundland, Quebec, Prince Edward Island, New Brunswick, Nova Scotia, and the French island of St. Pierre; 400 pairs), *New England* (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut; 625 pairs), *New York - New Jersey*; 575 pairs), and *Southern* (Delaware, Maryland, Virginia, North Carolina; 400 pairs), (2) Achieve for five yrs mean productivity of 1.5 fledged chicks per pair in each recovery unit, based on annual productivity data from $\geq$ 90% of the breeding population, (3) Institute long-term agreements among cooperator agencies, landowners and conservation organizations that will ensure protection and management sufficient to maintain the abundance and productivity targets for each recovery unit, and (4) Ensure long-term maintenance of wintering habitat sufficient in quantity, quality and distribution to maintain survival for a 2,000-pair population.

Population monitoring on the breeding grounds has been an integral part of the recovery program for Atlantic Coast Piping Plovers since 1986 (Melvin *et al.* 1991; USFWS 1996) and annual coastwide censuses have tracked local and regional progress toward recovery. In this paper, we compare abundance, distribution and reproductive success between 1986 and 2006 for the entire Atlantic Coast population of Piping Plovers and within individual recovery units, with emphasis on the U.S. portion of the range. We examine relationships between annual reproductive success and population growth, and consider implications for recovery criteria and long-term management.

METHODS

Annual censuses of breeding pairs of Atlantic Coast Piping Plovers were conducted throughout the breeding range from 1986 through 2006. Except as noted below, these were comprehensive censuses in that 95-100% of known or recently occupied breeding sites were surveyed annually in each state and province, as were additional sites that appeared suitable for breeding Piping Plovers but for which there were no recent breeding records. Annual reports from state coordinators indicated generally consistent census effort over time starting in 1989. For example, cooperators reported h/pair expended annually on monitoring and protection efforts, data compilation, report preparation, and planning averaged 93 h/pair in 1993 and 95 h/pair in 2002 for the U.S. portion of the Atlantic Coast population (Hecht and Melvin, unpublished data). Census effort, i.e. number of sites surveyed and skill levels of monitors, did increase in New York, New Jersey, and North Carolina between 1986 and 1989, and this likely was partly responsible for apparent population increases reported from those states during that period (USFWS 1996). Censuses were conducted in Eastern Canada at sites supporting ≥95% of the previous year's recovery unit total in all years except 1992 and 1993. We report population growth rates for variable time intervals as $\lambda = N_{t+1}/N_t$.

Annual data on abundance, distribution, and productivity were collected in the field by local monitors, then compiled by state coordinators employed by or under contract to state wildlife agencies and reported to the USFWS Atlantic Coast Piping Plover recovery coordinator (Hecht). Local monitors included full-time and seasonal biologists, researchers and trained volunteers who monitored Piping Plover breeding sites. Monitors performed repeated surveys at most sites, and recorded locations and observation dates for each pair; dates of nest discovery, clutch completion and hatching or failure; numbers of eggs laid and hatched; and number of chicks fledged. State coordinators communicated regularly with local cooperators to ensure that appropriate protocols for monitoring abundance and productivity were followed and that effort was sufficient to adequately census both occupied and potential breeding sites each year. Summary reports prepared by monitors facilitated quality control of data by supervisory biologists overseeing monitoring at many large sites or multi-site landownerships and by state coordinators. State coordinators contacted local cooperators when necessary to obtain missing information or to resolve inconsistencies or clarify ambiguities in census data. Low coordinator turnover (>17-year tenure by primary coordinators in Maine, Massachusetts, Rhode Island, Connecticut and New Jersey) and overlapping tenures of outgoing and new coordinators during every transition in Maryland, Virginia, and North Carolina facilitated consistent and complete census effort, data collection, and reporting. Abundance and productivity data from Eastern Canada were collected in a similar manner by local cooperators in each of the five provinces and the French island of St. Pierre, and then were quality checked and compiled by biologists with the Canadian Wildlife Service (CWS) (Amirault 2005), with only two primary coordinators spanning the period 1986-2006 (B. Johnson and D. Amirault, pers. comm.).

