BEACHED BIRD SURVEYS IN MASSACHUSETTS: THE SEABIRD ECOLOGICAL ASSESSMENT NETWORK (SEANET)

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Received 20 June 2005, accepted 28 October 2006

SUMMARY

HARRIS, R.J., TSENG, F.S., POKRAS, M.A., SUEDMEYER, B.A., BOGART, J.S.H., PRESCOTT, R.L. & NEWMAN, S.H. 2006. Beached bird surveys in Massachusetts: the Seabird Ecological Assessment Network (SEANET). *Marine Ornithology* 34: 115–122.

The Seabird Ecological Assessment Network (SEANET) is a collaborative project that investigates threats to marine and coastal birds in the northeastern United States, relying upon volunteer "citizen scientists" to monitor beaches regularly for beachcast birds. Before SEANET, systematic beached bird surveys had not been done on the Atlantic coast of the United States since the early 1980s. During the first two years of monitoring 41 beaches on Cape Cod and Buzzards Bay, Massachusetts, beached birds of 32 species were encountered at an average rate (± standard error) of 0.22 ± 0.04 birds/km, with an overall oiling rate of 2.5% (5 of 199). A high degree of seasonal and interannual variation was revealed between 2003 and 2004, with the highest carcass encounter rates in spring of 2003 and fall of 2004. Species-specific mortality events respectively affecting Red-throated Loons *Gavia stellata* and Common Terns *Sterna hirundo* influenced those patterns. Necropsies were performed on a subset of birds, revealing several potential causes of death, including emaciation and trauma. Anthropogenic causes of mortality included marine debris ingestion, pellet injuries, and entanglement in fishing gear.

Key words: beached bird monitoring, seabird mortality, seabird stranding, oil spill, chronic oil pollution, oiled wildlife, natural resource damage assessment

INTRODUCTION

The approach of surveying beaches for bird carcasses ("beached bird survey") has long been an important monitoring tool throughout the world's coastal areas. Beachcast birds can reveal long-term spatial and temporal trends in chronic oil pollution in the marine environment and responses to legislative and management actions such as availability of harbor reception facilities for oily bilge waste and dirty ballast water (reviewed by Camphuysen & Heubeck 2001, Seys *et al.* 2002a). Interpreting the extent to which carcass recovery represents actual levels of mortality can be difficult because of confounding factors such wind and current direction, sinking rates, scavenging rates at sea and on shore, survey effort, and observer efficiency (e.g. Van Pelt & Piatt 1995, Piatt & Ford 1996, reviewed by Camphuysen & Heubeck 2001). Nonetheless, oiling rates of beached birds have been used as an index of marine pollution (OSPAR 1996, Furness & Camphuysen 1997). Beach surveys can also quantify other threats to seabirds, such as bycatch in fishing operations (Forsell 1999, Zydelis *et al.* 2006), extreme weather (e.g. Piatt & Van Pelt 1997), disease, trauma, entanglement, and the prevalence and ingestion by birds of marine debris (Stephen & Burger 1994, van Franeker *et al.* 2004).

Beached bird surveys have been conducted sporadically on some coasts in the Northwest Atlantic since the 1970s, and marine bird mortality from oil was observed in Newfoundland as early as the 1950s (Piatt *et al.* 1985). The most systematic surveys in this region have been conducted in southeastern Newfoundland by the Canadian Wildlife Service and collaborators since 1984, revealing levels of oiling increasing to 74% in the late 1990s, largely the result of illegal dumping of oily bilge waste (Chardine *et al.* 1990, Wiese & Ryan 2003). Regular winter surveys have been carried out on Cape Breton, Nova Scotia, since 2001 by volunteers with Bird Studies Canada, showing highly variable oiling rates (mean rate 2001–2005: 43%; ranging from 0% the first year to 87.23% in the second year after an acute spill; Campbell 2005).

In the United States, observers monitored beached birds starting in 1974 at several sites from Long Island, New York, to Cape Romain, South Carolina, with coverage of Florida beaches added in 1975 (Simons 1985). Parts of the Texas Gulf coast and Plum and Nantucket Islands, Massachusetts, were monitored starting in 1977 until the project ended in 1983. During the eight-year period, an oiling rate of 6.6% of the carcasses was reported for the entire region (Simons 1985).

No systematic surveys on the Atlantic coast of the United States have been conducted since the work reported by Simons (1985). Because of this gap in data collection and concerns about the increasing rate of chronic oiling reported in Atlantic Canada, Tufts Cummings School of Veterinary Medicine initiated in Massachusetts in the fall of 2002 a volunteer-based beached bird survey called the Seabird Ecological Assessment Network (SEANET). The project expanded

to other states in the northeastern United States in the following years, from New Jersey north to Maine, and limited surveys were initiated in 2004 on the Gulf coast of Florida.

