Post-DDT Recovery of Osprey (*Pandion haliaetus*) Populations in Southern New England and Long Island, New York, 1970–2013

Author(s): Richard O. Bierregaard, Jr., Augustus Ben David, Lori Gibson, Robert S. Kennedy, Alan F. Poole, Michael S. Scheibel, and Julie Victoria

Source: Journal of Raptor Research, 48(4):361-374. 2014.
Published By: The Raptor Research Foundation
DOI: http://dx.doi.org/10.3356/JRR-OSPR-14-04.1
URL: http://www.bioone.org/doi/full/10.3356/JRR-OSPR-14-04.1

J. Raptor Res. 48(4):361–374

POST-DDT RECOVERY OF OSPREY (*PANDION HALIAETUS*) POPULATIONS IN SOUTHERN NEW ENGLAND AND LONG ISLAND, NEW YORK, 1970–2013

Richard O. Bierregaard, Jr.[1]
Biology Department, University of North Carolina at Charlotte, 9201 University City Boulevard, Charlotte, NC 28223 U.S.A.

Augustus Ben David
P.O. Box 1055, Oak Bluffs, MA 02557 U.S.A.

Lori Gibson
Rhode Island Department of Environmental Management, 235 Promenade Street, Providence, RI 02908 U.S.A.

Robert S. Kennedy
Maria Mitchel Association, 4 Vestal Street, Nantucket, MA 02554 U.S.A.

Alan F. Poole
Birds of North America Online, Cornell Laboratory of Ornithology, 159 Sapsucker Woods Road, Ithaca, NY 14850 U.S.A.

Michael S. Scheibel
NYS Department of Environmental Conservation, Bureau of Wildlife, Region 1 Headquarters, SUNY at Stony Brook, 50 Circle Road, Stony Brook, NY 11790 U.S.A.

Julie Victoria
Connecticut Department of Energy and Environmental Protection, 79 Elm Street, Hartford, CT 06106 U.S.A.

Abstract.—The Osprey (*Pandion haliaetus*) population nesting between New York City and Boston, Massachusetts, collapsed from approximately 1000 pairs in 1940 to 109 in the early 1970s. In the 1970s, within five or six years of the cessation of DDT use in the region, the Osprey population began recovering. The recovery was asynchronous across the region. Current (2013) distribution and numbers differ dramatically from those of the pre-DDT period. Colonies on Narragansett and Mount Hope bays in Rhode Island, the Connecticut River estuary, and on Gardiners Island, New York, failed to recover their former remarkable densities. Osprey populations expanded from eastern to western Long Island, New York. In Connecticut, Ospreys now occupy the entire coastline and are nesting inland. A new concentration of Ospreys has become established in southeastern Massachusetts on the Westport River, the islands of Martha's Vineyard and Nantucket, and most recently, on Cape Cod. From this area, the species' range has gradually expanded northward. The population in Massachusetts is now contiguous with the New Hampshire population, and pairs are nesting west of the Connecticut River. The current population in southern New England easily exceeds 1200 pairs and is predominantly (ca. 95%) nesting on human-made structures either erected as nest platforms or co-opted by Ospreys as nest support structures.

Key Words: *Osprey*; Pandion haliaetus; *DDT recovery*; *human-made nest structures*; *Long Island*; *nest platforms*; *New England*; *population*; *trends.*

---

[1] Present address: 421 Cotswold Lane, Wynnewood, PA 19096 U.S.A.; email address: rbierreg@gmail.com.

RECUPERACIÓN POS-DDT DE POBLACIONES DE *PANDION HALIAETUS* EN EL SUR DE NUEVA INGLATERRA Y LONG ISLAND, NUEVA YORK, 1970–2013

RESUMEN.—La población de *Pandion haliaetus* nidificando entre la ciudad de Nueva York y Boston, Massachusetts, colapsó de aproximadamente 1000 pares en 1940 a 109 a comienzos de la década de 1970. En dicha década, en cinco o seis años de cese en el uso de DDT en la región, las poblaciones de *P. haliaetus* comenzaron a recuperarse. La recuperación fue asincrónica a lo largo de la región. La distribución y los números actuales (2013) difieren dramáticamente de aquellos del periodo pre-DDT. Las colonias de las bahías de Narragansett y Mount Hope en Rhode Island, el estuario del Río Connecticut y en Gardiners Island, Nueva York, no pudieron recuperar sus notables densidades pasadas. Las poblaciones de *P. haliaetus* se expandieron desde el este hacia el oeste de Long Island, Nueva York. En Connecticut, *P. haliaetus* ahora ocupa la línea de costa completa y está nidificando tierra adentro. Una nueva concentración de individuos de *P. haliaetus* se ha establecido en el sudeste de Massachusetts en el Río Westport, las islas de Martha's Vineyard y Nantucket y más recientemente en Cape Cod. Desde esta área la distribución de la especie se ha expandido gradualmente hacia el norte. La población en Massachusetts ahora es contigua con la población de New Hampshire y las parejas están nidificando al oeste del Río Connecticut. La población actual al sur de Nueva Inglaterra fácilmente supera las 1200 parejas y nidifica predominantemente (ca. 95%) en estructuras hechas por el hombre, tanto las construidas como plataformas para nidos como aquellas que *P. haliaetus* utiliza como estructuras de soporte para sus nidos.

[Traducción del equipo editorial]

The Osprey population breeding in southern New England and Long Island, New York (hereafter, SNE-LI) was studied intensively before, during, and after the DDT/DDE-induced population crash in the 1950s, 1960s, and early 1970s. Historically, this population was isolated by 100–200 km from populations to the north and south and was concentrated near the coast on eastern Long Island and nearby islands and in adjacent regions of southeastern New England. There were noteworthy concentrations around the mouth of the Connecticut River on Connecticut's southern coast, on Gardiners Island, New York, off the eastern tip of Long Island, New York, and in Mount Hope and Narragansett bays in northeastern Rhode Island (Fig. 1).

Around 1940, Osprey pairs numbered 496 for Long Island, 120 for Rhode Island, and over 200 for the mouth of the Connecticut River (Bent 1937, Wilcox 1944, Emerson and Davenport 1963, Ames and Mersereau 1964). By 1970, these numbers had dwindled to 74, 8, and 8 pairs, respectively (Spitzer and Poole 1980), and the regional population was just over 100 pairs, or roughly 10% of its pre-1947 level of about 1000 pairs (Spitzer 1980). Studies conducted in this region by Ames (1966), Wiemeyer et al. (1975, 1978, 1980), Spitzer et al. (1978) and Spitzer (1980) were instrumental in the identification of DDT and DDE as causative agents in this decline.

Spitzer and Poole (1980), Poole and Spitzer (1983), and Spitzer et al. (1983) documented the initial post-DDT recovery of the SNE-LI population in the 1970s. Fishman and Scheibel (1990) reported on the Long Island population's recovery in the 1980s.

In this report, we bring these accounts of the population recovery up to date by summarizing data on population size and reproductive success from a number of previously unpublished surveys in southern New England and Long Island, New York, from the 1970s through 2013.