Cooperators reported abundance of Atlantic Coast Piping Plovers as numbers of breeding pairs, i.e. adult pairs that exhibited sustained (≥2 weeks) territorial or courtship behavior at a site or were observed with nests or unfledged chicks. Courtship, nesting and brood-rearing by Atlantic Coast Piping Plovers take place in relatively confined territories and predictable habitats, which facilitates detection, mapping and monitoring of breeding pairs. By contrast, efforts to count individual adults are more likely to be confounded by low detection or double-counting of non-tending or unpaired adults because they often forage away from nest sites (Cairns 1977, Patterson 1988). Intensive monitoring and management aimed at protecting breeding adults, eggs and unfledged chicks throughout the breeding season facilitated censuses based on repeated counts at most sites during May and June and subsequent review of detailed records of locations and chronologies of pairs, nests and broods.

Sites that could not be monitored repeatedly in May and June were surveyed at least once to count numbers of breeding pairs during a nine-day count period standardized each year for the entire Atlantic Coast (range of dates = 26 May-9 June) that coincided with the approximate peak of nesting activity. These were usually sites with few pairs (one-three), inconsistent occupancy or no record of past occupancy. Virginia in 1986-1995 and New York 1994-2006 reported only census data obtained during the nine-day count period for all sites. Census totals reported for Massachusetts in 2000-2006 were the average of two statewide counts, one derived from one or more censuses per site made during the standardized nine-day count period, and another derived from repeated censuses made during May and June, in order to correct for pairs that may have left nesting beaches early or arrived late and so would not have been present during the nine–day count period, and pairs that might have been double-counted over the course of the entire breeding season because they nested at >1 site.

We report productivity as number of chicks fledged per breeding pair. For purposes of measuring productivity, we considered chicks as fledged if they survived to 25 days of age or were seen flying, whichever occurred first. We calculated productivity by dividing the number of fledged chicks by the number of pairs that were monitored and for which number of fledglings could be determined. This included both successful pairs and pairs that fledged no chicks because they failed to nest or because no eggs hatched or no chicks survived to fledging. Accurate assessment of productivity was facilitated by repeated visits to nesting beaches to monitor individual nests and broods during May, June, July and, if necessary, August.

We used VassarStats (http://faculty.vassar.edu/lowry/VassarStats.html) to perform linear regressions to determine how annual population growth (λ) within recovery units was correlated with productivity in the preceding year, and to predict productivity levels necessary to sustain stationary populations (λ = 1.0) within recovery units. We performed regressions on untransformed data because scatter plots did not imply curvilinear relationships and indicated that neither log nor square root transformations of either lambda or both productivity and lambda increased rectilinearity (Zar 1984). We used productivity data only when reported for ≥60% of breeding pairs in a given recovery unit in a given year. For the New York-New Jersey recovery unit, we used only data from New Jersey, because productivity data were reported for only 32% and 36% of breeding pairs in New York in 1989 and 1990, and because estimates of productivity may have been inaccurate in New York in 1999 and 2000.

RESULTS

Counts of breeding pairs of Piping Plovers on the entire Atlantic Coast more than doubled, from 790 pairs in 1986 to 1,749 pairs in 2006. Even discounting apparent increases in New York, New Jersey and North Carolina between 1986 and 1989, which likely were due in part to increased census effort, the population still increased by 82% (λ = 1.82) between 1989 and 2006 (Table 1, Fig. 1).

The largest and most rapid population growth occurred in the New England and New York-New Jersey recovery units (Table 1, Fig. 1). The New England population grew most rapidly between 1991 and 1996 (λ = 2.46), leveled off for four years, peaked at 699 pairs in 2002, then declined to 634 pairs by 2006. In New York-New Jersey, population growth was most rapid between 1999 and 2003 (lambda = 1.51), declined in 2004 and 2005, then increased to 538 pairs in 2006. Population growth within the other two recovery units was more modest and some increases were short-lived (Table 1, Fig. 1). In the Southern unit, the overall growth rate

Table 1. Distribution, population growth (λ) 1989-2006, and productivity (chicks fledged per pair), by state and recovery units, of breeding pairs of Atlantic Coast Piping Plovers.