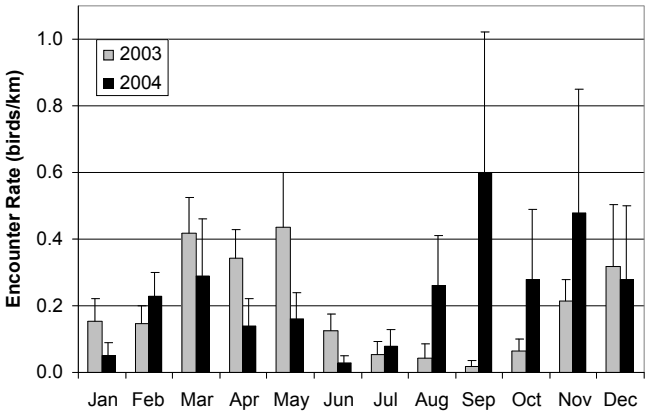

Fig. 1. Mean beached bird encounter rate (birds/km) on beaches in Buzzards Bay, Massachusetts, in 2003 and 2004, divided by quartiles.

SEANET aims to be a long-term effort to establish baseline data on beached bird mortality and oiling rates. In addition, it hopes to detect and investigate mass mortality events that might otherwise go unreported. Previous studies have recommended that surveys be conducted monthly or weekly at minimum coverages of 65% of regional coastline to produce reliable species occurrence data and of 40%–50% of the coastline to determine oiling rates (Seys *et al.* 2002a). Subject to limited resources and data collection by volunteers, we have attempted to follow survey design recommendations outlined by previous long-term studies (e.g. Camphuysen & Heubeck 2001, Seys *et al.* 2002a).

Here, we present results from surveys in Massachusetts during 2003–2004. Two large mortality events, for which detailed results are still in preparation, occurred in the survey region during the study period.

METHODS

In Massachusetts, 41 beach segments of 0.2–6 km each from Buzzards Bay to Cape Cod (geographic range: 41.45–42.10°N, 69.95–71.1°W) were monitored for dead birds (Figs. 1–3). Thirty of the beaches were