METHODS

Osprey Surveys. Most data were gathered through regional or statewide programs conducted by state natural resource officers and volunteers. We surveyed seven populations, some broadly distributed, others locally concentrated: (1) Long Island, New York; (2) Connecticut; (3) Rhode Island; and (4) Massachusetts (excluding the offshore islands of Martha's Vineyard and Nantucket). Three regions of Massachusetts were reported separately: (5) the island of Martha's Vineyard; (6) the island of Nantucket; and (7) the Westport River colony. Data for this last site were reported separately because the colony is discreet and was sampled long after Massachusetts statewide surveys were discontinued. In all subregions, nests were checked at least twice each breeding season—once to confirm whether nests were active and once at or near the time of fledging. (Active nests were those in which eggs were laid, as indicated by either a direct observation of the eggs or by the observation of an incubating female (Postupalsky 1974).)

Long Island, New York. MSS, working under the auspices of the New York State Department of

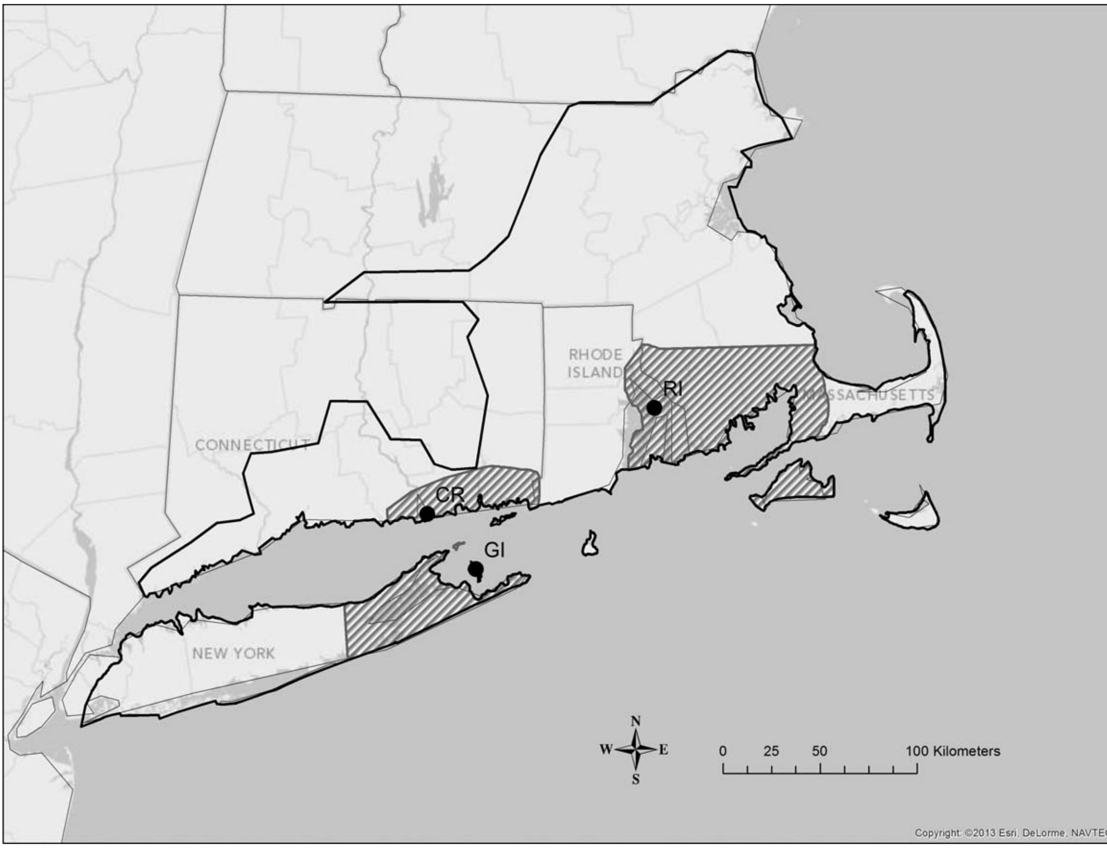

Figure 1. Distribution of nesting Ospreys in southern New England and Long Island, NY, ca. 1940 (cross hatching) and in 2009 (solid outline). The three major pre-DDT colonies are indicated on the map: GI = Gardiners Island; CR = Connecticut River Estuary; RI = Mount Hope and Narragansett bays.

Environmental Conservation (NYSDEC), surveyed Osprey numbers from New York City to Fisher's Island from 1978–2003. Surveys were conducted from the ground and from fixed- or rotary-wing aircraft; volunteer cooperators also contributed nest site information.

The last complete survey of Long Island was in 2003; only partial data are available for 1994 and 1995. In 2004–2012 only selected locations in eastern Long Island were surveyed (approximately one-third of the entire population).

Connecticut. JV coordinated the collection of the Connecticut data under the auspices of the Wildlife Division of Connecticut's Department of Environmental Protection (DEP). DEP personnel and volunteers conducted the nesting surveys from 1969 through 2009.

Rhode Island. Ornithologists in Rhode Island have maintained well over 100 yr of periodic surveillance of breeding Ospreys, beginning with A.C. Bent's summaries dating as far back as 1882 (Bent 1937). The Rhode Island Ornithological Club (now the Audubon Society of Rhode Island) began coordinating the statewide census in the 1940s. In 1978, the Rhode Island Department of Environmental Management Division of Fish and Wildlife began statewide surveillance. Division personnel and more than 40 volunteer cooperators continued the census until 2008; LG organized these surveys and collated the Osprey survey data during most of the post-DDT period. From 2010–the present, the Audubon Society of Rhode Island coordinated the statewide census.

Massachusetts. The Massachusetts data came from statewide surveys organized by Massachusetts Division of Fisheries and Wildlife under the supervision of William Davis. They did not include the islands of Martha's Vineyard and Nantucket, which were

Table 1. Number of breeding pairs of Ospreys in southern New England. LI = Long Island, CT = Connecticut, RI = Rhode Island, MA = mainland Massachusetts (excluding the Westport River), WPT = Westport River; MVY = Martha's Vineyard, Nan = Nantucket Island.

YEAR	LI	CT	RI	MA	WPT	MVY	NAN	TOTAL
1975	62	10	9	9	14[a]	3	0	**107**
1980	87	19	12	25	20	11	1	**175**
1985	129	44	20	83	45	26	3	**350**
1990	189	55	31	169	69	59	6	**578**
1995	256	103	43	240[a]	70	70	8	**790**
2000	303	158	58	299[a]	70	63	9	**960**
2005	325[a]	196[a]	98	349[a]	73	61	14	**1112**
2010	350[a]	235[a]	115	400[a]	66	74	14	**1274**

[a] Numbers are estimates, assuming regular changes between years with census data or estimates based on regional surveys or the Massachusetts Breeding Bird Atlas.

monitored by ABD and RSK, respectively (see below). Statewide data cover the period from 1963 to 1994, with estimates for 1995 through 2010 based on anecdotal reports and the Massachusetts Breeding Bird Atlas (Petersen and Meservey 2004).

