ABUNDANCE AND PRODUCTIVITY ESTIMATES – 2021 UPDATE
ATLANTIC COAST PIPING PLOVER POPULATION

Population monitoring on the breeding grounds has been an integral part of the recovery program for Atlantic Coast piping plovers since 1986, providing information to inform protection of breeding piping plovers and their habitat. Annual coastwide censuses are one component of monitoring that track local and regional progress toward recovery. This update describes the delisting criteria established in the recovery plan and discusses the role of abundance and distribution of breeding pairs in Atlantic Coast piping plover conservation. It summarizes the most current information about abundance and productivity with attention to changes since Endangered Species Act (ESA) listing and since the 2018 estimates that are reported in USFWS (2019) and the most recent 5-Year Review (USFWS 2020).

Recovery criteria and strategy

The objective of the 1996 revised Atlantic Coast Recovery Plan is to assure the long-term viability of the Atlantic Coast piping plover population in the wild, thereby allowing removal of this population from the Federal List of Endangered and Threatened Wildlife and Plants (50 CFR 17.11 and 17.12). The Atlantic Coast piping plover population may be considered for delisting when the following recovery criteria, established in the recovery plan, have been met:

1. Increase and maintain for 5 years a total of 2,000 breeding pairs, distributed among four recovery units.

Recovery Unit	Minimum Subpopulation
Atlantic (Eastern) Canada[1]	400 pairs
New England	625 pairs
New York-New Jersey	575 pairs
Southern (DE-MD-VA-NC)	400 pairs

2. Verify the adequacy of a 2,000-pair population of piping plovers to maintain heterozygosity and allelic diversity over the long term.

3. Achieve a 5-year average productivity of 1.5 fledged chicks per pair in each of the four recovery units described in criterion 1, based on data from sites that collectively support at least 90 percent of the recovery unit's population[2].

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[1] Canadian Wildlife Service documents and literature published since 2002 refer to piping plovers breeding in Nova Scotia, New Brunswick, Prince Edward Island, Quebec, and Newfoundland as the piping plover *melodus* subspecies or the "eastern Canada population." This subpopulation coincides exactly with the geographic area termed "Atlantic Canada Recovery Unit" in the Service's 1996 Recovery Plan. To reduce confusion, we refer henceforth in this status update to the Eastern Canada recovery unit.

[2] With regard to delisting criterion #3, the recovery plan further states that "The PVA [the population viability analysis, conducted to support development of the delisting criteria] shows that a population of only 2,000 pairs would remain highly vulnerable to extinction unless average productivity is sustained above 1.5 chicks per pair. However, since the PVA is based on several assumptions that *may* underestimate survival rates for some or all

4. Institute long-term agreements to assure protection and management sufficient to maintain the population targets and average productivity in each recovery unit.

5. Ensure long-term maintenance of wintering habitat sufficient in quantity, quality, and distribution to maintain survival rates needed for a 2,000-pair population.

The recovery strategy, as articulated in the plan, recognizes that attainment of abundance targets for each recovery unit increases the probability of survival and recovery of the entire population: "Dispersal of the population across its breeding range serves as a hedge against catastrophes, such as hurricanes, oil spills, or disease, which might depress regional survival and/or productivity. Maintaining robust, well-distributed subpopulations should reduce variance in survival and productivity of the Atlantic Coast population as a whole, facilitate interchange of genetic material between subpopulations, and promote recolonization of any sites that experience declines or local extirpations due to low productivity and/or temporary habitat succession (USFWS 1996)."

Role of Breeding Abundance and Distribution in Recovery

As discussed below, the subpopulation abundance and distribution targets in recovery criterion #1 ensure **representation, redundancy, and resiliency** for Atlantic Coast piping plovers in their breeding range, consistent with current Service recovery planning guidance[3] (see also Schaffer and Stein 2000).

Representation supports the adaptability and evolutionary capacity of a species to accommodate long-term environmental changes (e.g., climate, habitat conditions or structure across large areas, emerging pathogens, novel competitors and/or predators, invasive species). The breadth of genetic, ecological, demographic, and behavioral diversity across a range of ecologically diverse locations or niches on the landscape are the best available and most useful expressions of representation (USFWS 2016b). A comprehensive molecular-genetic investigation of piping plovers by Miller et al. (2010) found strong genetic structure, supported by significant correlations between genetic and geographic distances in both mitochondrial and microsatellite

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recovery units and/or the percentage of one-year old adults that breed, this productivity figure may be revised downward if (1) it is demonstrated that survival rates are higher in some regions, and (2) a scientifically credible, stochastic model that incorporates the best available estimates of survival and other demographic variables shows that lower productivity rates will assure a 95 percent probability of survival for 100 years (see task 3.5). Adjustments to this criterion may be applied to the population as a whole or to one or more of the four recovery units, as supported by observed productivity and population trend data (USFWS 1996)." Citing findings of latitudinal variation in productivity needed to maintain a stationary population (Calvert et al. 2006, Hecht and Melvin 2009), the 2009 Piping Plover 5-Year Review (USFWS 2009) recommends 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 to support revision of criterion #3.

[3] USFWS (2016a) states: "Recovery criteria: The objective, measurable thresholds for the parameters that contribute to the resiliency, redundancy, representation, including the level of amelioration of the factors negatively affecting the 3Rs (i.e., threats) needed to achieve the recovery vision for any species (delisting)."

data sets for birds breeding along the Atlantic Coast from Newfoundland to North Carolina. Atlantic birds showed evidence of isolation-by-distance patterns, indicating that dispersal, when it occurs, is generally associated with movement to relatively proximal breeding territories. Maintaining geographically distributed subpopulations across the four recovery units serves to conserve representation of genetic diversity and adaptability to variable environmental selective pressures.