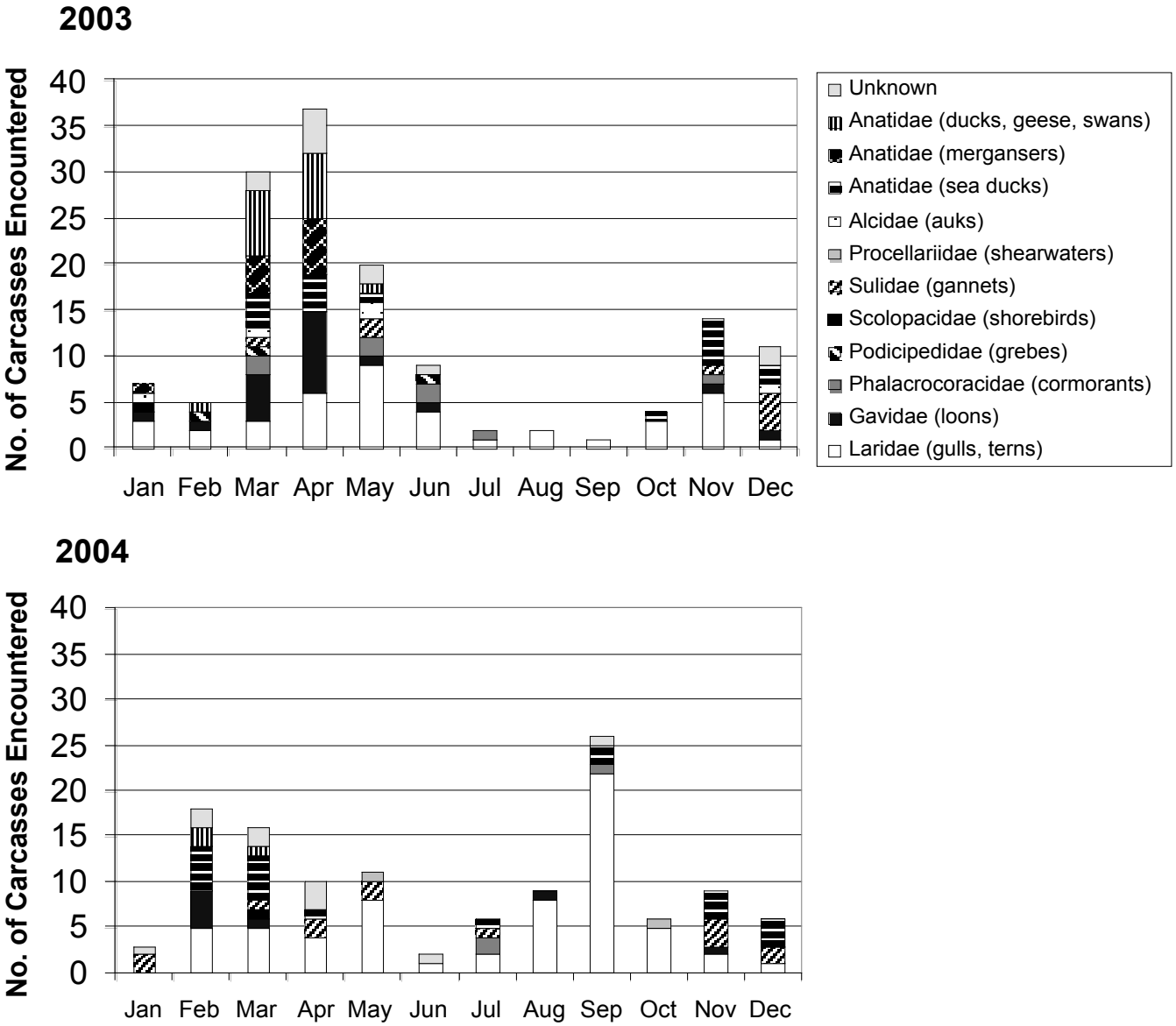

Fig. 2. Mean beached bird encounter rate (birds/km) on beaches in Cape Cod, Massachusetts, in 2003 and 2004, divided by quartiles.

monitored in both years, and all surveys were conducted by trained observers. Teams of one to three people surveyed beach segments by foot, actively searching the most recent wrack line and scanning the rest of the beach at low-to-medium tide.

Surveys were usually conducted monthly, but less frequently in some instances, with an average of 7.5 surveys per beach per year. With the exception of December 2003 (when fewer surveys were conducted on all beaches), beach coverage was not consistently biased toward certain beaches or times of year (2003: single-factor ANOVA: $df = 10$, $F = 1.32$, $P = 0.22$; 2004: single-factor ANOVA: $df = 11$, $F = 1.29$, $P = 0.23$). The mean distance covered monthly was 61 km (14% of the regional beach coastline), exceeding the length (but not the percentage) of coastline coverage recommended by Seys *et al.* (2002a) to achieve reliable estimates of oiling rates (25–30 km, 40%–50%) and species occurrence (40 km, 65%). Frequency of surveys approached the recommended regularity, based on Seys *et al.* (2002a) findings that monthly surveys provide data that is nearly as reliable as weekly surveys regarding species occurrence and encounter rates.

Observers used the survey protocols recommended by Camphuysen & Heubeck (2001) to photograph and record species and number of dead birds. They noted incidence and degree of oil on dead birds and beaches. Sex and age of specimens were noted where possible, and wing chord, tarsus and culmen length were measured. When necessary, assessments and identifications were confirmed from photographs and measurements by an ornithologist (all cases when observers questioned their identification, about 50% of the time overall). When practical, fresh dead specimens were transferred to Tufts Wildlife Clinic for necropsy; otherwise, specimens were left in place and marked by clipping primary feather tips or a toe.

Volunteers whose live bird identification skills were confirmed in training sessions also took data on live birds, recording high counts of species seen during their beach walks. Data on wind directions in the study area were obtained from weather buoys off southeastern Cape Cod (41°15′30″N, 69°17′40″W), offshore due east of Nantucket (40°30′00″N, 69°25′53″W), and at the southeastern edge of Buzzards Bay (41°23′48″N, 71°02′00″W). Mean wind direction was calculated for each buoy by averaging annual wind direction in circular plots and classifying the relative wind direction as onshore, offshore, or along shore (NOAA C-MAN, www.gomoos.org).

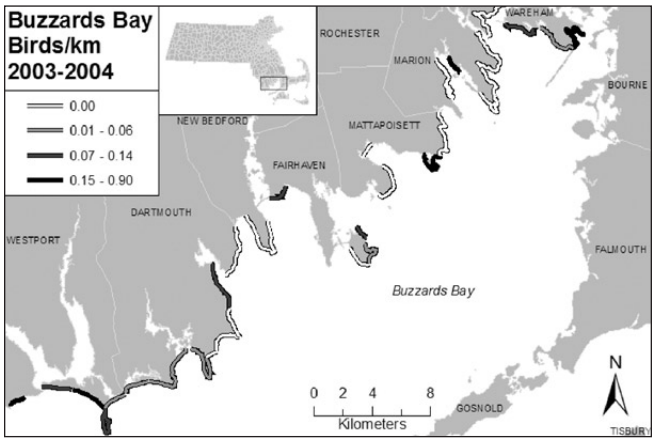

Fig. 3. Difference in mean beached bird encounter rate (birds/km) from 2003 to 2004 on beaches in Cape Cod, Massachusetts. Positive values (with banded symbols) indicate that the 2004 rate was higher than the 2003 rate.