RECOVERY UNIT/State	Number (%) breeding pairs 1989	Number (%) breeding pairs 2006	λ[a] (1989-2006)	Number (%) breeding pairs Overall (range)
EASTERN CANADA	233 (24.3)	256 (14.6)	1.10	1.61 (0.69-2.10)
Maine	16 (1.7)	40 (2.3)	2.50	1.65 (0.55-2.50)
New Hampshire	0 (0.0)	3 (0.2)	—	1.40 (0.00-2.67)
Massachusetts	137 (14.3)	482 (27.6)	3.52	1.41 (1.00-2.03)
Rhode Island	19 (2.0)	72 (4.1)	3.79	1.41 (0.77-2.00)
Connecticut	34 (3.6)	37 (2.1)	1.09	1.48 (0.38-2.14)
NEW ENGLAND	206 (21.5)	634 (36.2)	3.08	1.44 (1.04-1.91)
New York	191 (20.0)	422 (24.2)	2.21	1.29 (0.80-1.62)
New Jersey	128 (13.4)	116 (6.6)	0.91	1.00 (0.39-1.40)
NY-NJ REGION	319 (33.3)	538 (30.8)	1.69	1.18 (0.88-1.49)
Delaware	3 (0.3)	9 (0.5)	3.00	1.48 (0.50-2.50)
Maryland	20 (2.1)	64 (3.7)	3.20	1.33 (0.41-2.41)
Virginia	121 (12.6)	202 (11.6)	1.67	1.35 (0.59-2.23)
North Carolina	55 (5.7)	46 (2.6)	0.84	0.54 (0.07-0.92)
SOUTHERN REGION	199 (20.8)	321 (18.4)	1.61	1.19 (0.62-1.95)
U.S.TOTAL	724 (75.7)	1,493 (85.4)	2.06	1.31 (1.06-1.56)
ATLANTIC COAST TOTAL	957 (100.0)	1,749 (100.0)	1.83	1.35 (1.16-1.54)

[a] $\lambda = N_{t+1}/N_t$.
[b] productivity = chicks fledged per pair.