Further evidence of adaptive variability across recovery unit subpopulations is found in latitudinal differences in Atlantic Coast piping plover breeding habitat requirements. Zeigler et al (2021) found significant differences in the elevations, distances to ocean, and distances to low-energy shorelines of nesting habitats in the three U.S. Atlantic recovery units that are consistent with literature from more localized studies. Although piping plovers breeding in the northern part of their Atlantic Coast range mostly avoid sections of beach with high steep foredunes (Strauss 1990, Fraser et al. 2005), they are capable of thriving on beaches where chick access is limited to ocean foraging habitats[4] (Jones 1997, Boyne et al. 2014). In New York and New Jersey, however, the species demonstrates strong preference for sites that also offer chick access to ephemeral pools and bayside tidal flats (Elias et al. 2000, Cohen et al. 2009, Stantial et al. 2021). In Delaware, Maryland, Virginia, and North Carolina, Southern recovery unit breeding sites are almost completely restricted to low-lying barrier island flats and spits that also feature moist foraging substrates away from the ocean intertidal zone (McConnaughey et al. 1990, Loegering and Fraser 1995, Boettcher et al. 2007, NPS 2008). In addition to these well-documented geographic differences in habitat preferences, latitudinal variability may also provide Atlantic Coast piping plovers with adaptive capacity for changing climatic factors such as breeding season temperatures and storm patterns that may affect the birds directly or indirectly (e.g., via changes in prey composition or phenology).

Another line of evidence for latitudinal adaptation within Atlantic Coast piping plovers is manifested in a strong pattern of higher productivity rates needed to maintain stable populations with increasing latitude (Hecht and Melvin 2009) and concomitant differences in annual survival rates. Although the underlying causes and mechanisms are not yet well understood, this striking demographic variability among recovery units may also contribute to evolutionary capacity. In summary, maintaining geographically well-distributed populations across the four recovery units serves to conserve representation of genetic diversity and adaptations to variable environmental selective pressures evidenced by genetic structure, diverse habitat requirements, and differences in vital rates.

Redundancy safeguards the ability of representative units to withstand catastrophic events. The number and distribution of resilient populations within each representative unit contribute to redundancy, thereby assuring that the loss of an individual population does not lead to loss of representation (USFWS 2016b). The 1996 recovery plan articulates the role of the recovery units in buffering Atlantic Coast piping plovers against catastrophic events such as large storms and oil spills during the breeding season, and this need is likewise served by attaining and maintaining robust, well-distributed populations within each recovery unit. The probability of piping plover dispersal is inversely proportional to distance from previous breeding and natal sites, and movements of piping plovers between recovery units are rare (Wilcox 1959, MacIvor

[4] Management of human disturbance and human-abetted predation must also be provided.

et al. 1987, Loegering 1992, Cross 1996, Cohen et al. 2006, Hecht and Melvin 2009, Rioux et al. 2011, Stantial pers. comm. 2016). Thus, the ability of piping plovers in each recovery unit to rebound from events that depress unit-wide productivity or survival and to colonize newly formed or improved habitat (e.g., after storms or artificial habitat enhancement projects) depends on within-unit redundancy that is measured via progress towards abundance targets. Maintenance of these abundance targets for at least 5 years provides evidence that recovery will be sustainable.

Resiliency is the ability to sustain populations in the face of demographic variation and environmental stochasticity. Resiliency depends on a number of vital rates that ultimately affect population size and growth rate, as well as distribution (USFWS 2016b). In the case of Atlantic Coast piping plovers, resiliency (like redundancy) is provided via widely distributed populations meeting abundance targets for breeding pairs within each recovery unit. Hecht and Melvin (2009) found significant positive relationships between productivity and population growth in the subsequent year for each of the three U.S. recovery units, and abundance of piping plovers in each recovery unit population is almost entirely dependent on within-recovery unit productivity. As noted above, dispersal rates decline steeply with distance from previous breeding and natal sites. Thus, robust numbers of evenly distributed breeding pairs support dispersal and within-recovery unit recolonization of any sites that experience declines or local extirpations due to low productivity and/or temporary habitat succession (Gilpin 1987, Goodman 1987, and Thomas 1994).

Wide distribution of breeding pairs within representative units also provides a buffer against environmental stochasticity. For example, weather events such as storms that flood nests may affect the south-facing beaches within a recovery unit in a given year more than north- and east-facing sites (or vice-versa). When environmental factors adversely affect productivity across a region, more abundant populations are inherently less susceptible to reaching the very low numbers from which it is difficult to rebound, and which make them vulnerable to local or regional extirpations if multiple years of poor productivity occur in close succession. Similarly, robust numbers of breeding pairs in each recovery unit will provide Atlantic Coast piping plovers with a buffer against stressors (e.g., weather, habitat degradation, disturbance) in their migration and wintering range that may affect survival rates (Saunders et al. 2014, Gibson et al. 2018, Ellis et al. 2021).

Representation, redundancy, and resiliency are interconnected. Populations must be resilient in order to contribute to redundancy or representation. Likewise, redundant populations within a representative genotype or ecological setting contribute to maintenance of adaptive and evolutionary capacity (USFWS 2016b). For Atlantic Coast piping plovers, this is provided via subpopulation targets for four representative recovery units, thereby increasing the likelihood of survival and recovery of the Atlantic Coast population as a whole. Dispersal of the population across its breeding range in four robust subpopulations serves to protect against environmental and demographic variation and catastrophic events, and to conserve adaptive capacity.

Abundance and trends

Abundance of Atlantic Coast piping plovers is reported as numbers of breeding pairs, that is, adult pairs that exhibit sustained ($\geq$ 2 weeks) territorial or courtship behavior at a site or are observed with nests or unfledged chicks (USFWS 1996). Annual estimates of breeding pairs of Atlantic Coast piping plovers are based on multiple surveys of almost all breeding habitat, including many currently unoccupied sites. Sites that cannot be monitored repeatedly in May and June (primarily sites with few pairs or inconsistent occupancy) are surveyed at least once during a standard 9-day count period (Hecht and Melvin 2009).

The 2021 Atlantic Coast piping plover population estimate of 2,289 pairs is 22 percent higher than the 2018 estimate and almost triple the estimate of 790 pairs at the time of the 1986 ESA listing (Table 1 and USFWS 1996). 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 (USFWS 1996), the population more than doubled between 1989 and 2021.