To control for variation in observer effort and beach lengths among different areas of the coastline, deposition rates were calculated as birds/km (± standard error) per beach. Marked birds that had been previously encountered were not included in the calculations so

TABLE 1
Counts of individual carcasses of each species found on beached bird surveys in Massachusetts during 2003–2004[a]

Species	Count (% of total identified)[b]	Mean encounter rate
Great Black-backed Gull *Larus marinus*	46 (19.2)	0.027
Herring Gull *Larus argentatus*	30 (12.5)	0.032
Northern Gannet *Morus bassanus*	21 (8.8)	0.033
Common Eider *Somateria mollissima*	17 (7.1)	0.027
Common Loon *Gavia immer*	16 (6.7)	0.021
Common Tern *Sterna hirundo*	15 (6.3)	0.0073
American Black Duck *Anas rubripes*	13 (5.4)	0.0053
Red-breasted Merganser *Mergus serrator*	12 (5.0)	0.0048
Red-throated Loon *Gavia stellata*	10 (4.2)	0.0057
Ring-billed Gull *Larus delawarensis*	9 (3.8)	0.0072
White-winged Scoter *Melanitta fusca*	9 (3.8)	0.0059
Double-crested Cormorant *Phalacrocorax auritus*	8 (3.3)	0.0059
Black Scoter *Melanitta nigra*	5 (2.1)	0.0035
Great Cormorant *Phalacrocorax carbo*	3 (1.3)	0.0026
Long-tailed Duck *Clangula hyemalis*	3 (1.3)	0.0027
Bufflehead *Bucephala albeola*	2 (0.8)	0.00063
Canada Goose *Branta canadensis*	2 (0.8)	0.00039
Common Murre *Uria aalge*	2 (0.8)	0.0015
Horned Grebe *Podiceps auritus*	2 (0.8)	0.0012
Laughing Gull *Larus atricilla*	2 (0.8)	0.0015
Razorbill *Alca torda*	2 (0.8)	0.0015
American Crow *Corvus brachyrhynchos*	1 (0.4)	0.0019
Brant *Branta bernicla*	1 (0.4)	0.00039
Domestic Goose *Anser domesticus*	1 (0.4)	0.00043
Dovekie *Alle alle*	1 (0.4)	0.0030
Dunlin *Calidris alpina*	1 (0.4)	0.00088
Great Blue Heron *Ardea herodias*	1 (0.4)	0.0087
Mute Swan *Cygnus olor*	1 (0.4)	0.00024
Northern Fulmar *Fulmarus glacialis*	1 (0.4)	0.016
Red-necked Grebe *Podiceps grisegena*	1 (0.4)	0.00036
Sanderling *Calidris alba*	1 (0.4)	0.0019
Sooty Shearwater *Puffinus griseus*	1 (0.4)	0.0011

[a]Mean encounter rates are obtained by averaging encounter rate (birds/km) for each species on each beach during each month, and then averaging over 2 years.
[b]Carcasses unidentified to species are not included.

that encounter rates would better reflect actual deposition rates of beached birds. To determine seasonal patterns, monthly averages of recovered birds on all beaches were compiled.

Oiling rate was calculated as the proportion of complete, intact bird carcasses with external signs of oil: n_{oiled} / n_{all} birds * 100% (Camphuysen 1998, Camphuysen & Heubeck 2001, Seys *et al.* 2002a, Wiese & Ryan 2003).

Analyses are based on 786 surveys, covering 1340 km of beach completed from January 2003 to December 2004 in Buzzards Bay and from March 2003 to December 2004 on Cape Cod. The Bouchard 120 barge oil spill in Buzzards Bay released an estimated 98 000 gal. No. 6 fuel oil on 28 April 2003 (Costa 2005). Analyses do not include data collected during the spill response because effort increased disproportionately on certain beaches at that time, survey techniques were variable, and results from the damage assessment are not yet publicly available.

Gross necropsies using standard avian necropsy protocols (Work 2000) were performed by Tufts veterinarians and veterinary students on a subset of 45 birds. Necropsies included gross external evaluation of birds; radiographs to detect fractures, trauma and foreign bodies; and internal evaluation of all organ systems. Fresh carcasses were frozen before transport to Tufts, preventing histopathologic assessment. All birds examined at necropsy were assigned a body condition score based on subjective evaluation of subcutaneous and abdominal fat deposits and atrophy of pectoral muscle. Body scores ranged from 1 to 3, including half scores, with a score of 1 indicating emaciation and complete depletion of internal (including cardiac) and subcutaneous fat reserves, 2 indicating intermediate fat reserves, and 3 indicating healthy fat reserves and pectoral muscles (Work 2000).

During investigations into large mortality events or unusual die-offs, additional specimens were obtained for necropsy from wildlife rehabilitators and other collaborators. Necropsies of beached Red-throated Loons *Gavia stellata,* including six specimens obtained from a wildlife rehabilitator (Humane Society of the United States, Cape Wildlife Center) are reported here. As part of an ongoing study of heavy metals in aquatic bird tissues and an investigation into a die-off of Red-throated Loons in 2003, six liver samples were analyzed at the University of Pennsylvania, New Bolton Center, Laboratory of Pathology and Toxicology, for heavy metals, following protocols outlined in Pokras *et al.* (1991).

RESULTS

Carcass encounter rates

The average encounter rate across all beaches was 0.22 ± 0.04 birds/km for the two-year period. Encounter rates per survey ranged from 0 to 10 birds/km. In all, 262 carcasses of 32 species were found; 240 (92%) were identified to species (Table 1). The Great Black-backed Gull *Larus marinus* was the most frequently observed species, comprising 46 of 240 identified carcasses (19.2%).