ABD collected the data from Martha's Vineyard from 1971–1991 using ground-based and aerial surveys from a fixed-wing aircraft. No data were collected from 1992–1997. From 1998–the present, ROB coordinated ground-based surveys of all known nesting sites and available nest poles. AFP coordinated the Westport River surveys from 2003–the present, and RSK monitored the Nantucket population from 1997–2013.

Reproductive Success. Estimates of breeding productivity are reported as the number of fledglings/active nest. Although efforts were made to count young as close as possible to the actual fledging date, some young were counted 1–2 wk before they actually left the nest. As a benchmark for assessing the recovery, we used Spitzer's (1980) estimate of 0.8 fledglings/active nest as the average productivity required to maintain a stable population. We used repeated measures ANOVA with subpopulations as the repeated measure and Tukey's HSD tests to investigate decadal changes in productivity in various regional populations.

Population Change in Local Colonies. The Martha's Vineyard (1998–2010) and Westport (2003–2008) colonies are of similar size (70–80 pairs), are separated by only 30 km, and are the most intensely monitored subpopulations in the region. We used linear regression to test for population trends in these two areas.

RESULTS

Population Growth. Numbers of breeding Ospreys in the SNE-LI region started to increase in the mid-1970s and have increased steadily thereafter, although growth patterns varied among populations (Table 1). Initially, most new nests were established close to established colonies, but new areas were colonized as numbers increased in the old colonies.

By 1990, the once discrete southern New England and Long Island Osprey population was actually or virtually contiguous with neighboring populations to the south and north (Fig. 1). Ospreys on western Long Island nest about 35 km from their neighbors in northern New Jersey—close enough that foraging ranges of males in the two areas could overlap. The Osprey distribution now includes areas north of Boston and up the coast through New Hampshire and into Maine, melding the southern New England population with that of Maine.

Long Island, New York. The Long Island population reached its nadir of 69 active nests in 1976. Beginning in the late 1970s, Ospreys spread west to areas they had not occupied in recent times, reaching Jamaica Bay, at the outskirts of New York City, in 1988.

Currently (2013), nesting ospreys are distributed along both shorelines of Long Island from Jamaica Bay, Queens, to Montauk, and from Manhasset Bay, Nassau, east to Fisher's Island. Notable concentrations are found on salt marshes in Jamaica Bay (15 nests) and Hempstead Bay (60 nests), along the North Fork in Southold (63 nests), and on Shelter (34 nests), and Gardiners (22 nests) islands. Numbers at Gardiners Island increased from 38 pairs in 1969 to 71 pairs in 1994, but then declined steadily to 22 pairs in 2009. Incomplete data for the period 2003–2012 indicated a continuing increase from about 150 to about 206 active nests in the eastern portion of Long Island alone, so we are confident that our current estimate of 350 pairs (Table 1) in 2010 is conservative.

Connecticut. Historically, Ospreys were concentrated around the mouth of the Connecticut River (Fig. 1). In the mid-1970s, the statewide population was <20 pairs, with no young fledged at the mouth of the Connecticut River from 1974–1976. Population recovery started in this area and the Connecticut River colony reached a plateau of about 70 pairs in 1998. The population began to spread east and west in 1989 and had reached the westernmost town in the state by 1999, with three pairs inland (i.e., more than 10 km from the shoreline). The population grew during the 2000s by 72 pairs (44.4%) to 234, with substantial numbers inland.

Rhode Island. Historical records showed that Rhode Island supported a large number of Ospreys (peaking at 140 pairs in 1949), mostly in the northeastern corner of the state on the shores of Narragansett and Mount Hope bays. The state population shrank to a low of two pairs in 1967 in the Pawtucket River valley in the southwestern corner of the state and then increased steadily from 8 pairs in 1970 to 115 pairs in 2009, at which point they occupied most of the state, with the surprising exception of the southeastern coast close to the flourishing population in the Westport River area of Massachusetts.

Massachusetts. The Massachusetts population grew steadily from the mid-1970s through the mid-1990s, when statewide systematic surveys were discontinued. Since the mid-1990s, growth continued apace across the state, especially on Cape Cod (M. Faherty pers. comm.) and in Essex County on the northeast shore (D. Rimmer pers. comm.). As the population grew, it expanded north from its southeastern strongholds (Westport and Martha's Vineyard), while pairs also began nesting along the Connecticut River in central Massachusetts.

On Cape Cod, numbers increased from five pairs in 1983 (Veit and Petersen 1993) to >140 pairs in 2012 (M. Faherty pers. comm.). The most dramatic growth of the number of Ospreys on Cape Cod occurred during the first decade of this century.

Martha's Vineyard and Nantucket Island. The Nantucket population grew slowly from a single pair in 1979 to 14 pairs in 2005 and has since stabilized at about that number. The population on Martha's Vineyard, distributed around the perimeter of the 230-km^2 island, more than doubled every 5 yr through the mid-1970s and 1980s, reaching 74 pairs in 1991. After the census was resumed in 1998, numbers fluctuated between 57 and 67 pairs until 2007, but then increased to 77 pairs in 2012 (linear regression of number of breeding pairs on year: $R^2 = 0.347$, $P = 0.021$).

Westport River. By the late 1960s, the Westport River colony had moved from tree nests along the river onto artificial nest platforms located on about 20 km^2 of marshes and islands in the estuary. Between 1963 and 1968, the population grew from 11 to 23 pairs and then declined to 12 pairs in 1974, when data collection ceased. In 1981, when monitoring began anew, 21 pairs were breeding. The population then grew by an average of 14% annually, reached a peak of 83 pairs in 1991, and then declined to 71 pairs in 1994. From 2003, when AFP began the census again, to 2012, the population fluctuated between 67 and 80 pairs, with no significant trend (linear regression of number of breeding pairs on year: $R^2 = 0.121$, $P > 0.05$).

Reproductive Success. Productivity increased rapidly in all regions during the 1970s. With few exceptions, the number of young/active nest was well above the threshold of 0.8 fledglings/active nest from the mid-1970s to the present. Three-point running averages for our separate study areas never dropped below 0.8 young/active nest after they first exceeded it (Fig. 2).

Mean productivity in the 1970s was 2.58 young/active nest (SD = 0.78, n = 9 nests; Fig. 3) in the small but remarkably productive population on Martha's Vineyard and 1.07 (SD = 0.48, n = 45) in the rest of the study region. Region-wide, mean productivity increased to 1.54 (SD = 0.36, n = 59) in the 1980s and then declined to 1.28 (SD = 0.32, n = 41) in the 1990s and 1.26 (SD = 0.31, n = 46) in the 2000s. In the full dataset, the only significant difference between decadal means was between the 1980s and 2000s ($P = 0.014$). The data from the highly productive population on Martha's Vineyard obscured differences among the other populations in statistical analyses, so we excluded them and ran the analyses again. Without the 1970s Martha's Vineyard data, decadal means for the 1980s were significantly different from all other decades (ANOVA with Tukey's tests, $P = 0.0018$; Fig. 3).

Timing of Recovery. In 1973, average productivity in the SNE-LI region exceeded the threshold of 0.8 young/active nest. Four years later, the population showed its first increase in three decades. From 1975 to 1980, our study populations increased by an average of 113%. The regional population has continued to grow ever since.