Overall population growth is tempered by very substantial geographic and temporal variability (Figure 1). Between 2018 and 2021, abundance of breeding pairs increased in the New England and New York-New Jersey recovery units but decreased in Eastern Canada and the Southern recovery unit. By far, the largest population increase between 1989 and 2021 occurred in New England (514 percent). Abundance in the New York-New Jersey recovery unit experienced a net increase of 81 percent between 1989 and 2021. However, this population declined sharply from a peak of 586 pairs in 2007 to 378 pairs in 2014, before rebounding to 576 pairs in 2021. Net growth in the Southern recovery unit population was 35 percent between 1989 and 2021. Most of the Southern recovery unit breeding population increase occurred in 2003 to 2005 and 2011 to 2012, and the population decreased 30 percent between 2016 and 2021. In Eastern Canada, where increases have often been quickly eroded in subsequent years, the population posted a net 23-percent decline between 1989 and 2021. See further discussion of recovery unit trends below.

Productivity

Atlantic Coast piping plover productivity is reported as number of chicks fledged per breeding pair. For purposes of measuring productivity, chicks are counted as fledged if they survive to 25 days of age or are seen flying, whichever occurs first. Productivity for each state and recovery unit is calculated 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 includes both successful pairs and pairs that fledged no chicks either because they failed to nest or because no eggs hatched or no chicks survived to fledging. Accurate assessment of productivity is facilitated by repeated visits to nesting beaches to monitor individual nests and broods during May, June, July, and, if necessary, August.

Hecht and Melvin (2009) evaluated latitudinal trends in Atlantic Coast piping plover productivity and relationships between productivity and population growth. Rangewide productivity for the Atlantic Coast population from 1989 through 2006 was 1.35 chicks fledged per pair (annual range = 1.16 to 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 (Hecht and Melvin 2009). Within recovery units, productivity was variable from year to year 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. Regression analysis indicated a latitudinal trend in predictions of annual productivity needed to support stationary populations within recovery units, increasing from 0.93 chicks fledged per pair in the Southern unit to 1.44 in Eastern Canada. Relatively small coefficients of determination ($r^2 = 0.09$ to 0.59) for the relationships between annual productivity and population increases in the subsequent year indicate that other factors, most likely annual survival rates of both adults and fledged chicks, also had important influences on population growth rates. In some parts of the range, habitat availability may also be constraining recruitment into the breeding population.

Annual productivity estimates for the 1992-2021 period are summarized by recovery unit and state in Table 2 and estimates for 1989-1991 may be found in USFWS (1996). Average annual productivity for the U.S. Atlantic Coast during 1989-2018 was 1.25 fledged chicks per pair. The overall 2019 U.S. Atlantic Coast productivity estimate was 1.38 fledged chicks per pair, 1.25 chicks per pair in 2020. In 2021, average U.S. Atlantic productivity (1.09 fledged chicks per pair) was the fifth lowest since 1989 (Table 2 and USFWS 1986), with a number of states reporting substantial nest loss to overwash during a multi-day late-May storm (New Jersey Division of Fish and Wildlife 2021, Pearl pers. comm. 2021, Boettcher pers. comm. 2021, Massachusetts Division of Fisheries and Wildlife 2022).

Status by Recovery Unit

The demographic status of each recovery unit and implications for the survival and recovery of the coastwide population are summarized below.

Eastern Canada recovery unit[5] - Despite much higher long-term average productivity than the other recovery units, the Eastern Canada subpopulation decreased from 233 pairs in 1989 to 158 pairs in 2020 before rebounding to 180 pairs in 2021. Very high 2020 productivity (1.87 fledged chicks per pair) was a likely contributor to the increase in breeding pairs between 2020 and 2021. Productivity of 1.55 fledged chicks per pair in 2021 may be sufficient to maintain abundance in 2022.

In-depth evaluation of Eastern Canada piping plover population and productivity trends and environmental factors by the Wildlife Research Division of the Wildlife and Landscape Science Directorate, Environment Canada, concluded that the limiting factors now impeding recovery are primarily occurring outside Canada, during migration or on the wintering grounds (Gratto-Trevor et al. 2013). Efforts to identify these factors are in progress, but the difficulties inherent to

[5] The piping plover listing under the United States ESA designates the species as threatened across its range, except in the watershed of the Great Lakes where it is listed as endangered (USFWS 1985). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2001) currently recognizes piping plovers breeding in Eastern Canada as *Charadrius melodus melodus* and designates the subspecies as "Endangered" (Department of Justice Canada 2002). This supersedes 1978 and 1985 designations assigned to the entire Canadian population of piping plovers (COSEWIC 2001). The Canadian piping plover recovery strategy recognizes the importance of conserving migration and wintering habitat (Environment Canada 2012). Canadian piping plover breeding sites identified as critical habitat receive legal protections under the Species at Risk Act (Environment Canada 2012).

discerning links between environmental factors in the nonbreeding range and vital demographic rates mean that rapid results are unlikely. Furthermore, the availability of measures to ameliorate causal factors that may be identified is unknown. Meanwhile, Canadian Wildlife Service and other conservation partners continue ongoing intensive efforts to protect breeding habitat and activity to maximize productivity and reverse or slow the population decline. Low abundance, a declining overall population trend since 2007, and lack of identified causal factors that can be remedied make the prospects for recovery of the Eastern Canada recovery unit highly uncertain.

New England recovery unit - The largest and most sustained population increase has occurred in New England, where the recovery unit population has exceeded (or been within 3 pairs of) its 625-pair abundance goal since 1998. The population posted healthy 7-percent increases in 2019 and 2020, then jumped another 21 percent in 2021 to an estimated 1,264 pairs. Productivity in six of the last eight years exceeded the estimated rate needed to maintain a stationary population in New England (Hecht and Melvin 2009). Indeed, productivity of 1.56 fledged chicks per pair in 2019 matches or exceeds all productivity estimates attained since 1999. Productivity of 1.15 fledged chicks per pair in 2021 was below average but is not considered cause for concern in the context of current abundance of breeding pairs in New England.