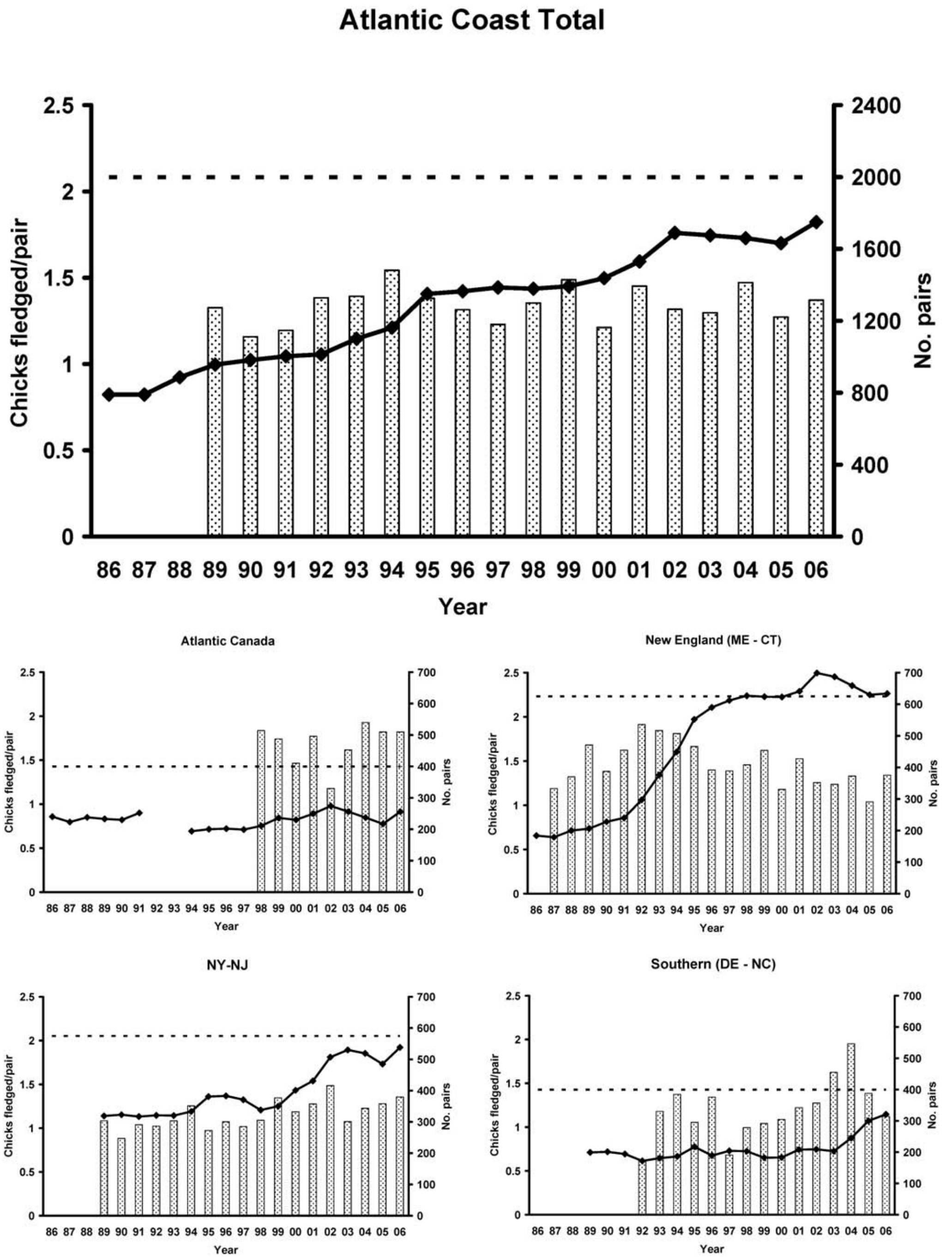

Figure 1. Trends in abundance (breeding pairs) and productivity (chicks fledged per pair) for the Atlantic Coast population of Piping Plovers and individual recovery units established in the U.S. recovery plan for the Atlantic Coast population of Piping Plovers (U.S. Fish and Wildlife Service 1996). Abundance data are indicated by lines connecting points, productivity data are indicated by bars. Dashed lines indicate abundance objectives established for the Atlantic Coast population as a whole and for individual recovery units in the U.S. recovery plan (U.S. Fish and Wildlife Service 1996). Abundance data are not plotted for Eastern Canada in 1992 and 1993 and for the New York-New Jersey and Southern recovery units in 1986-1988 because of incomplete census efforts in those years. Productivity data are not plotted in 1986-1997 for Eastern Canada, 1986-87 for New England, 1986-88 for New York-New Jersey, and 1986-91 for the Southern recovery unit because percent of pairs for which productivity data were reported was ≤60%.

between 1989 and 2006 was 1.61, but 80% of this growth occurred in just two years, 2003-2005. In Eastern Canada, the breeding population increased from 240 pairs in 1986 to 274 pairs in 2002, then declined to 217 pairs in 2005 before rebounding to 256 pairs in 2006.

Breeding Atlantic Coast Piping Plovers became less evenly distributed among the four recovery units between 1989 and 2006. Percentage of the population breeding in New England increased from 21.5% to 36.2% and declined in each of the other three regions during that period (Table 1). In particular, the percentage breeding in Eastern Canada declined from 24.3% to 14.6%. In 2006, Massachusetts and New York collectively supported 904 pairs or 52% of the Atlantic Coast breeding population.

The latitudinal extent of the breeding population did not change 1986-2006, as Piping Plovers nested annually from southern North Carolina north to the western coast of Newfoundland. Breeding Piping Plovers were present each year in all Atlantic Coast states from North Carolina to Maine, except for New Hampshire, where they were reported in 1997 for the first time since ESA listing. One to three pairs were reported nesting in South Carolina in 1986, 1990, 1991 and 1993. Breeding sites along the Atlantic Coast 1986-2006 remained exclusively along coastal beaches, with no reported inland nesting along shores of rivers, lakes, or reservoirs or in commercial sand and gravel pits, as occurs in the Great Lakes and Northern Great Plains populations (U.S. Fish and Wildlife Service 1988b; Sidle and Kirsch 1993). The largest discontinuity in the Atlantic Coast breeding population, 400 km from Reid State Park along the south-central Maine coast to sites on the south coast of Nova Scotia, remained unchanged 1986-2006, although numbers of breeding pairs in south Nova Scotia declined between 2001 and 2005 (Calvert *et al.* 2006).