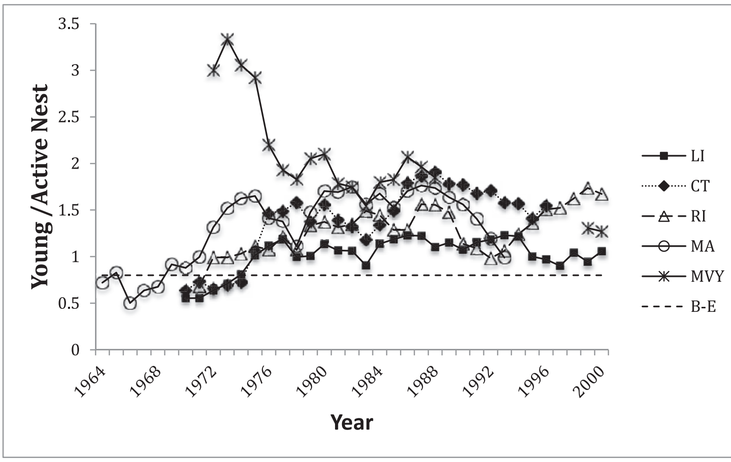

Figure 2. Three-point running means of the number of young fledged/active nest in our larger regional populations (LI = Long Island, New York; CT = Connecticut; RI = Rhode Island; MA = Massachusetts; MVY = Martha's Vineyard, Massachusetts). ''B-E'' indicates the reproductive rate necessary for a stable population as calculated by Spitzer (1980).

Martha's Vineyard was the first population to show a strong increase in reproductive rates. We do not have data to document when the reproductive rates increased, but by the time we started surveying this population (1971) and for the ensuing decade, reproductive rates were the highest that have been recorded in the entire region during the entire post-DDT era (see Fig. 2, 3), although the number of nests was low.

On Long Island, Osprey reproduction exceeded the 0.8 young/active nest threshold in 1973. Three years later (1976), the population did not decline for the first time in decades, and, beginning the following year (1977) with the exception of a 1.2%

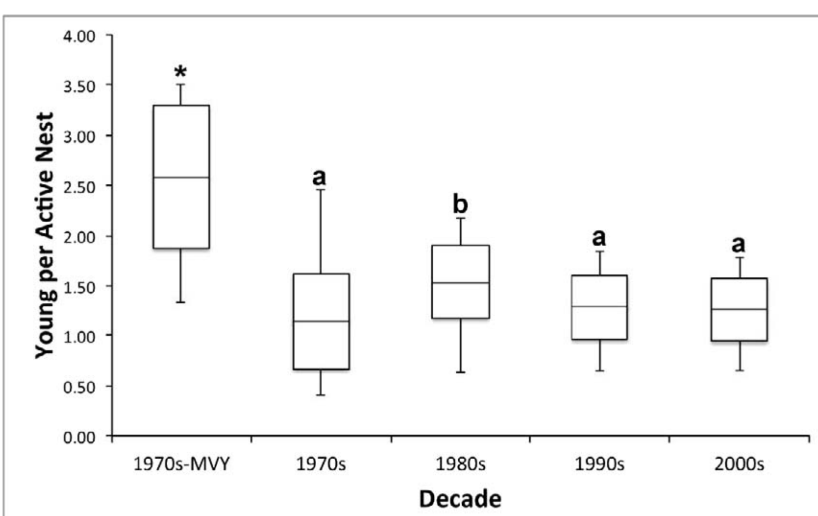

Figure 3. Average reproductive rate (young/active nest) by decade with Martha's Vineyard data separated for the 1970s but included in all other decades. Whiskers represent maximum and minimum values, boxes represent the mean ± 1 SD. Samples with the same letter are not significantly different ($P > 0.05$) in pair-wise Tukey HSD tests. Data from the 1970s for Martha's Vineyard were not included in the statistical comparison.

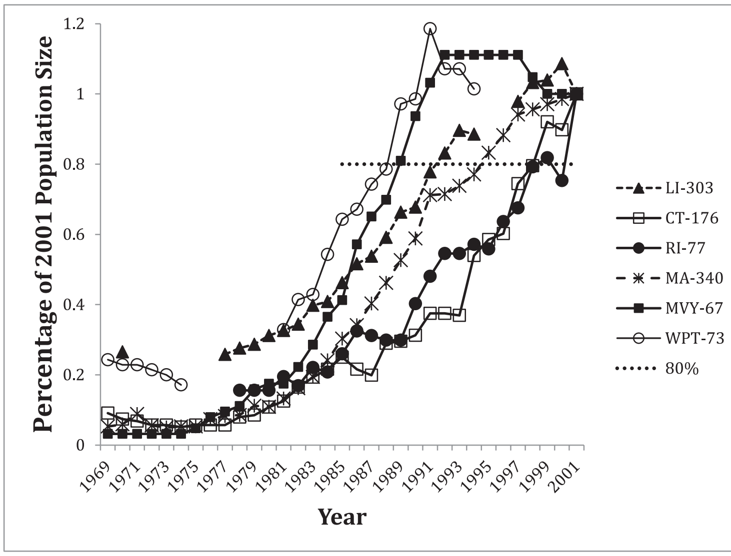

Figure 4. Population growth in regional populations measured as a percentage of the number of breeding pairs in that region in 2001. (LI = Long Island, New York; CT = Connecticut; RI = Rhode Island; MA = Massachusetts; MVY = Martha's Vineyard, Massachusetts; WPT = Westport River, Massachusetts). Numbers after each label are the number of pairs for that region in 2001.

decline in 1994, the population increased in every subsequent year through the end of the century.

DISCUSSION

Within a decade or less of the local cessation of DDT application, all regional populations between New York City and Boston, as well as the rest of the country, were growing. Although the population now exceeds that of the pre-DDT era, its distribution is markedly different. It is no longer concentrated in several colonies of 2–300 pairs, but rather is spread across the region from the eastern boroughs of New York City to the Massachusetts-New Hampshire border.

Our data raise four questions. (1) Why have the old colonies (Gardiners Island, New York, the Connecticut River estuary, and Narragansett and Mount Hope bays in Rhode Island) not regained their former numbers despite reproductive rates well above the replacement level of 0.8 young/active nest? (2) In the post-DDT era, what triggered the widespread expansion of the species across the region, including inland to freshwater habitats? (3) Why did productivity peak in many regions in the 1980s and then drop off in the 1990s and 2000s? (4) Why was the recovery asynchronous across the region?

Frustratingly, although we have solid data to document the recovery and reproductive output of the population in our study area, we lack the essential information to answer these four questions conclusively. The answers to the first three questions are all likely to be related to changes in food and nest-site availability. The answer to the fourth question may be related to regional differences in pesticide use.