Continuing growth of the New England piping plover population is generally attributable to the species' ability to breed productively on a wider range of microhabitats than in the other U.S. recovery units (Zeigler et al. 2021), along with intensive management of human disturbance and predation. Since 2016, the Massachusetts portion of the population has continued to increase concurrent with implementation of specific activities that may cause take of piping plovers under the auspices of the Massachusetts Habitat Conservation Plan (Massachusetts Division of Fisheries and Wildlife 2016). Additional carefully managed flexibility may be feasible for the relatively robust population in the New England recovery unit, especially if frameworks automatically adjust the amount of allowable flexibility in response to future changes in the abundance of breeding piping plovers[6].

New York-New Jersey recovery unit – In 2021, abundance in the New York-New Jersey recovery unit reached 576 pairs, surpassing the recovery unity goal of 575 pairs for the second time since listing. The prior post-listing peak of 586 pairs was attained in 2007, but the population began to decline the following year. Abundance of breeding pairs decreased 35 percent to 378 pairs in 2014 following 7 years of low productivity (including 4 years when it was less than 1.0 chick per pair). Improved productivity in 2014 and 2015 fueled a partial rebound to 496 pairs in 2016, but the population estimate increased by only one pair in 2017 and declined slightly in 2018 (despite high productivity in both 2016 and 2017) before increasing again in 2019. The apparent population dip in 2020 may be partially an artifact of decreased monitoring intensity in New York during the COVID-19 pandemic (McMaugh pers. comm. 2021).

Changes in the Long Island population account for most of the increases and decreases in the recovery unit population. The New Jersey piping plover population has fluctuated at low

[6] For example, the Massachusetts Habitat Conservation Plan adjusts the amount of allowable flexible management in response to the size of the 3-year average breeding population in the State. This increases flexibility as the population increases, and it also provides a brake on authorized take in the event of a future decline in the breeding population (regardless of the cause).

numbers (1989–2021 range = 92 to 144 pairs). Eighty-five percent of the New Jersey nesting pairs was concentrated along less than 14 percent of the State's sandy ocean beaches in 2016 (Rice 2017, Pover and Davis 2016). Periodic declines and lack of population growth following some years with productivity well-above the rate estimated necessary to maintain a stationary population in this part of the range (Hecht and Melvin 2009, Weithman et al. 2019) and response to habitat-creating events (Cohen et al. 2009, Robinson et al. 2019, 2020), suggesting that habitat may be limiting breeding abundance. Additional measures to conserve the carrying capacity of breeding habitat in the New York-New Jersey recovery unit may be necessary for its piping plover population to sustain its abundance goal and thereby assure its long-term resiliency.

Southern recovery unit – The Southern recovery unit piping plover population increased 5 percent in 2019 before declining in both 2020 and 2021. Abundance of breeding pairs was 269 pairs, 30 percent lower than the post-listing high of 386 breeding pairs in 2016. Productivity rates in 2020 and 2021 (0.54 fledged chicks per pair in both years) were the lowest on record, indicating that a further decline is very likely in 2022.

The Southern subpopulation responded positively to habitat creation events such as the 1992-1993 Nor'easters, Hurricane Isabel in 2003, Hurricane Ophelia in 2005, and Hurricane Irene in 2011 (Boettcher et al. 2007, Schupp et al. 2013, USFWS 2014, Robinson et al. 2019). Past years of low productivity (especially successive years of low productivity such as occurred in 2007-2008) have been followed by declines in breeding abundance, but the decline that began in 2016 is the steepest and most sustained that has been observed during the last 35 years (Figure 1). Ongoing collaborative efforts by Southern recovery unit biologists to identify and address the causes of such a large regional decline were initiated in early 2021, but no single explanatory factor has emerged to date. Increasing Southern recovery unit productivity and reversing the trend in breeding abundance are urgent priorities.

Summary

Although population growth, from approximately 957 pairs in 1989 to an estimated 2,289 pairs in 2021, has reduced the Atlantic Coast piping plover's vulnerability to extinction since listing under the ESA, the distribution of population growth remains very uneven. Declines of 32 percent in the Eastern Canada breeding population since 2007 and 30 percent in the Southern recovery unit in just the last 5 years typify long-standing concerns about the uneven distribution of Atlantic Coast piping plovers (Hecht and Melvin 2009, USFWS 2009, USFWS 2020). Future trends in breeding abundance will help inform assessments of whether current habitat and ongoing management are sufficient to sustain the New York-New Jersey subpopulation goal, attained in 2021. The New England recovery unit constitutes a stronghold, but there is no evidence of demographically meaningful dispersal to either Eastern Canada or New York-New Jersey, and any future inter-recovery unit "rescue" will be very slow. The survival and recovery of Atlantic Coast piping plovers remain dependent on rangewide conservation of remaining habitats and habitat-formation processes, as well as annual implementation of labor-intensive management to minimize the effects of pervasive and persistent threats from predation and disturbance by humans and pets (USFWS 2009, USFWS 2020).

References Cited

Boettcher, R., T. Penn, R.R. Cross, K.T. Terwilliger, and R.A. Beck. 2007. An overview of the status and distribution of piping plovers in Virginia. Waterbirds 30 (special publication 1):138-151.

Boyne, A.W., D.L. Amirault_Langlais, and A.J. McCue. 2014. Characteristics of piping plover nesting habitat in the Canadian Maritime Provinces. Northeastern Naturalist, 21(2):164-173.

Calvert, A.M., D.L. Amirault, F. Shaffer, R. Elliot, A. Hanson, J. McKnight, and P.D. Taylor. 2006. Population assessment of an endangered shorebird: the Piping Plover (*Charadrius melodus*) in Eastern Canada. Avian Conservation and Ecology 1(3):4. Accessed on April 30, 2008, at http://www.ace-eco.org/vol1/iss3/art4/.