Seasonal and interannual variation

Considerable interannual and seasonal variation in beached bird deposition occurred in 2003 and 2004 (Fig. 4). Apart from the effects of the April 2003 Bouchard oil spill in Buzzards Bay, a high "background level" of unoiled birds (particularly ducks, loons and mergansers) was observed during the period March–May 2003, particularly as compared with the same region and time period in 2004. Although sea ducks, especially young male Common Eiders *Somateria mollissima,* were encountered in both years (Fig. 5), no mergansers or Red-throated Loons were found in 2004. SEANET volunteers detected an elevated mortality of Red-throated Loons in 2003, recording 10 dead loons on regular surveys from February to May. This species represented 7.8% (10 of 128) of all carcasses identified that year.

In all likelihood, the mortality of Red-throated Loons was incompletely documented because of scavenging and disruption

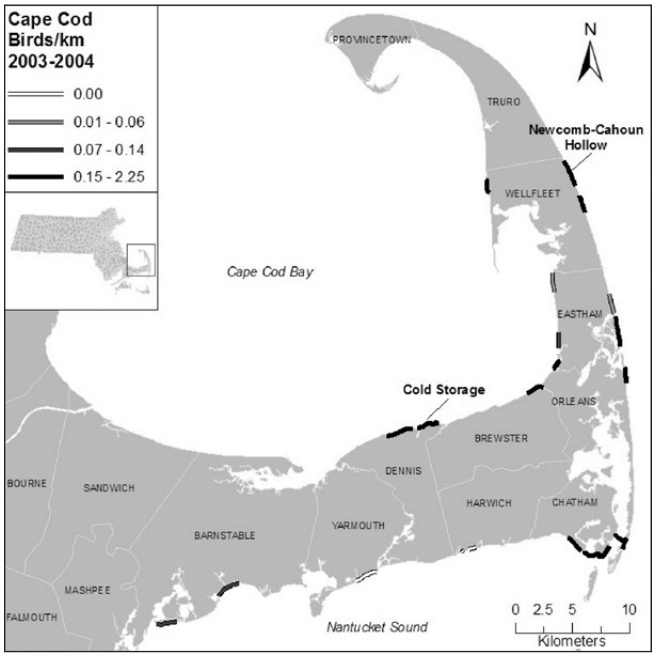

Fig. 4. Mean monthly encounter rates (birds/km) for beached birds from January–December in 2003 and 2004. Extended vertical lines show the standard error.

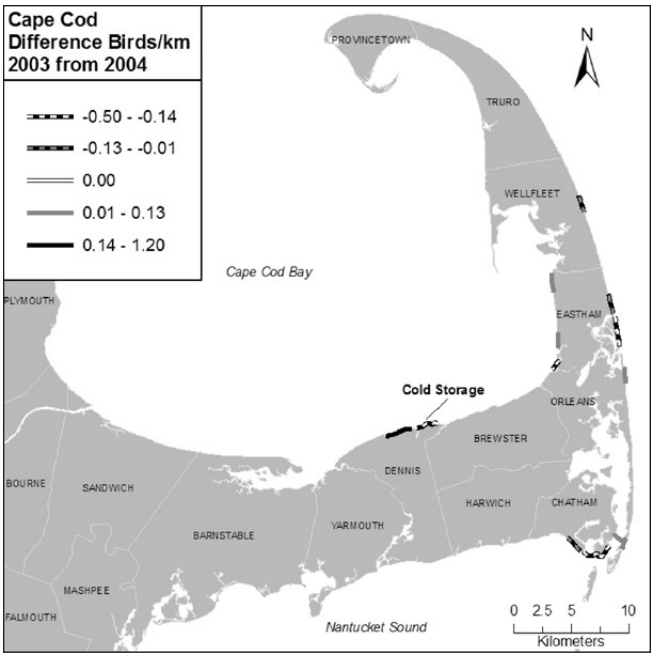

Fig. 5. Monthly counts of carcasses by avian family or species group from Massachusetts beaches surveyed in 2003 and 2004.

of regular surveys by oil spill clean-up activity on some Buzzards Bay beaches during the same period in 2003. Although no Red-throated Loons were found the following year, Common Loons *Gavia immer* were fairly common in both 2003 and 2004 [16 (6.7% of all carcasses)].

High encounter rates during August and, particularly, September 2004 were attributable to a large die-off of Common Tern *Sterna hirundo* fledglings at the end of the breeding season (Figs. 4 and 5). Carcasses were encountered on several Cape Cod beaches, with the single highest encounter rate (10 birds/km) reported from Newcomb–Cahoun Hollow beach in Wellfleet. Necropsy results from that event are still pending, although initial findings include high levels of *Salmonella typhimurium* from spleen swabs of three of the specimens recovered from Cape Cod beaches (October 2006).

Geographic variation

Overall, encounter rates on Cape Cod were higher than those in Buzzards Bay. The highest mean encounter rate for any beach was 2.3 birds/km at Cold Storage Harbor, Cape Cod (Fig. 2). On beaches facing Nantucket Sound, offshore winds were most common in both years. Offshore or along-shore winds were most common in Buzzards Bay (University of Maine, Ocean Circulation Modeling, www.gomoos.org), whereas winds on outer Cape Cod were variable over the two years, with no consistent direction.