Although dramatic, long-term changes in traditionally important prey species across the region have been documented (see below), the fisheries data do not have the spatial resolution we would need to fully explain our results. More importantly, we have little qualitative, and no quantitative data on actual prey species use by breeding Ospreys during the study period. Regarding nest-site availability, with the exception of Martha's Vineyard and Westport, we cannot document the number of nest platforms that were provided during the study period, nor can we quantify regional changes in the number of available alternative sites such as cell-phone towers. Similarly, although we know when DDT application was ceased in the subregions, we have neither accurate records of local levels of DDT applications, nor measurements of DDT levels in local prey species populations.

Although we can only speculate about possible explanations of the trends we report in this paper, we feel it is productive to do so. A further caveat is that, as with many ecological patterns in the field, the causes may not be mutually exclusive. The underlying causes of the patterns we have documented are likely to be found in some combination of changing prey densities, nest-site availability, and contamination levels.

Why have the Old Colonies not Regained their Former Numbers? The SNE-LI population now exceeds that of the pre-DDT era, but the old colonies are not as big as they were formerly, and neither of the new colonies (Westport River and Martha's Vineyard) has grown to the size of any pre-DDT colony. With the exception of Gardiners Island, the colonies are stable at around 70–80 pairs.

One explanation for the inability of the old keystone colonies to reach their former densities could be the changes in their prey base discussed below. Yet, despite drastic reductions in the abundance of two of their three traditional prey species prior to the 1980s, the 1980s was the decade of highest reproductive rate in the period of our study. At least regionally, menhaden (*Brevoortia tyrannus*) densities were relatively high, and Ospreys were apparently able to switch to other coastal prey species such as bluefish (*Pomatomus saltatrix*) and striped bass (*Morone saxatilis*). Additionally, they may have relied more heavily on freshwater species than they had in the past.

Although the region-wide landscape is awash with human-made nesting opportunities for Ospreys, a decline in nest-site availability may have played a role in limiting the growth of the Connecticut and Rhode Island colonies to pre-DDT levels. Human development around the Connecticut River colony has certainly reduced the number of available tree nest sites, and increased raccoon densities associated with increased human densities (Prange et al. 2004) may have reduced the desirability of tree nests away from the marshes and islands in the mouth of the river. Although nest platforms have been provided, they may not have compensated for the loss of potential tree nesting sites lost to development.

Prior to the DDT era, the Rhode Island population, which was originally centered in Mount Hope Bay, made a southward shift toward Newport that has never been adequately explained (Bent 1937). Perhaps the farmers' tradition of providing nesting sites around Mount Hope Bay disappeared. During the DDT era, this colony was completely lost and it did not reappear during the post-DDT recovery. Unlike the Connecticut River and Gardiners Island colonies, where a core group of breeding adults survived the prolonged period of depressed reproductive output, there were no experienced adults to reseed the colony, and as Ospreys recolonized the state from the vestigial population in the southwest, there was no combination of a locally abundant prey population and abundant nest sites that would form the basis for another concentration. Although this colony did not reappear in Rhode Island, the Westport River colony, only 20 km southeast of the old Rhode Island nesting areas, can be considered its modern reincarnation.

Nest-site limitation may also come in the form of territorial behavior. Although Ospreys are territorial around their nests, over time density can increase at long-established colonies. The Gardiners Island colony famously had nests as close as 10 m apart. The colony had achieved that density as long ago as the early 1800s (Wilson 1812) and maintained it until the end of the pre-DDT era. The new generation of Ospreys nesting at old colony sites simply may not have developed the tolerance of near neighbors that had developed over centuries at the long-established colonies. The Westport colony at first glance does not appear to be nest-site limited, as there are unoccupied platforms available each year, but resident males will drive away birds trying to establish a nest on a pole near their own. Perhaps this explains the stability of this colony, whereas the population on Martha's Vineyard, spread out over 10 times the area of the Westport colony, continues to gradually increase.

The post-DDT Gardiners Island population is anomalous in that it has not remained stable. It had increased to 71 pairs—about one-quarter of its pre-DDT size—by the early 1990s. The dramatic decline in nesting pairs (Osprey numbers were reduced to just over 20 pairs) was coincident with the late-1980s decline in menhaden numbers (Fig. 5). Gardiners Island is unique among the SNE-LI populations because the island is situated in deep water. Freshwater foraging alternatives are more distant than for the other SNE-LI breeders, and thus the Ospreys nesting there may be the most vulnerable to declines in their marine prey base.

What Triggered the Widespread Expansion of the Species Across the Region in the Post-DDT Era? Ospreys typically nest in trees that are either isolated or project above the surrounding forest. When trees are not available, they will nest on any prominent landscape element such as rocky promontories. With no other options available, Ospreys will nest on the ground. This strategy is safe only on

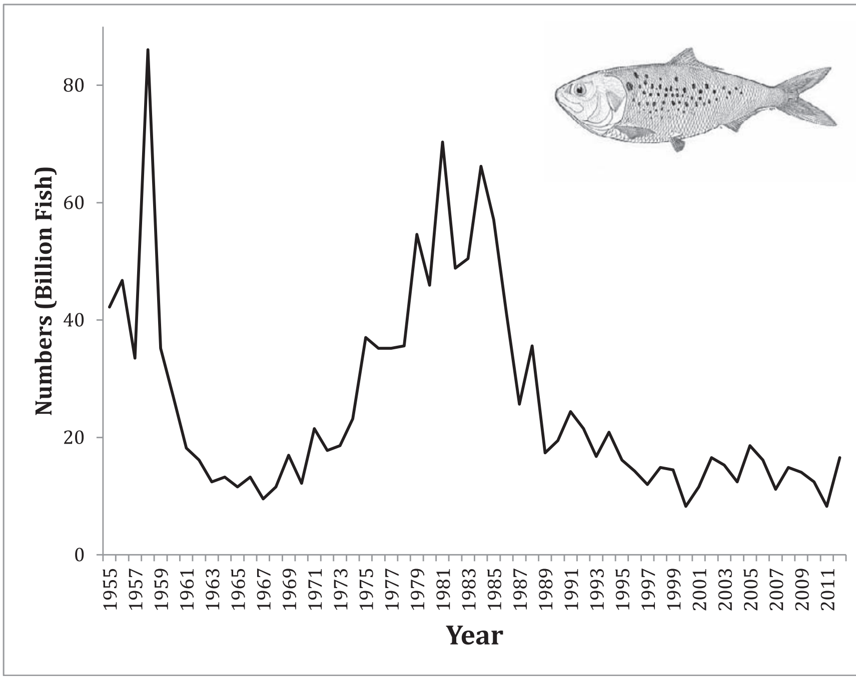

Figure 5. Estimated numbers (billions of fish) of Atlantic menhaden based on the Atlantic States Marine Fisheries Commission Beaufort Assessment Model (BAM) (after ASFMC 2012a).

predator-free islands, such as Gardiners or the marshy islands in the mouth of the Connecticut River.

In the 19th and early 20th century, the heavily agrarian and largely treeless landscape of southern New England did not provide abundant ''traditional'' structures (i.e., trees) for Osprey nesting. This might have been a contributing factor in concentrating Ospreys into the Connecticut River and Mount Hope Bay colonies of that era. Gardiners Island was never deforested for agriculture, so there were many tree-nesting opportunities. The island was also free of mammalian predators, and thus many Ospreys there nested on the ground. Similarly, at least part of the Connecticut River estuary colony nested on the ground out on marshes. The Rhode Island colony was dependent to some extent on nest platforms provided by farmers in the hope that nesting Ospreys would keep Red-tailed Hawks (*Buteo jamaicensis*) away from their farmyards (Bent 1937).