Cohen, J.B., J.D. Fraser, and Daniel H. Catlin. 2006. Survival and site fidelity of piping plovers on Long Island, New York. J. Field Ornithology. 77(4):409-417.

Cohen, J.B., L.M. Houghton, and J.D. Fraser. 2009. Nesting density and reproductive success of piping plovers in response to storm- and human- created habitat changes. Wildlife Monographs 173.

COSEWIC. 2001. Canadian Species at Risk, May 2001. Committee on the Status of Endangered Wildlife Species in Canada. Ottawa, Ontario, Canada.

Cross, R.R. (unpubl. data *in* USFWS 1996).

Department of Justice Canada. 2002. Annual Statutes of Canada 2002, Chapter 29. Species at Risk Act, Schedule 1, Part 2.

Elias, S.P., J.D. Fraser, and P.A. Buckley. 2000. Piping plover brood foraging ecology on New York barrier islands. Journal of Wildlife Management. 64(2): 346-354.

Ellis, K.S., M.J. Anteau, F.J. Cuthbert, C.L. Gratto-Trevor, J.G. Jorgensen, D.J. Newstead, L.A. Powell, M.M. Ring, M.H. Sherfy, R.J. Swift, D.L. Toy and D.N. Koons. 2021. Impacts of extreme environmental disturbances on piping plover survival are partially moderated by migratory connectivity. Biological Conservation 264.

Environment Canada. 2012. Recovery strategy for the piping plover (*Charadrius melodus melodus*) in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa.

Fraser, J.D., S.E. Keane, and P.A. Buckley. 2005. Pre-nesting use of intertidal habitats by piping plovers on South Monomoy Island, Massachusetts. Journal of Wildlife Management 69:1731-1736.

Gibson, D., M.K. Chaplin, K.L. Hunt, M.J. Friedrich, C.E. Weithman, L.M. Addison, V. Cavalieri, S. Coleman, F.J. Cuthbert, J.D. Fraser, W. Golder, D. Hoffman, S.M. Karpanty, A. Van Zoeren, and D.H. Catlin. 2018. Impacts of anthropogenic disturbance on body condition, survival, and site fidelity of nonbreeding Piping Plovers. The Condor 120(3):566-580.

Gilpin, M.E. 1987. Spatial structure and population vulnerability, pp 125-139 in M.E. Soule (ed) Viable populations for Conservation. Cambridge University Press, New York.

Goodman, D. 1987. How do species persist? Lessons for Conservation Biology. Conservation Biology 1: 59-62.

Gratto-Trevor, C.L., G.J. Robertson, and C.A. Bishop. 2013. Scientific review of the recovery program for Piping Plover (*melodus* subspecies) in Eastern Canada. Unpublished report, Science and Technology Branch, Environment Canada, PNWRC, 115 Perimeter Road, Saskatoon, Saskatchewan.

Hecht, A., and S.M. Melvin. 2009. Population trends of Atlantic Coast piping plovers, 1986-2006. Waterbirds 32:64-72.

Jones, K. 1997. Piping plover habitat selection, home range, and reproductive success at Cape Cod National Seashore, Massachusetts. National Park Service Technical Report NPS/NESO-RNR/NRTR/97-03.

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.

Loegering, J.P. and J.D. Fraser. 1995. Factors affecting piping plover chick survival in different brood-rearing habitats. Journal of Wildlife Management 59(4): 646-655.

MacIvor, L.H., C.R. Griffin, and S.M. Melvin. 1987. Management, habitat selection, and population dynamics of piping plovers on outer Cape Cod Massachusetts; 1985-1987. Submitted to National Park Service, Cape Cod National Seashore, South Wellfleet, Massachusetts.

Massachusetts Division of Fisheries and Wildlife. 2016. Massachusetts Division of Fisheries & Wildlife (DFW) habitat conservation plan for piping plover. Prepared by MADFW and ICF International. Westborough, Massachusetts and Fairfax, Virginia.

Massachusetts Division of Fisheries and Wildlife. 2022. Summary of the 2021 Massachusetts piping plover census. Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries & Wildlife. February 2022.

McConnaughey, J.L., J.D. Fraser, S.D. Coutu, and J.P. Loegering. 1990. Piping plover distribution and reproductive success on Cape Lookout National Seashore. Unpublished Report submitted to the National Park Service. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Miller, M.P., S.M. Haig, C.L. Gratto-Trevor, and T.D. Mullins. 2010. Subspecies status and population genetic structure in piping plover *(Charadrius melodus).* Auk 127:57-71.

National Park Service [NPS]. 2008. Piping plover (*Charadrius melodus*) monitoring at Cape Lookout National Seashore, 2008 summary report. Cape Lookout National Seashore, Harkers Island, North Carolina.

New Jersey Division of Fish and Wildlife. 2021. Piping plover nesting results in New Jersey: 2021. New Jersey Division of Fish and Wildlife, Endangered Species and Nongame Species Program.

Pover, T. and C. Davis. 2016. Piping plover nesting results in New Jersey: 2016. Conserve Wildlife Foundation of New Jersey and New Jersey Division of Fish and Wildlife.

Rice, T.M. 2016. Inventory of habitat modifications to tidal inlets in the U.S. Atlantic Coast breeding range of the piping plover (*Charadrius melodus*) as of 2015: Maine to North Carolina. Report submitted to the U.S. Fish and Wildlife Service, Hadley, Massachusetts.

Rice, T.M. 2017. Inventory of habitat modifications to sandy oceanfront beaches in the U.S. Atlantic Coast breeding range of the piping plover (*Charadrius melodus*) as of 2015: Maine to North Carolina. Report submitted to the U.S. Fish and Wildlife Service, Hadley, Massachusetts.

Rioux, S., D.L. Amirault-Langlais, and F. Shaffer. 2011. Piping plover make decisions regarding dispersal based on personal and public information in a variable coastal ecosystem. Journal of Field Ornithology 82:32–43.