The change in encounter rates from 2003 to 2004 was more dramatic on Cape Cod than in Buzzards Bay (mean change in rate between years for Cape Cod: 0.26 ± 0.10 birds/km; for Buzzards Bay: 0.057 ± 0.02; Kolmogorov–Smirnov $Z = 1.404$, $P = 0.04$). However, little spatial consistency to the pattern was seen, even when the change from one year to the next was large (Fig. 3). For example, two adjacent beaches in Dennis had opposite changes in beached bird encounters between years.

Oiling rates

Five of 199 (2.5%) birds for which presence or absence of oil was assessed had detectable oil. For species groups such as gulls, loons, ducks and gannets, we obtained sufficient numbers of individuals to estimate oiling rates reliably, at least at the family level (Seys *et al.* 2002a). The same cannot be said for the Alcidae (only five carcasses encountered in this study), which include some of the most commonly oiled seabirds. All birds reported as oiled were described as moderately oiled. They occurred on beaches with generally high encounter rates in Chatham, Cape Cod. In 2003, an oiled Common Loon was found in June, and a Herring Gull *Larus argentatus* in August. In 2004, a Northern Gannet *Sula bassanus* and a Common Eider were found in July, and a Great Black-backed Gull in September.

Our estimate of overall oiling rate excludes the Buzzards Bay Bouchard 120 oil spill of April 2003, for which preliminary reports indicated a total of 479 oiled birds (Costa 2005). Because of ongoing litigation and damage assessment, official bird mortality estimates have not yet been released for the Bouchard spill. SEANET data contributed to the damage assessment process, and volunteers monitored affected beaches for months following the spill. Few oiled birds were found subsequent to the initial recovery of dead and live oiled birds immediately after the spill, although one heavily oiled bird was found by a SEANET volunteer in Buzzards Bay one month post spill.

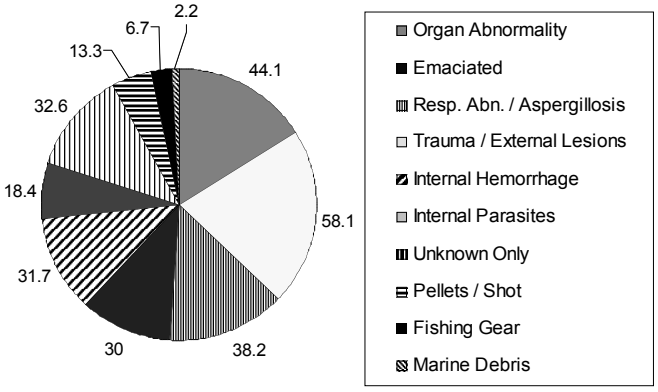

Fig. 6. Pathologies identified in beached birds recovered during surveys in Massachusetts, 2003–2004 (n = 45). The percentage of birds showing each finding is indicated. Pathologies not necessarily identified as the definitive cause of death, and many individuals had more than one pathology finding.

Necropsy results

Gross necropsies were performed on 45 birds of 20 species recovered on beaches in 2003 and 2004 (Fig. 6). In most cases, a definitive cause of mortality was not determined. Emaciation was common, occurring in 58.1% of the birds examined.

Six of 45 birds (13.3%) necropsied had been shot, including three Common Eiders and three non-game species (Razorbill *Alca torda,* Common Loon, and Herring Gull). Three birds (6.7%)—a Herring Gull, a Common Eider, and a White-winged Scoter *Melanitta fusca*—were entangled in fishing line, hooks or nets. Excluding traumas of unknown origin, more than 22% of necropsied birds had suffered possible human-caused mortality.

Age was determined by plumage for 93.3% of the birds at necropsy (33 adults, 10 immatures and one fledgling), whereas only 62.6% of beached carcasses were aged by volunteers or from photos. Most of the species encountered are sexually monomorphic, so external sexing was not possible. Of the necropsied birds, 74% were sexed by internal examination (44.1% females, 55.9% males); remaining specimens could not be sexed because of immaturity or autolysis.

Necropsies of Red-throated Loons (n = 8) from Buzzards Bay revealed emaciation in five of the six specimens intact enough for nutritional status to be evaluated. An additional six birds obtained from a wildlife rehabilitator on Cape Cod were also examined, of which half were emaciated. Four of the 14 birds showed signs of trauma, but no other gross pathology was evident.

Liver samples from six birds (three from beached bird surveys and three from wildlife rehabilitation) were analyzed for heavy metals. One bird's liver had a lead level of 8.32 ppm wet weight [liver levels of 6–8 ppm wet weight or higher are suggestive of lead poisoning in aquatic birds (Friend 1999)]. This bird may have ingested lead from the road environment in which it was found, but it showed no outward signs of lead poisoning upon gross examination. No other samples were found to have elevated lead levels. Mercury levels ranged from 2.58 ppm to 5.94 ppm wet weight, well below the level at which a diagnosis of mercury poisoning is indicated in aquatic birds [20 ppm wet weight (Franson 1999)].