Overall productivity for the U.S. portion of the Atlantic Coast population 1989-2006 averaged 1.31 chicks fledged per pair (annual range = 1.06-1.56) (Table 1). Only in 1994 did overall productivity attain the U. S. Atlantic Coast recovery objective of 1.5 chicks fledged per pair. Overall productivity 1989-2006 within recovery units decreased with decreasing latitude: Eastern Canada = 1.61, New England = 1.44, New York-New Jersey = 1.18, and Southern unit = 1.19. However, within each recovery unit annual productivity was variable and showed no sustained increasing or decreasing trend (Fig. 1). Only New Jersey and North Carolina failed to achieve productivity >1.5 in at least one year, and only those states plus New York failed to achieve overall productivity ≥2.0 in at least 1 year (Table 1).

There were significant, positive relationships between annual population growth rate (λ) and productivity in the previous year for each of the three U.S. recovery units (Table 2). Regression analysis indicated a latitudinal trend in annual productivity predicted to result in a stationary population ($\lambda = 1.0$), increasing from 0.93 chicks fledged per pair in the Southern recovery unit to 1.44 in Eastern Canada.

DISCUSSION

Results of annual censuses on the breeding grounds indicate that the Atlantic Coast population of Piping Plovers has increased substantially toward the abundance objective of 2,000 breeding pairs contained in the U.S. recovery plan for the Atlantic Coast population of this species (USFWS 1996). Population increases between 1986 and 2006 followed intensive, expensive, and sustained management on the breeding grounds by USFWS and state wildlife agencies, federal, state, municipal and private landowners, non-governmental organizations, academic institutions and interested individuals. In most States and Provinces, managers have used regulatory tools to substantially reduce habitat degradation, disturbance and direct mortality to eggs and chicks caused by off-road vehicles, and symbolic fencing, wardening, and public education to protect habitat, nests and unfledged chicks from impacts of pedestrian recreation (Melvin *et. al.* 1991, 1994; USFWS 1996). Federal, State, and Provincial environmental regulations have been

Table 2. Results of regression analysis to estimate annual productivity (chicks fledged per pair) necessary to maintain stationary populations (λ = 1.0) in each of the four Atlantic Coast Piping Plover recovery units (U.S. Fish and Wildlife Service 1996).

Recovery unit	n (years)	r^2	Productivity for $\lambda^a = 1.0$	*p*
Eastern Canada, 1998-2006[b]	9	0.094	1.44	0.459
New England, 1987-2006	20	0.540	1.21	<0.001
New Jersey, 1989-2006[c]	18	0.590	1.01	<0.001
Southern, 1992-2006[d]	15	0.396	0.93	0.016

[a]$\lambda = N_{t+1} / N_t$.

[b]Census data from Eastern Canada prior to 1998 were not used in regression analysis because the percentage of pairs for which productivity was reported was < 60% or because census data (abundance) were incomplete (1992, 1993).

[c]In New Jersey, census effort increased until 1989. New York data were not used in regression analysis because productivity was reported for only 32 and 36% of pairs in 1989 and 1990, respectively, and because inaccuracies are suspected in estimates of productivity in 1999 and 2000.

[d]For the Southern recovery unit, <60% of pairs reported productivity prior to 1992.

used to protect breeding habitat from a variety of coastal development and shoreline stabilization activities, with varying degrees of success. Wire predator exclosures have been widely deployed to protect individual nests from mammalian and avian predators (Rimmer and Deblinger 1990; Melvin *et al.* 1992), and more recently, targeted predator removal has contributed to increased productivity at sites in several states. Intensive site-specific monitoring of breeding pairs during territory establishment and courtship, nesting and chick-rearing periods, that produced the data reported in this paper, has been integral to many management activities, for example installation of warning signs and rope fencing to protect nests and nesting habitat from human disturbance, deployment of predator exclosures around nests, and restrictions on use of off-road vehicles dictated by knowledge of hatching dates and brood locations.