Robinson, S.G., J. Fraser, D. Catlin, S.M. Karpanty, J. Altman, R. Boettcher, K. Holcomb, C. Huber, K. Hunt, and A. Wilke. 2019. Irruptions: evidence for breeding season habitat limitation in piping plover (*Charadrius melodus*). Avian Conservation and Ecology 14(1):19. https://doi.org/10.5751/ACE-01373-140119.

Robinson, S.G., D. Gibson, T. V. Riecke, J. D. Fraser, H. A. Bellman, A. DeRose-Wilson, S.M. Karpanty, K. M. Walker, and D. H. Catlin. 2020. Piping plover population increase after Hurricane Sandy mediated by immigration and reproductive output. The Condor:122. DOI: 10.1093/condor/duaa041.

Saunders, S.P., T.W. Arnold, E.A. Roche, and F.J. Cuthbert. 2014. Age-specific recruitment of piping plovers *Charadrius melodus* in the Great Lakes region. Journal of Avian Biology, 45(5) 437–449.

Schaffer, M.L. and B.A. Stein. 2000. Safeguarding our precious heritage. Pages 301–321 in B.A. Stein, L.S. Kutner, and J.S. Adams, eds. Precious heritage: The status of biodiversity in the United States. Oxford University Press.

Schupp, C.A., N.T. Winn, T.L. Pearl, J.P. Kumer, T.J.B. Carruthers, and C.S. Zimmerman. 2013. Restoration of overwash processes creates piping plover (*Charadrius melodus*) habitat on a barrier island (Assateague Island, Maryland). Estuarine, Coastal, and Shelf Science 116:11-20.

Stantial, M.L., J.B. Cohen, A.J. Darrah, S. Farrell, and B. Maslo. 2021. Habitat-specific behavior, growth rate, and survival of piping plover chicks in New Jersey, USA. Ecosphere 12(10):e03782. 10.1002/ecs2.3782.

Strauss, E. 1990. Reproductive success, life history patterns, and behavioral variation in populations of piping plovers subjected to human disturbance (1982-1989). Ph.D. Dissertation. Tufts University, Medford, MA.

Thomas, C.D. 1994. Extinction, colonization, and metapopulations: environmental tracking by rare species. Conservation Biology 8:373-378.

U.S. Fish and Wildlife Service [USFWS]. 1985. Determination of endangered and threatened status for the piping plover. Federal Register 50:50726-50734.

USFWS. 1996. Piping plover (*Charadrius melodus*), Atlantic Coast population, revised recovery plan. Hadley, Massachusetts.

USFWS. 2009. Piping plover (*Charadrius melodus*) 5-year review: Summary and evaluation. Northeast Regional Office, Hadley, Massachusetts.

USFWS. 2014. Biological Opinion and Conference Opinion Fire Island Inlet to Moriches Inlet Fire Island Stabilization Project, Suffolk County, New York. Prepared for U.S. Army Corps of Engineers, New York District by U.S. Fish and Wildlife Service, Northeast Region. Dated October 15, 2014.

USFWS. 2016a. Terms for recovery planning and implementation REV (Recovery Enhancement Vision) Training Class. September 2016.

USFWS. 2016b. Clarification of the 3R's for the purpose of identifying recovery criteria. FWS, August 2016.

USFWS. 2019. Abundance and productivity estimates – 2018 update: Atlantic Coast piping plover population. Hadley, Massachusetts.

USFWS. 2020. Piping plover (*Charadrius melodus*) 5-year review: Summary and evaluation. Michigan Field Office, East Lansing, Michigan and Northeast Regional Office, Hadley, Massachusetts.

Weithman, C. E., S.G. Robinson, K.L. Hunt, J. Altman, H.A. Bellman, A.L. DeRose-Wilson, K.M. Walker, J.D. Fraser, S.M. Karpanty, and D.H. Catlin. 2019. Growth of two Atlantic Coast piping plover populations. The Condor 121. DOI: 10.1093/condor/duz037.

Wilcox, L. 1959. A twenty year banding study of the piping plover. Auk 76:129-152.

Zeigler, S.L., B.T. Gutierrez, A. Hecht, N.G. Plant, and E.J. Sturdivant. 2021. Piping plovers demonstrate regional differences in nesting habitat selection patterns along the U.S. Atlantic coast. Ecosphere 12(3):e03418.

Electronic and personal communications

Boettcher, R. 2021. July 28, 2021 telephone conversation between Ruth Boettcher, Virginia Department of Wildlife Resources and Anne Hecht.

McMaugh, A. June 9, 2021 email from Andria McMaugh, New York State Department of Environmental Conservation to Anne Hecht regarding 2020 piping plover estimates.

Pearl, T. 2021. Attachment to October 29, 2021 email from Tami Pearl, Assateague Island National Seashore to Anne Hecht regarding 2021 Atlantic Coast piping plover and least tern abundance and productivity estimates.

Stantial, M. 2016. February 10, 2016 email from Michelle Stantial, State University of New York to Anne Hecht regarding piping plover dispersal.

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Table 1. Estimated abundance of Atlantic Coast piping plovers 1992 – 2021*