DISCUSSION

Carcass encounter rates

Judging from our first two years of beached bird surveys in Massachusetts, overall carcass encounter rates are below most others recorded worldwide. For example, surveys on the Pacific coast of the United States reported mean encounter rates over four years of 8.5 ± 1.4 birds/km (Parrish 2005), resulting largely from "wrecks," or mass mortalities of locally breeding alcids (young of the year) and other species.

It is possible that the offshore and nearshore populations of marine and coastal birds are lower in our area than in other studies. Higher encounter rates in areas such as the North Sea—for example, 2–18 birds/km on the Netherlands coast (Camphuysen & Heubeck 2001), 2.6 ± 2.1 birds/km from the annual Belgian International Beached Bird Surveys (IBBS) (Seys *et al.* 2002a)—may reflect larger concentrations of live birds, high mortality because of chronic oiling, or a combination of factors. Coastal areas of the North Sea have comparatively high oiling rates (Camphuysen 1998, Seys *et al.* 2002b). Prevailing onshore winds and habitat features that concentrate birds may also contribute to high rates of beached bird deposition. Such factors have not been analyzed systematically for US coasts or in the North Sea.

Comparing carcass encounter rates in the northwest Atlantic, the mean rate from this study (0.22 ± 0.04 birds/km) is slightly higher than that observed in four years at Cape Breton, Canada [0.12 birds/km; range: 0.04–0.27 (Campbell 2005)], but lower than the mean rate calculated for Newfoundland during 1984–1999 [2.25 birds/km (Wiese & Ryan 2003)]. In surveys of the US Atlantic coast during the 1970s and early 1980s, encounter rates ranged from 0.7 birds/km to 3.1 birds/km (Simons 1985). Thus far, our study is of smaller scope, both temporally and geographically. Given additional years of effort and expanded surveys, the range of encounter rates may increase.

Seasonal and interannual variation

Although it is common for immature Common Eiders to die during late winter in our study region (R. Prescott, unpubl. data), the mortality of all ducks, loons and mergansers was striking in 2003. Baseline mortality of these species was high in the months preceding the Bouchard oil spill (Fig. 5), and increased mortality of some species (particularly loons) resulted during the Bouchard spill (Costa 2005). Interannual variation in beached bird deposition points to the importance of multiyear surveys, especially for use in oil spill damage assessment.

In Red-throated Loons, we found a marked difference in encounter rates between years and between our high year [7.8% (10 of 128 carcasses in 2003)] and historical surveys. This species constituted only 0.41% (33 of 8128) of bird carcasses recovered from the Atlantic and Gulf coasts of the United States over an eight-year period, 1975–1983 (Simons 1985). In contrast, Common Loons were the second-most common species reported in the 1975–1983 surveys [789 (9.7%) of carcasses found (Simons 1985)], as compared with 16 (6.7%) of all carcasses in the present study. Unlike Red-throated Loons, Common Loons have a molt-related flightless period in winter (Spitzer 1995).

Based on limited data from SEANET volunteers and local birdwatchers, we do not believe that offshore populations of loons, mergansers and ducks were unusually large in Massachusetts in 2003. Birdwatchers submitting their records to the Massachusetts Bird Observer reported a total of 611 Red-throated Loons nearshore from March to June in 2003; 1970 Red-throated Loons were reported from the same geographic area and time period in 2004 (M. Rines, unpubl. data). In the past 10 years, an average of 923 Red-throated Loons (range: 103–2025 birds) were reported off the Massachusetts coast (M. Rines, unpubl. data). Similarly, live bird sightings by SEANET volunteers argue against the possibility of mortality related to exceptional density. On spring surveys in Buzzards Bay during 2003, no Red-throated Loons occurred in 149 sightings of 47 species.

Higher carcass encounter rates during August and September 2004 were due to Common Tern fledgling mortality at the end of the breeding season (Figs. 4 and 5). More than 2025 tern fledglings were reported dead, mainly from South Monomoy National Wildlife Refuge, the largest breeding colony in New England (M. Williams, pers. comm.). Interannual variation in species and seasonal deposition patterns highlight the importance of long-term monitoring in assessing baselines.

Geographic variation

Cape Cod Bay had a higher beached bird density than the more exposed ocean side (two of the three highest encounter rates were in the bay), similar to results reported for sea turtles (R. Prescott, unpubl. data) and marine mammals (Vanman 2005). Of 1400 sea turtle strandings reported by the Massachusetts Audubon Society, only three were on the ocean side; north-northwest winds push turtles onto Bay beaches in the fall and winter (R. Prescott, unpubl. data). Overall, Cape Cod had higher mean encounter rates of beached birds than Buzzards Bay did, which may reflect the distribution of live birds, wind patterns and a "trapping" effect of the Cape Cod peninsula. Whereas onshore winds and currents have been found to increase carcass deposition in other studies (Hlady & Burger 1993, Camphuysen & Heubeck 2001), offshore or along shore winds were most common in Buzzards Bay during 2003 and 2004. Cape Cod Bay frequently experiences onshore currents (University of Maine Ocean Circulation Modeling, www.gomoos.org).

