GREAT SHEARWATER (*PUFFINUS GRAVIS*) MORTALITY EVENTS ALONG THE EASTERN COAST OF THE UNITED STATES

Katherine H. Haman, [1, 2] **Terry M. Norton**, [2] **Robert A. Ronconi**, [3] **Nicole M. Nemeth**, [1] **Austen C. Thomas**, [4] **Sarah J. Courchesne**, [5] **Al Segars**, [6] **M. Kevin Keel** [7, 8]

[1] Southeastern Cooperative Wildlife Disease Study, University of Georgia College of Veterinary Medicine, 501 DW Brooks Drive, Athens, Georgia 30602, USA

[2] Georgia Sea Turtle Center, Jekyll Island Authority, 214 Stable Road, Jekyll Island, Georgia 31527, USA

[3] Grand Manan Whale and Seabird Research Station, 24 Rte. 776, Grand Manan, New Brunswick, E5G 1A1, Canada

[4] Marine Mammal Research Unit, Fisheries Centre, Room 247, AERL, 2202 Main Mall, The University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada

[5] Center for Conservation Medicine, Tufts Cummings School of Veterinary Medicine, 200 Westboro Road, North Grafton, Massachusetts 01536, USA

[6] South Carolina Department of Natural Resources Marine Resources Division, 16 Coastal Seafood Road, St Helena Island, South Carolina 29920, USA

[7] Department of Pathology, Microbiology and Immunology, School of Veterinary Medicine, UC Davis, Davis, California 95616, USA

[8] Corresponding author (email: mkkeel@ucdavis.edu)

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ABSTRACT: The Great Shearwater (*Puffinus gravis*) is an abundant pelagic seabird that undertakes transequatorial migrations between the North and South Atlantic Ocean. This species is a useful indicator of large-scale alterations in marine dynamics due to its wide geographic range, long-distance migrations and relative abundance. From 1993 to 2011, 12 separate mortality events involving 4961 Great Shearwaters were documented along the eastern coast of the United States (US). Of these, seven events (n=4885) occurred in the Southeast (SE) and five (n=76) in the Northeast (NE) US. The cause of death was determined either by necropsy (n=60) or external examination (n=4901). All Great Shearwaters stranded along the SE US were emaciated while 58% were emaciated in the NE US. No plastic was observed in Great Shearwaters in the SE US (n=27), but the gastrointestinal tract of 82% (n=27) of all stranded birds along the NE US had at least one plastic bead. There was no evidence of infectious disease or heavy metals in stranded Great Shearwaters examined (n=14, from the 2005 SE event). Stable isotope analysis of feathers (n=9, from a 2007 SE event) suggests dietary differences between emaciated stranded birds and live caught healthy birds. The temporal distribution of stranding detections suggests a general increase in the number of observed Great Shearwater strandings over the past two decades. From 1993-2000 there was a total of three mortality events with 296 individual Great Shearwaters. However, there was a three-fold increase in the number of mortality events from 2001-2011 (nine events involving 4665 individuals). The causes of this apparent increase in strandings remain unknown but may be due to an increase in reporting effort over the past two decades combined with changing oceanographic conditions in the South Atlantic, leading to large-scale mortality of emaciated Great Shearwaters along the east coast of the US.

Key words: bycatch, emaciation, Great Shearwater, infectious disease, mortality event, Atlantic Ocean, plastics, stranding

INTRODUCTION

Shearwaters (*Puffinus* spp) are among the most widespread, abundant seabirds on the world's oceans (Brown et al., 1978). The Great Shearwater (*Puffinus gravis*), a common pelagic species, undertakes transequatorial migrations that encompasses both the northern and southern Atlantic Oceans (Brooke, 2004b). Both breeding and nesting occur in the Southern Hemisphere during the austral summer, with over 5 million breeding pairs of Great Shearwaters (Brooke, 2004a). Following the breeding season, adults and juveniles migrate to the Northern Hemisphere to feed primarily on fish, krill, and squid in the pelagic North Atlantic Ocean during the boreal summer (Ronconi et al., 2010a). The Great Shearwater is a useful indicator species for monitoring large-scale marine dynamics of the pelagic Atlantic due to its widespread use of Atlantic Ocean basins, long-range migrations, and relative abundance.