In the early 1960s, concerned that the low productivity of the Connecticut River estuary Ospreys might have been the result of flooding of ground-nesting pairs or predation from raccoons, Roger Tory and Barbara Peterson, along with Peter Ames, provided predator-protected nest poles on the marshes (Ames 1964). Although getting the Connecticut River Ospreys up on nest platforms did not improve their reproductive success, Ospreys were quick to use them and the effort spread. As the species began to recover from the effects of DDT, nest poles were erected in many places across the region. By the late 1960s, the Westport colony was largely nesting on platforms, as were a substantial number of pairs on Long Island.

The high reproductive rates in the 1980s led to population growth. At that time, Ospreys began a significant expansion of their range such that the population is now spread across a much wider landscape (ca. 25,000 km^2 vs. about 4600 km^2 pre-DDT, see Fig. 1). The process was slow because of male philopatry (Spitzer et al. 1983), but enabled by an abundant supply of human-made nest sites. Given that many of the nests in the recovering core areas were on human-made structures, ''nest-type imprinting'' likely facilitated the expansion as Henny and Kaiser (1996) suggested occurred in Ospreys in the Pacific Northwest. There, soon after a few pioneering pairs began nesting on human-made

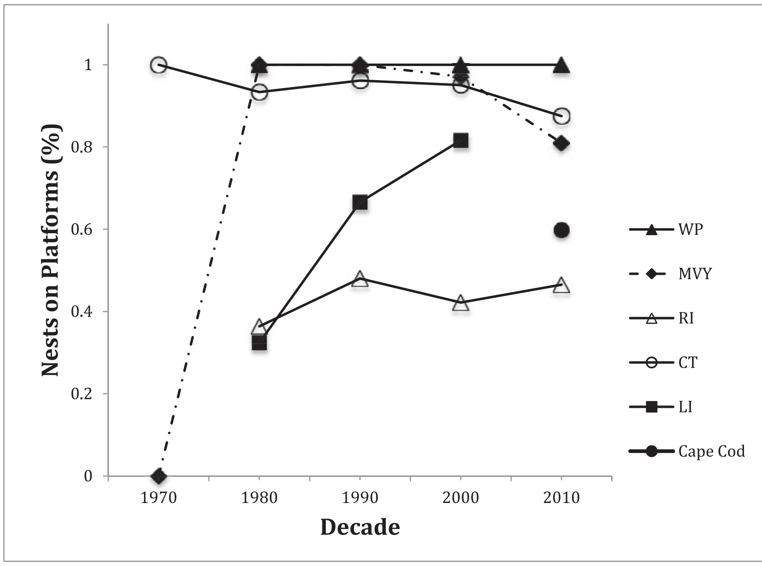

Figure 6. Percentage of known Osprey nests on nest platforms across the study area over time. (WP = Westport River, Massachusetts; MVY = Martha's Vineyard, Massachusetts; RI = Rhode Island; CT = Connecticut; LI = Long Island, New York).

structures, many followed suit and the population expanded.

Ospreys in the post-DDT era of the late 20th and early 21st centuries inhabited a landscape replete with human-made nesting sites. Many of these were platforms erected specifically for Ospreys, but many other opportunities were also available to Ospreys arriving from the wintering grounds each spring. Utility poles, light and cell-phone towers, floating rafts, billboards, chimneys, channel markers and buoys, and bridge superstructures are among the stable, albeit often dangerous, nest sites co-opted for their own breeding by Ospreys in the human-dominated modern landscape (Poole 1989).

As Osprey numbers increased in the 1980s and 1990s, our regional populations used different nest sites in very different proportions. The Connecticut, Westport River, Nantucket, and Martha's Vineyard populations all relied heavily (≥93% of reported nests) on nest platforms, the Long Island population was intermediate (67–82%), and the Rhode Island population was the least reliant on nest platforms (<50% of active nests; Fig. 6). Rhode Island Ospreys used existing utility poles (phone and high-tension towers) for approximately one-third of recorded nesting attempts, and Long Island pairs had the highest percentage of nests in trees (29% in 1990).

By 2010, the percentage of nests on utility poles declined somewhat as pairs nested more on cell towers, trees, and other structures. Across the region, the percentage of nests on platforms in 2010 was 72% (Table 2). Utility poles were the next most frequently used nest structure (8% of recorded nests). Rhode Island and Cape Cod used utility poles more than any other region (15.2% and 14%, respectively). Cell towers were the third most important nest structure (6.5% overall, 17.2% in Rhode Island).

Although the specific types of nest structures varied from region to region, the structures used were nonetheless almost all human-made. It is telling that we can state toward the end of the study period that tree-nest use *climbed* to 4.3% overall (6.8 and 6.7% in Rhode Island and Cape Cod, respectively). The expansion of the species across such a wide expanse of southern New England is clearly due in large part to this acceptance of human-made nest structures.

Why did the Productivity Peak in the 1980s and then Drop Off? Historically, the southern New England population was highly reliant on menhaden, which once appeared in migratory shoals so massive that over 150 000 could be taken in a single haul from the near-shore waters of Long Island by land-based, horse-driven seining operations, and twenty

Table 2. Percentage of Osprey nests on different support structures in southern New England and Long Island in 2010. LI = Long Island, CT = Connecticut, RI = Rhode Island, MA[a] = Cape Cod only; WPT = Westport River; MVY = Martha's Vineyard; Nan = Nantucket Island).

REGION	n	PLATFORM	UTILITY POLE	LIGHT TOWER	CELL/COM TOWER	TREE	GROUND	OTHER STRUCTURES
LI	0	n.d.	n.d	n.d.	n.d.	n.d.	n.d	n.d.
CT	264	87.5	1.14	1.5	4.2	1.1	0	4.5
RI	103	46.5	15.2	15.2	17.2	6.1	0	0
MA[a]	328	59.8	14.0	2.7	7.6	6.7	0.3	8.8
WPT	66	100	0	0	0	0	0	0
MVY	84	81.0	4.8	1.2	1.2	4.8	1.2	6.0
Nan	14	100	0	0	0	0	0	0
TOTAL	**845**	**72.0**	**8.1**	**3.5**	**6.5**	**4.2**	**0.2**	**5.4**

[a] Numbers for Cape Cod are 2008–2013 combined (M. Faherty unpubl. data).

factories were running simultaneously around Gardiners Bay to render menhaden into various industrial products (Franklin 2007). Alewives and herring (*Alosa* spp.), which spawn in fresh water while Ospreys are nesting, and winter flounder (*Pseudopleuronectes americanus*) were also important prey species in the breeding season (Poole 1984, 1989).