State/RECOVERY UNIT	Pairs																													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Maine	24	32	35	40	60	47	60	56	50	55	66	61	55	49	40	35	24	27	30	33	42	44	50	62	66	64	68	89	98	125
New Hampshire						5	5	6	6	7	7	7	4	3	3	3	3	5	4	4	6	7	6	8	7	7	9	11	12	13
Massachusetts	213	289	352	441	454	483	495	501	496	495	538	511	488	467	482	558	566	593	591	656	676	666	663	683	641	650	688	743	794	967
Rhode Island	20	31	32	40	50	51	46	39	49	52	58	71	70	69	72	73	77	84	85	86	90	92	91	99	97	87	87	80	85	99
Connecticut	40	24	30	31	26	26	21	22	22	32	31	37	40	34	37	36	41	44	43	52	51	45	51	62	63	66	64	57	58	60
NEW ENGLAND	297	376	449	552	590	612	627	624	623	641	700	687	657	622	634	705	711	753	753	831	865	854	861	914	874	874	916	980	1047	1264
New York	187	193	209	249	256	256	245	243	289	309	369	386	384	374	422	457	443	437	390	318	342	289	286	308	381	392	390	426	405	439
New Jersey	134	127	124	132	127	115	93	107	112	122	138	144	135	111	116	129	111	105	108	111	121	108	92	108	115	105	96	114	103	137
NY-NJ	321	320	333	381	383	371	338	350	401	431	507	530	519	485	538	586	554	542	498	429	463	397	378	416	496	497	486	540	508	576
Delaware	2	2	4	5	6	4	6	4	3	6	6	6	7	8	9	9	10	10	9	8	7	6	6	6	8	13	16	19	21	24
Maryland	24	19	32	44	61	60	56	58	60	60	60	59	66	63	64	64	49	45	44	36	41	45	38	36	34	34	23	24	24	22
Virginia	97	106	96	118	87	88	95	89	96	119	120	114	152	192	202	199	208	193	192	188	259	251	245	256	291	269	227	233	201	183
North Carolina	49	53	54	50	35	52	46	31	24	23	23	24	20	37	46	61	64	54	61	62	70	56	65	64	53	43	29	33	31	40
South Carolina		1			0					0						0														
SOUTHERN	172	181	186	217	189	204	203	182	183	208	209	203	245	300	321	333	331	302	306	294	377	358	354	362	386	359	295	309	277	269
U.S. TOTAL	790	877	968	1150	1162	1187	1168	1156	1207	1280	1416	1420	1421	1407	1493	1624	1596	1597	1557	1554	1705	1609	1593	1692	1756	1730	1697	1829	1832	2109
EASTERN CANADA**	223	223	194	200	202	199	211	236	230	250	274	256	237	217	256	266	253	252	225	209	179	184	186	179	176	173	181	190	158	180
ATLANTIC COAST TOTAL	1013	1100	1162	1350	1364	1386	1379	1392	1437	1530	1690	1676	1658	1624	1749	1890	1849	1849	1782	1763	1884	1793	1779	1871	1932	1903	1878	2019	1990	2289

* Estimates for 1986-1991 available in USFWS 1996 and USFWS 2019. Incorporates minor corrections to previous 2015 and 2016 Massachusetts abundance estimates, 2016 and 2018 Rhode Island estimates, 2017 Eastern Canada estimate, and 2019 New York estimate.

** Includes 0-5 pairs on the French islands of St. Pierre and Miquelon, reported by the Canadian Wildlife Service.

Table 2. Estimated productivity of Atlantic Coast piping plovers 1992-2021*

State/RECOVERY UNIT	Chicks fledged/pair																													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Maine	2.00	2.38	2.00	2.38	1.63	1.98	1.47	1.63	1.60	1.98	1.39	1.28	1.45	0.55	1.35	1.06	1.75	1.70	1.63	2.12	1.52	1.93	1.94	1.95	1.53	1.59	1.88	1.97	2.03	1.70
New Hampshire						0.60	2.40	2.67	2.33	2.14	0.14	1.00	1.00	0.00	0.67	0.33	2.00	0.40	1.50	2.00	0.67	1.71	0.33	1.50	2.14	0.71	1.89	1.82	1.33	1.00
Massachusetts	2.03	1.92	1.81	1.62	1.35	1.33	1.50	1.60	1.09	1.49	1.14	1.26	1.38	1.14	1.33	1.25	1.41	0.91	1.50	1.18	0.85	0.87	1.18	1.30	1.46	1.08	1.30	1.54	1.31	1.06
Rhode Island	1.55	1.80	2.00	1.68	1.56	1.34	1.13	1.79	1.20	1.50	1.95	1.03	1.50	1.43	1.03	1.48	1.68	1.46	1.76	1.49	1.06	0.98	1.63	1.58	1.49	0.66	0.87	1.20	1.41	1.23
Connecticut	1.45	0.38	1.47	1.35	1.31	1.69	1.05	1.45	1.86	1.22	1.87	1.30	1.35	1.62	2.14	1.92	2.49	1.68	1.91	1.37	1.18	1.82	2.27	1.81	1.38	1.52	1.17	1.72	1.00	1.33
NEW ENGLAND	1.91	1.85	1.81	1.67	1.40	1.39	1.46	1.62	1.18	1.53	1.26	1.24	1.40	1.15	1.34	1.30	1.51	1.04	1.56	1.27	0.93	1.00	1.33	1.41	1.47	1.10	1.30	1.56	1.37	1.15
New York	0.98	1.24	1.34	0.97	1.14	1.36	1.09	1.35	1.11	1.27	1.62	1.15	1.46	1.44	1.55	1.15	1.21	0.93	0.79	1.07	0.72	0.71	1.30	1.52	1.72	1.32	1.47	1.36	1.41	1.30
New Jersey	1.07	0.93	1.16	0.98	1.00	0.39	1.09	1.34	1.40	1.29	1.17	0.92	0.61	0.77	0.84	0.67	0.64	1.05	1.39	1.18	0.72	0.85	1.36	1.29	1.35	1.29	1.51	1.24	1.29	0.85
NY-NJ	1.02	1.08	1.25	0.97	1.07	1.02	1.09	1.35	1.19	1.28	1.49	1.07	1.23	1.28	1.36	1.03	1.10	0.96	0.92	1.09	0.72	0.74	1.32	1.46	1.62	1.32	1.48	1.33	1.38	1.19
Delaware	1.00	0.50	2.50	2.00	0.50	1.00	0.83	1.50	1.67	1.50	1.17	2.33	1.14	1.50	1.44	1.33	0.30	1.30	1.56	1.00	1.00	1.17	1.33	1.17	1.63	1.08	2.25	2.74	2.24	0.79
Maryland	1.00	1.79	2.41	1.73	1.49	1.02	1.30	1.09	0.80	0.92	1.85	1.56	1.86	1.25	1.06	0.78	0.41	1.42	1.09	1.25	1.02	0.76	1.55	1.31	1.47	0.82	1.30	1.00	0.21	0.68
Virginia	0.59	1.45	1.66	1.00	1.54	0.71	1.01	1.21	1.42	1.52	1.19	1.90	2.23	1.52	1.19	1.16	0.87	1.19	1.35	1.36	0.95	1.15	1.34	1.26	0.92	0.68	0.76	0.72	0.39	0.52
North Carolina	0.41	0.74	0.36	0.45	0.86	0.23	0.61	0.48	0.54	0.50	0.17	0.46	0.65	0.92	0.87	0.26	0.30	0.70	0.77	0.77	0.59	0.96	0.22	0.64	0.15	0.26	0.90	0.61	0.52	0.43
SOUTHERN	0.62	1.18	1.37	1.05	1.34	0.68	0.99	1.04	1.09	1.22	1.27	1.63	1.95	1.38	1.12	0.92	0.67	1.14	1.20	1.21	0.89	1.07	1.15	1.15	0.88	0.65	0.90	0.86	0.54	0.54
U.S. average	1.35	1.47	1.56	1.35	1.30	1.16	1.27	1.45	1.17	1.40	1.34	1.24	1.43	1.24	1.30	1.13	1.19	1.03	1.27	1.21	0.86	0.94	1.29	1.37	1.38	1.08	1.28	1.38	1.25	1.09
EASTERN CANADA**	1.55	0.69	1.25	1.69	1.72	2.10	1.84	1.74	1.47	1.77	1.18	1.62	1.93	1.82	1.82	1.14	1.47	1.22	1.59	1.19	1.38	1.36	1.37	1.60	1.39	1.66	1.80	1.18	1.87	1.55