Seabirds, especially pelagic species such as the Great Shearwater, are affected by dynamic oceanographic conditions including equatorial fronts, currents, sea surface temperature and salinity, and oceanographic parameters that affect the distribution and abundance of both phytoplankton and plankton (Ballance et al., 2006). Changes in these oceanographic parameters potentially alter the life history and health of pelagic seabirds. Inclement weather events, such as hurricanes (Bugoni et al., 2007), as well as harmful algal blooms (Jessup et al., 2009), may result in increased pelagic seabird strandings along the associated coasts. As with marine mammals, stranding events of pelagic seabirds provide an opportunity to assess mortality and thus population threats, stressors and trends of species that are normally difficult to observe (Norman et al., 2011). Investigations of such strandings typically emphasize the geographic extent of the mortality as well as the demographic trends of affected species (Work and Rameyer, 1999). Recently it has been suggested that the increased numbers of Great Shearwater strandings are related to changing oceanographic conditions (Lee, 2009). However, there are scant scientific data to support this hypothesis.

Another potential agent of mortality in the North Atlantic is fishing gear. Birds entangled and drowned in fishing gear (considered "bycatch") are presumed healthy since they were incidentally killed while actively foraging (Hamel et al., 2009). This is in contrast to stranded birds, which are often diseased, emaciated, or have suffered from traumatic injury and are thus considered unhealthy (Lee, 2009). In the present study we provide a retrospective examination of 18 years (1993-2011) of stranding data to assess trends in Great Shearwaters stranding and bycatch events along the eastern coast of the US. We also compare feather stable isotope signatures between healthy and stranded (n=9, 2007 SE stranding event) Great Shearwaters in the North Atlantic. Based on these data, we suggest a correlation between the foraging ecology of Great Shearwaters in the South Atlantic prior to migration, and mortality in juveniles stranded in the past decade along the shores of the western North Atlantic.

MATERIALS AND METHODS

Stranding data were obtained from The Seabird Ecological Assessment Network (SEANET) database (Harris et al., 2006) as well as the Southeastern Cooperative Wildlife Disease Study (SCWDS), National Wildlife Health Center (NWHC), the Georgia Sea Turtle Center (GSTC), and the South Carolina Department of Natural Resources (SCDNR). All data originated either as official stranding and necropsy reports or observations made by state and federal officials during a given mortality event. All reports from the abovementioned agencies were cross-referenced to ensure that a single event or mortality was not counted multiple times and that there were no overlapping data.

Data were compiled into a single database and the mortality of each individual was defined as either a stranding or bycatch (due to fishing gear), and assigned an event number based on the time of occurrence (single season) and geographic location. An event was defined as Great Shearwater strandings or bycatch mortalities that occurred in a geographic location (Southeast, SE; Northeast, NE) within a single season (spring=March 22 – June 21; summer=June 22 – September 21; fall=September 22 – December 21; or winter=December 22 – March 21); bycatch and stranding events were each analyzed separately. There were 12 separate stranding events over the past 18 years. The general category of mortality for stranding events was determined based on gross observation and included emaciation, trauma, oiling, and undetermined. Cause of death determined by necropsy included the above categories as well as foreign body, infectious diseases such as West Nile Virus, Newcastle, and Avian Influenza, and heavy metals. Note that drowning as a cause of death was determined at time of death, by visual observation of the drowned bird entangled in fishing gear, and not via necropsy or histopathologic examination. Body condition score (BCS) on animals not necropsied was based on palpation of muscle mass along the vertebrae, ventral abdomen, and the keel using an ordinal scale: 1=emaciated; 2=thin; 3=normal; 4=overweight; 5=obese.