All three of these key ''species'' (lumping herring species) declined precipitously during the study period. The Atlantic States Marine Fisheries Commission (ASMFC) estimates showed a precipitous 80% decline in menhaden biomass during 1960–1961, followed by a period of relatively high population levels in the early to mid-1980s, and then another precipitous drop in the late 1980s with no recovery through 2010 (Fig. 5; ASMFC 2012a). Winter flounder harvest in southern New England waters declined by 90% from 1981 to 1991 (ASMFC 1993). The decline in harvest has continued for the whole mid-Atlantic to Maine fishery since then, with the estimated standing stock biomass remaining relatively stable from the early 1990s through 2011 at about 20–25% of 1980 levels (ASMFC 2011). Similarly, alewives and herring have suffered population declines. Offshore sampling of herring showed low levels in the mid-1970s through the late 2000s, with several spikes during that period (NMFS 2012). During this period, alewives showed a decline beginning in 1974, with the lowest numbers from 1983 to 1989, and then an upswing in 2009 (NMFS 2012). Sampling of spawning runs of herring and alewives in rivers in Connecticut, Rhode Island, and Massachusetts in the early 2000s showed such low numbers that bans were enacted on any harvesting of river herring in all three states (ASMFC 2012b).

The high productivity of Ospreys in the 1980s may be explained by the combination of relatively high densities of menhaden and low densities of Ospreys as they recovered from their low numbers in the 1970s. In the late 1980s and 1990s, Osprey densities increased and menhaden numbers crashed. In concert, these changes likely had negative effects on Osprey productivity.

Why was the Recovery Asynchronous Across the Region? The regional populations in our study area recovered from the DDT era at different times and rates. In 1969, the Massachusetts population was the first to exhibit a three-point running average of young/active nest above the 0.8 threshold (Fig. 2). Rhode Island, in 1972, was the next population to pass the threshold. The Connecticut and Long Island populations followed in 1974.

We do not know when the Martha's Vineyard population's reproductive rate recovered, or in fact if it ever fell below the 0.8 threshold. When we began collecting data there, in a period when no other population was reproducing above the 0.8 young/active nest threshold, the reproductive rate of this small population was the highest of any over the entire span of this study.

Two factors set the Martha's Vineyard population apart from others in the region and may explain the remarkably high reproductive rates of the early 1970s. First, the island is separated from the mainland by 5 km of deep water and is large enough to contain many fresh, brackish, and saltwater ponds and shallow bays where Ospreys can fish. Gardiners Island also sits in deep water, but it is so small (13.4 km^2) that adults must cross open water to eastern Long Island when near-shore marine prey (mostly menhaden) are not available. More importantly, in about 1958, almost a decade before Long Island townships stopped applying it, towns on Martha's Vineyard ceased helicopter-based DDT application on marshes (for economic, rather than conservation reasons). Thus, with a half-life for DDE of 5.7 yr (Thomas et al. 2008), by 1970 Ospreys on Martha's Vineyard were likely feeding in a relatively clean aquatic ecosystem. Additionally, they were far removed from sources of dieldrin, which has been suggested as an additional causative factor in the decline of the Ospreys around Long Island Sound (Wiemeyer et al. 1975). The delay in the population recovery was due to a systematic program by the local power company of removing nests from power lines, not because of a lack of increased reproductive rates. When, in the mid-1970s, the program of nest removal came to our attention, safe nest sites were provided each time a new pair tried to nest, and the population grew exponentially.

Using an arbitrary benchmark of 80% of the 2001 population level to compare the timing of the recovery, we found that the Westport River and Martha's Vineyard were the first areas to recover. Both areas reached 80% of 2001 levels in 1989 (Fig. 4). The Connecticut and Rhode Island populations grew more slowly, reaching the 80% benchmark 10 yr after the southeastern Massachusetts colonies. The Westport colony was the first to increase because nest platforms had been in place since the 1960s and thus were available as soon as the population began to reproduce above the threshold rate. The Westport and Martha's Vineyard populations probably increased faster than other areas because they were in relatively small areas where dedicated programs were in place to provide nesting platforms.

Predictions, Reality, and the Future. As Ospreys began to recover from the DDT era, researchers speculated on the future of the species. A comparison of these predictions with current reality is informative and offers insights into the future of the species in this portion of its worldwide distribution.

Poole and Spitzer (1983) reviewed the recovery of our study population through the late 1970s and early 1980s. They predicted that suburban and urban areas would not support large Osprey concentrations. Growth in large colonies would depend on undisturbed, extensive coastal habitat. A decade earlier, in a more widespread context, Henny et al. (1977) suggested that loss of habitat would prevent populations from returning to pre-DDT levels. Based on population growth through the 1980s, Poole and Spitzer (1983) made the prescient prediction that the SNE-LI population could reach 1000 pairs by 2005, although they allowed that this required ''making the unrealistic assumption that the habitat could support them.''

In fact, the SNE-LI population probably reached 1000 pairs in 2002, three years before Poole and Spitzer's ''unrealistic'' prediction. So, what assumptions that made this prediction seem unrealistic in 1983 can now be seen as unwarranted? One was that recovery to pre-DDT levels would depend on the re-establishment of high-density colonies. A corollary to that was the assumption, based on the lack of any evidence to the contrary, that the southern New England habitat would not support a low-density, broadly distributed population. We now see that Ospreys can indeed thrive across much of the region, albeit at much lower densities than were once experienced in the big colonies. Why was there no widely distributed population in the pre-DDT era? Male Ospreys are extremely philopatric, so populations tend to spread slowly. With super-abundant resources at the few major colonies where high-density nesting was long established, perhaps there was no pressure to expand away from the three big colonies.

It is not clear whether Henny et al. (1977) were referring to nesting or foraging habitat when they suggested that habitat quality would preclude a recovery to pre-DDT levels. In either case, Ospreys have demonstrated an astonishing tolerance for nesting in extremely close proximity to humans and their current slow expansion across the southern New England landscape demonstrates that they can find enough fish to rear young in a remarkably wide range of ecological situations.

Future research should carefully track the percentage of pairs using different types of nest structures and the reproductive success experienced on them. The nearly complete shift of nesting to human-made structures carries with it a dependence on very active management of the species, which has led Saurola (2011) to call Finnish Ospreys ''prisoners of platforms.'' Nest platforms have a finite life expectancy and will deteriorate. If they are not maintained and replaced, Ospreys will be driven to nest on other human-made structures, many of which place the Ospreys or the function of the structure (e.g., power transformers) in jeopardy.

Long-term studies of prey species use in populations whose reproductive success is monitored, combined with color-banding of breeding adults and high-resolution satellite telemetry provided by

GPS-GSM transmitters might help us understand limits on population growth. The Westport River colony, with its well-defined and densely nesting population on easily accessible nest poles, is the ideal candidate for such a study.

Ongoing programs monitoring regional population levels and reproductive rates should be continued because Ospreys are an ideal environmental ''sentinel species'' (Henny et al. 2010). Sudden declines in regional reproductive success may alert us to environmental contamination as they did with DDT. Thorough, long-term databases, such as that available for Rhode Island, are particularly important in this regard and should be maintained as they will enable us to quickly detect downward trends in the population.