While the entire Atlantic Coast population of Piping Plovers nearly doubled between 1989 and 2006, this increase was not evenly distributed between the four recovery units. Most of the increase occurred in the New England and New York-New Jersey units, with a more modest, recent increase in the Southern unit and an even smaller increase in Eastern Canada. By 2006, New England was the only recovery unit that had attained its recommended target population. Periodic rapid declines in populations at the level of the recovery unit raise concerns about the long-term risk of extirpation faced by the Atlantic Coast population. For example, the Eastern Canada population declined by 21% in just three years, and the southern half of the Southern recovery unit population declined by 68% in seven years.

In New England, Massachusetts and Rhode Island more than tripled their breeding populations between 1989 and 2006, and Maine between 1998 and 2005 supported > three times the number of breeding pairs present in 1989. The largest increase was in Massachusetts, from 137 to 538 pairs between 1989 and 2002 ($\lambda = 3.93$), and likely resulted from widespread protection efforts combined with abundant habitat. However, increases in Maine and Rhode Island demonstrated that, with adequate protection, areas with more limited potential breeding habitat, i.e. relatively short or narrow beaches, could also support relatively high densities of Piping Plovers with high reproductive success.

Most of the growth in the New York-New Jersey recovery unit occurred in New York, while the New Jersey population fluctuated between 93 and 144 pairs. The New Jersey population remains vulnerable to future declines because of the scarcity of undeveloped coastal habitat and resultant concentration of ≥40% of the population at a few sites that have been subject to periodic episodes of poor reproductive success, largely due to predation and flooding. Piping Plover breeding habitat is comprised of relatively flat, low-lying, and unvegetated or sparsely vegetated beaches, sandspits, and foredunes that are created and maintained by natural processes of shoreline erosion and accretion (Melvin *et. al.* 1991; USFWS 1996). However, widespread beach stabilization in both New York and New Jersey, including construction of jetties, seawalls, and revetments, planting of vegetation and placement of sand-trapping fences, has degraded or inhibited formation of habitats that might otherwise support higher densities of nesting pairs (Elias *et al.* 2000; Cohen 2005; Fraser *et al.* 2005) and has constrained nesting and chick-rearing to artificially nourished oceanfront beaches where conflicts with human recreation are most severe (Houghton 2005). While the increased abundance in New York between 1999 and 2006 is encouraging, Piping Plovers in that state also face pervasive threats from existing, on-going and proposed human development and intensive recreation on stabilized beaches.

Recent population growth in the Southern recovery unit must be sustained to alleviate the risk of extirpation faced by this small population. This risk is exacerbated by a history of relatively high annual variances in both abundance and productivity (Goodman 1987). Breeding pairs in North Carolina and the southern half of the Virginia barrier island chain, which comprise 75% of the recovery unit coastline, declined from 75 pairs in 1995 to only 25 pairs in 2001, thereby concentrating >85% of the nesting pairs in the recovery unit along less than 20% of its shoreline. However, rapid population growth in Maryland between 1993 and 1996 (from 19 to 61 pairs) and between 2003 and 2006 in Virginia (from 114 to 202 pairs) demonstrates that substantial population increases, concomitant with productivity rates ≥1.5 chicks fledged per pair, are possible in the southern-most portion of the breeding range. In both Maryland and Virginia, managers postulated that recent high productivity and resultant population growth were likely due, in part, to effects of localized predator removal and storm-related improvement of habitat at sites where management to minimize human disturbance was ongoing.

Results of regression analysis to estimate productivity necessary to achieve stationary populations (λ = 1.0) reveal a latitudinal trend (Table 2), with an estimated 1.44 chicks fledged per pair necessary to maintain a stationary population in Eastern Canada, compared with only 0.93 chicks fledged per pair in the Southern recovery unit. Compared with U.S. recovery units, the Eastern Canada subpopulation has exhibited slower gains in spite of relatively high productivity. Overall productivity 1989-2006 in Canada of 1.61 versus 1.31 in the U.S. resulted in population growth (λ) of 1.10 versus 2.06. This pattern could explain the disparity between observed population trends for Atlantic Coast Piping Plovers and population model predictions based on an assumption of geographically uniform survival rates (Plissner and Haig 2000).