* Estimates for 1987-1991 available in USFWS 1996 and USFWS 2019. Incorporates minor corrections to previous 2015 and 2016 Massachusetts abundance estimates, 2016 and 2018 Rhode Island estimates, and the 2019 New York estimate.
** Includes productivity on the French islands of St. Pierre and Miquelon, reported by the Canadian Wildlife Services

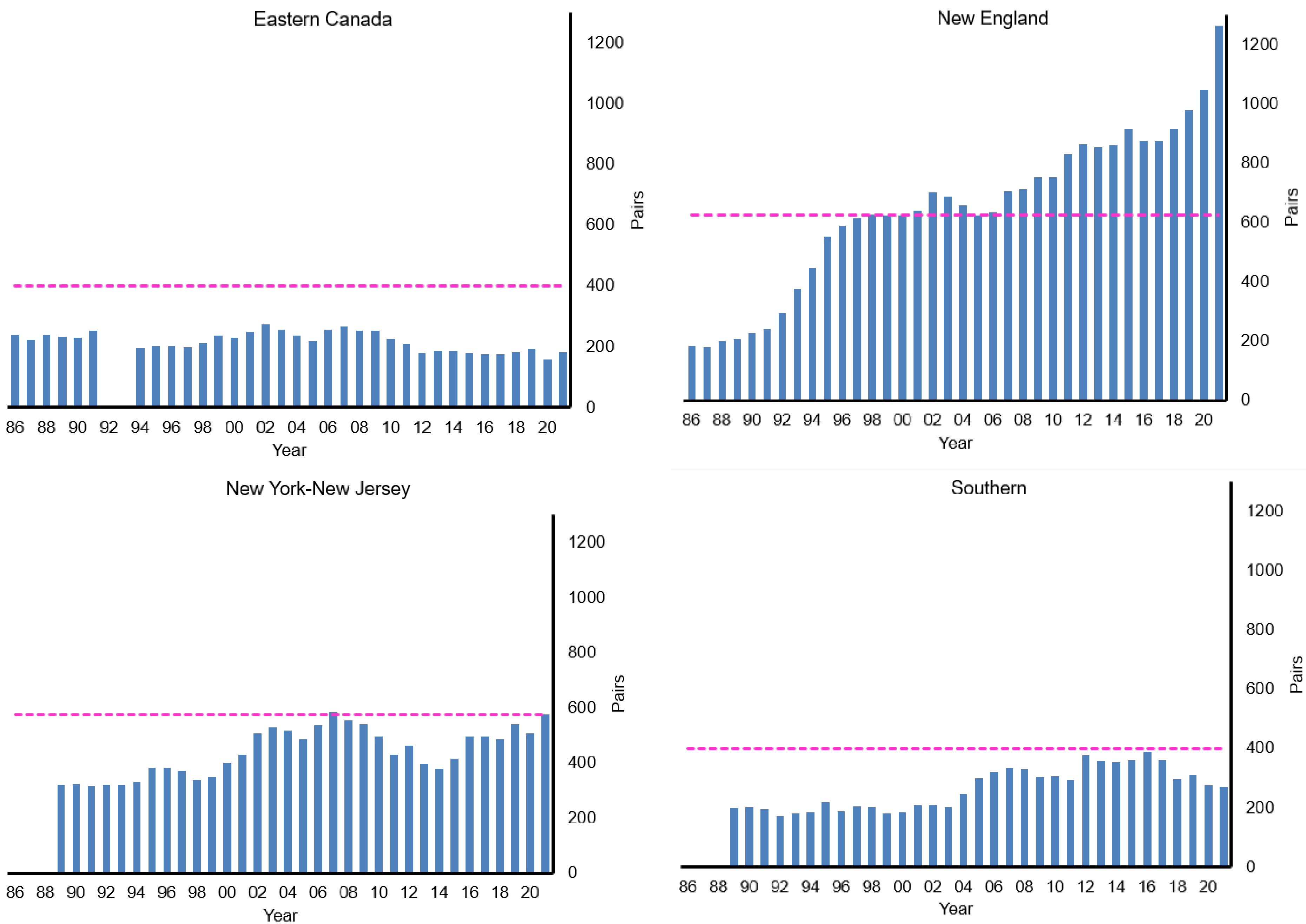

Figure 1. Abundance of Atlantic Coast piping plover breeding pairs by recovery unit, 1986-2021. Blue bars denote the annual pair estimate. Dashed pink lines indicate abundance objectives established in the 1996 revised recovery plan.