ACKNOWLEDGMENTS

This report would not have been possible were it not for the foresight of state and local organizations who continued monitoring Osprey populations long after the recovery from the DDT era was well under way and the species was no longer considered of conservation concern. As important as those who approved continuing the surveys were the dozens and dozens of volunteers who monitored nests over the decades. Ian Nisbet and an anonymous reviewer made extensive suggestions that greatly improved the paper, as did the *Journal of Raptor Research* editors.

LITERATURE CITED

AMES, P.L. 1964. Notes on the breeding behavior of the Osprey. *Atlantic Naturalist* 19:15–27.

———. 1966. DDT residues in the eggs of the Osprey in the northeastern United States and their relation to nesting success. *Journal of Applied Ecology* 3:87–97.

——— AND G.S. MERSEREAU. 1964. Some factors in the decline of the Osprey in Connecticut. *Auk* 81:173–185.

ATLANTIC STATES MARINE FISHERIES COMMISSION (ASMFC). 1993. Stock assessment update and overview of interstate fishery management activities for inshore stocks of winter flounder (*Pseudopleuronectes americanus*). R.T. Christian [ED.]. 1993. Atlantic States Marine Fisheries Commission, Baltimore, MD U.S.A.

———. 2011. Southern New England Mid-Atlantic (SNE/MA) winter flounder assessment summary for 2011. Atlantic States Marine Fisheries Commission. http://www.asmfc.org/uploads/file/parta.pdf (last accessed 28 May 2014).

———. 2012a. 2012 Atlantic menhaden stock assessment update. National Oceanic and Atmospheric Administration. http://www.asmfc.org/uploads/file/2012MenhadenStockAssmtUpdate_July2012.pdf (last accessed 28 May 2014).

———. 2012b. River herring benchmark stock assessment, Vol. 2. Atlantic States Marine Fisheries Commission. http://www.asmfc.org/uploads/file/riverHerringBenchmarkStockAssessmentVolumeIIR_May2012.pdf (last accessed 28 May 2014).

BENT, A.C. 1937. Life histories of North American birds of prey. Part 1. Smithsonian Institution, Washington DC U.S.A.

EMERSON, D. AND M. DAVENPORT. 1963. Profile of the Osprey. *Narragansett Naturalist* 6:56–58.

FISHMAN, M.S. AND M. SCHEIBEL. 1990. Osprey productivity on Long Island 1978–87: a decade of stabilization. *Kingbird* 40:2–8.

FRANKLIN, H.B. 2007. The most important fish in the sea. Island Press, Washington, DC U.S.A.

HENNY, C.J., M.A. BYRD, J.A. JACOBS, P.D. MCLAIN, M.R. TODD, AND B.F. HALLA. 1977. Mid-Atlantic coast Osprey population - Present numbers, productivity, pollutant contamination, and status. *Journal of Wildlife Management* 41:254–265.

———, R.A. GROVE, J.L. KAISER, AND B.L. JOHNSON. 2010. North American Osprey populations and contaminants: historic and contemporary perspectives. *Journal of Toxicology and Environmental Health: Part B* 13: 579–603.

——— AND J.L. KAISER. 1996. Osprey population increase along the Willamette River, Oregon, and the role of utility structures, 1976–1993. Pages 97–108 *in* D.M. Bird, D.E. Varland, and J.J. Negro [EDS.], Raptors in human landscapes. Academic Press Inc., San Diego, CA U.S.A.

NATIONAL MARINE FISHERIES SERVICE (NMFS). 2012. River herring extinction risk analysis working group report. Report to the National Marine Fisheries Service, Northeast Regional Office. National Oceanic and Atmospheric Administration, Washington, DC USA.

PETERSEN, W.R. AND W.R. MESERVEY. [EDS.]. 2004. Massachusetts breeding bird atlas, I. Massachusetts Audubon Society, Lincoln, MA USA.

POOLE, A.F. 1984. Reproductive limitation in coastal Ospreys: an ecological and evolutionary perspective. Ph.D. dissertation, Boston University, Boston, MA U.S.A.

———. 1989. Ospreys: a natural and unnatural history. Cambridge University Press, New York, NY U.S.A.

——— AND P.R. SPITZER. 1983. An Osprey revival. *Oceanus* 26:49–54.

POSTUPALSKY, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. Pages 21–31 *in* F.N. Hamerstrom, Jr., B.E. Harrell, and R.R. Olendorff [EDS.], Management of raptors. Raptor Research Report 2. Raptor Research Foundation, Inc., Vermillion, SD U.S.A.

PRANGE, S., S.D. GEHRT, AND E.P. WIGGERS. 2004. Influences of anthropogenic resources on raccoon (*Procyon lotor*) movements and spatial distribution. *Journal of Mammalogy* 85:483–490.

SAUROLA, P. 2011. Finnish Ospreys (*Pandion haliaetus*) 2010. *Linnut Yearbook* 2010:28–35 (In Finnish with English summary).

SPITZER, P.R. 1980. Dynamics of a discrete coastal breeding population of Ospreys in the northeastern USA, 1969–1979. Ph.D. dissertation, Cornell University, Ithaca, NY U.S.A.

——— AND A.F. POOLE. 1980. Coastal Ospreys between New York City and Boston: a decade of reproductive recovery 1969–1979. *American Birds* 34:234–241.

———, ———, AND M. SCHEIBEL. 1983. Initial population recovery of breeding Ospreys in the region between New York City and Boston. Pages 231–241 *in* D.M. Bird [ED.], Biology and management of Bald Eagles and Ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec, Canada.

———, R.W. RISEBROUGH, W.W. IL, R. HERNANDEZ, A.F. POOLE, D. PULESTON, AND I.C.T. NISBET. 1978. Productivity of Ospreys in Connecticut-Long Island increases as DDE residues decline. *Science* 202:333–335.

THOMAS, J.E., I.-T. OU, AND A. AL-AGELY. 2008. DDE remediation and degradation. *Review of Environmental Contamination and Toxicology* 194:55–69.

VEIT, R.R. AND W.R. PETERSEN. 1993. Birds of Massachusetts. Massachusetts Audubon Society, Lincoln, MA U.S.A.

WIEMEYER, S.N., T.G. LAMONT, AND L.N. LOCKE. 1980. Residues of environmental pollutants and necropsy data for eastern United States Ospreys, 1964–1973. *Estuaries* 3:155–167.

———, P.R. SPITZER, W.C. KRANTZ, T.G. LAMONT, AND E. CROMARTIE. 1975. Effects of environmental pollutants on Connecticut and Maryland Ospreys. *Journal of Wildlife Management* 39:124–139.

———, D.M. SWINEFORD, P.R. SPITZER, AND P.D. MCLAIN. 1978. Organochlorine residues in New Jersey Osprey eggs. *Bulletin of Environmental Contamination and Toxicology* 19:56–63.

WILCOX, S.L. 1944. Banding Ospreys on Long Island. *Bulletin to Schools from the University of the State of New York* 30:262–264.

WILSON, A. 1812. American ornithology, Philadelphia, PA U.S.A.

Received 24 February 2014; accepted 2 July 2014
Associate Editors: Ian G. Warkentin and
Brian E. Washburn