Although regression analysis demonstrated significant positive relationships between annual productivity and population increases in the subsequent year in three of four recovery units (Table 2), the relatively small coefficients of determination (r^2 = 0.09-0.59) indicate that other factors also had important influences on population growth rates. Presumably annual survival rates of both adults and fledged chicks were important factors. Population models have demonstrated that Piping Plover population trends and extinction probabilities are most sensitive to changes in survival rates, especially for adults (Melvin and Gibbs 1996; Larson *et al.* 2002; Wemmer *et. al.* 2001; Calvert *et. al.* 2006). In contrast, extensive efforts to re-sight >1,400 Atlantic Coast Piping Plovers color-banded in Virginia, Maryland, Massachusetts and five Eastern Canadian provinces between 1985 and 2003 have resulted in only four records of plovers breeding outside the recovery unit in which they were banded (USFWS files; D. Amirault, CWS, pers. comm.), suggesting that immigration and emigration had relatively little influence on recent abundance trends at the scale of the recovery unit. As local breeding populations have increased, habitat availability may have become a more important factor limiting population growth. The lack of a significant relationship between productivity and population growth in the subsequent year in Eastern Canada may be due in part to a relatively small sample of years (n = 9) when complete censuses of abundance were completed and productivity was reported from ≥60% of pairs. However, the apparent weak relationship between productivity and population growth also suggests that in the northern portion of the range, population trends are, at least at present, more sensitive to other demographic variables such as survival rates.

Estimation of productivity levels necessary for sustaining or increasing local and regional populations of Piping Plovers is important for managers who are engaged in a variety of recovery activities. However, risk of leg injuries associated with banding of Atlantic Coast Piping Plovers (Lingle *et al.* 1999; Amirault *et al.* 2006a) constrains use of banding to estimate survival rates as a means of estimating productivity needed to sustain or increase breeding populations. Evaluation of the relationship between productivity and subsequent population increase (λ) provides another means to estimate productivity needed to sustain or increase populations, as well as to infer regional differences or long-term changes in survival rates, and is a task identified in the Atlantic Coast recovery plan (USFWS 1996). Our estimate from regression analysis of productivity needed to maintain a stationary population within New England, 1.21 chicks fledged per pair (Table 2), is similar to the value of 1.24 that was estimated through population modeling based on survival estimates derived from banding studies in Massachusetts (Melvin and Gibbs 1996; L. H. MacIvor, C. R. Griffin and S. M. Melvin, Univ. of Massachusetts-Amherst, unpubl. data). Our analysis estimates a productivity of 1.44 chicks fledged per pair needed to maintain a stationary population in Eastern Canada (Table 2), while Calvert *et al.* (2006) estimated 1.63 chicks per pair for Eastern Canada exclusive of southern Nova Scotia, based on estimates of survival derived from recent banding studies.

Our estimates of productivity needed to maintain stationary populations within recovery units increased from south to north across the breeding range of Atlantic Coast Piping Plovers, while by far the weakest correlation between productivity and subsequent population increase occurred in the most northerly recovery unit. These patterns are consistent with the hypothesis that survival rates of Atlantic Coast Piping Plovers decline with increasing latitude of breeding sites, perhaps due to the rigors of longer migrations that may differ by ≥1,600 km between northern and southern ends of the breeding range. Banding studies of Piping Plovers breeding in Eastern Canada between 1998 and 2003 (Amirault *et al.* 2006b) estimated lower survival rates of one-year-old birds compared with similar studies at U.S. Atlantic Coast breeding areas (Calvert *et al.* 2006), raising concerns about factors that affect survival rates of more northerly nesting birds during migration and winter. Further studies of factors contributing to this pattern are warranted.

If productivity necessary to sustain or increase populations varies with latitude, perhaps due to latitudinal variation in survival rates, this suggests that modified productivity criteria that are specific to recovery units may be appropriate, rather than the "one-size-fits-all" criterion of 1.5 chicks fledged per pair that currently is applied to the entire Atlantic Coast population (USFWS 1996). For example, the breeding population in the Southern unit may be able to increase to recovery and then sustain itself with an annual productivity <1.5 chicks fledged per pair. In contrast, results from Calvert *et al.* (2006) suggest that annual productivity >1.5 may be necessary to recover and sustain the Eastern Canada subpopulation. However, any revisions in recovery criteria should be contingent on demographic modeling that explores effects of variation in productivity, survival rates, and carrying capacity of habitat on population viability within individual recovery units and the Atlantic Coast population as a whole.

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