The change in encounter rate between 2003 and 2004 on Cape Cod was spatially patchy (Fig. 3). The increase in 2004 was primarily attributable to tern fledgling mortality, but the locations of colony sites had little to do with the distribution of dead birds, as has been reported in other studies (Camphuysen & Heubeck 2001).

Oiling rates

The oiling rate in the present study was much lower than that observed in Newfoundland, where a mean rate of 62% was reported for 1984–1999 (Wiese & Ryan 2003). An oiling rate of 8.5% occurred from the late 1970s to the early 1980s on the northern Atlantic coast of the United States (Simons 1985), but unlike the current analysis, that value included large oil spills. Including the Bouchard oil spill of April 2003 (479 oiled birds), our oiling rate was 64%. That value incorporates intensive searching carried out as part of the spill response; however, it is not reflective of our normal survey effort or chronic conditions.

In Atlantic Canada, the Pacific United States, and several European sites, alcid populations passing through or breeding in beach-surveyed areas are high. In most studies, alcids are the group with the highest oiling rate (e.g. Seys *et al.* 2002b, Roletto *et al.* 2003, Wiese & Ryan 2003). Although alcids pass through Massachusetts waters during the winter in fairly large numbers (e.g. Veit & Petersen 1993), our recoveries included only five unoiled individuals from the alcid family. Oiling rates tend to be higher during winter months

(e.g. Wiese & Ryan 2003), yet all of the oiled birds found in this study were recovered during summer months.

The oiling rates for beached birds in Massachusetts during 2003–2004 represent some of the lowest reported worldwide [ranging from 3%–84% (Camphuysen 1998)], but it is important to note that most studies of chronic oiling are several years to decades long. Internal oiling can occur where no signs of external oiling exist (e.g. Briggs *et al.* 1997), although no such incidences were observed in the present study. Vauk (1984) suggested that internal oiling might affect up to 20% of beached birds with clean plumage in certain areas in Europe, and o necropsies are an important part of beach survey efforts.

Necropsy results

We assigned 56% of the birds we examined to diagnostic categories, as compared with 84% diagnoses in beached birds from British Columbia as reported by Stephen & Burger (1994). The difference between studies may reflect different diagnostic categories and a greater proportion of more grossly evident human-caused sources of mortality in the British Columbia study (40% versus 22% in the present study). About one quarter of the necropsied birds in British Columbia were externally oiled, whereas none of the externally oiled birds recovered in Massachusetts were necropsied. Stephen & Burger (1994) did not report the incidence of internal oiling.

Future studies

More frequent surveys on a subset of beaches and expansion of beached bird surveys to other areas in the northeastern United States will help to confirm or alter our early conclusions from SEANET activities in Massachusetts. Long-term monitoring is vitally important. Power analyses in previous studies suggested that 12–15 years of beached bird survey data are necessary to detect trends in beached bird deposition and oiling rates (Camphuysen 1998, Camphuysen & Heubeck 2001, Seys *et al.* 2002b).

Drift experiments using real or simulated carcasses have demonstrated that oceanographic conditions, season, geographic features, beach type and buoyancy influence the deposition and recovery of carcasses. Results are highly variable among studies, ranging from 0% to 59% of carcasses at sea recovered on shore (e.g. Bibby 1981, Piatt *et al.* 1985, Hlady & Burger 1993, Piatt & Ford 1996, reviewed by Camphuysen & Heubeck 2001, Wiese & Jones 2001). Few drift experiments have been done in the western Atlantic (but see Piatt *et al.* 1985, Wiese & Jones 2001, Wiese 2003), and none are reported for northeastern US waters. Such research would be highly useful in future assessments of beached bird encounter rates.

ACKNOWLEDGMENTS

We thank all collaborators and volunteers from the Lloyd Center for Environmental Studies and Massachusetts Audubon Wellfleet Bay Wildlife Sanctuary who participated in beached bird surveys; without them, data collection would be impossible. We especially thank Maryann Zbel at Wellfleet Bay, who coordinates Cape Cod volunteers, and Mark Mello at The Lloyd Center, who was instrumental in establishing SEANET in Buzzards Bay. At Monomoy National Wildlife Refuge, Stephanie Koch, Janet Thibault, Monica Williams, and other US Fish and Wildlife personnel have helped greatly in the collection of bird mortality data. Marj Rines contributed Massachusetts Bird Observer data. SEANET has been funded in part by The Geraldine R. Dodge Foundation, Lynn Trayser Mitchell Memorial Bird Fund, the Gulf of Maine Council on the Marine Environment, the Fuller Foundation, the Davis Conservation Foundation, Massachusetts Environmental Trust, Disney Wildlife Conservation Fund, International Fund for Animal Welfare, NOAA Coastal Services Center GIS Integration and Development, National Fish and Wildlife Foundation, and Wildlife Trust.

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