Stranding events were categorized by geographical region as NE or SE, as delineated by the most eastern point of Massachusetts, approximately at latitude 41°N (Fig. 1). This geographical division was chosen for oceanographic and biological reasons. Cape Cod, MA represents an inflection point of the Gulf Stream in the Atlantic Ocean; areas south of this location are typically characterized by the warm-water influence of the Gulf Stream while the cold, temperate waters of the Gulf of Maine characterize areas north of 41°N (Mann, 1967). For the *Puffinus* shearwaters there is an ecological difference between the NE and SE, delineated approximately at 41°N (Hedd et al., 2012); south of this latitude the birds are migrating and not foraging while north of 41°N they have entered their boreal summer foraging grounds. The proportion of birds in each mortality category was determined for the SE and NE by dividing the number of birds observed or necropsied in the specific category by the total number of birds stranded in the geographic region (NE or SE).

Sixty necropsies were conducted on stranded or bycaught birds between 2004-2011 (NE=33, SE=27); during this time period at least one Great Shearwater was necropsied for each individual stranding event, as defined in this paper, in the NE and SE. No necropsies were conducted on Great Shearwaters that stranded either in the NE or SE between 1993-2003. Trained veterinarians associated with Cummings School of Veterinary Medicine at Tufts University or the Southeastern Cooperative Wildlife Disease Study (SCWDS) conducted all necropsies. Gastrointestinal contents were thoroughly analyzed using sieves to separate and identify contents, at the time of necropsy. Ancillary tests for West Nile, Avian Influenza, and Newcastle Disease viruses were performed on brain tissue and tracheal/cloacal swabs from 14 individual birds necropsied during the SE mortality event in 2005 (n=1668). Toxicology screenings for heavy metal (arsenic and lead), organochlorine, and polychlorinated biphenyls (PCB) were also performed on liver and renal tissues from the same 14 birds. Ancillary tests were performed at SCWDS as previously described (Stallknecht et al., 1990; Gibbs et al., 2005). Body condition score (BCS), based on the ordinal scale of one to five, was determined on necropsy by the degree of atrophy of pectoral muscles, presence/absence of subcutaneous or coelomic fat, and presence/absence of and/or serious atrophy of cardiac fat along the coronary groove. Due to the relatively small number of birds necropsied, these data were analyzed and presented separately from stranded birds generally observed. The proportion of birds from each geographical region (NE and SE) with specific necropsy findings was determined by dividing the number of necropsied birds within a category by the total number of birds necropsied in that region. Age was determined at necropsy or general observation and was based on plumage.

To examine potential associations between southern hemisphere foraging conditions and stranding events, the diets of stranded birds (n = 9 from June 2007 stranding event in Florida) were compared to apparently healthy birds that had recently completed their northward migration in 2006, 2007, and 2008 to the Bay of Fundy, Canada (Ronconi et al., 2010a). Diets were assessed by carbon (δ^{13}C) and nitrogen (δ^{15}N) stable isotope analysis of ventral body feathers. δ^{15}N values represents relative foraging trophic levels, while δ^{13}C values are associated with specific prey sources. With seabirds, carbon isotope signatures can be used for assessing general shifts in dietary source from inshore to offshore areas (Hobson et al., 1994) as well as assessment of specific prey species consumed (Ronconi et al., 2010a). Isotopic signatures of feathers reflect the diet at the time of feather growth; therefore, it is important to understand the timing of molt. Great shearwaters molt wing feathers in the western North Atlantic between May and August (peak in June) (Brown, 1988) and body feather molt may occur simultaneously during wing molt (Ginn and Melville, 1983), though other shearwater species (*Calonectris diomedea*) show peak body molt in adults during chick-rearing periods (Ramos et al., 2009). Thus, stable isotope signatures from ventral body feathers may represent diets during some unknown portion of the year, but likely from late chick-rearing (April/May in Great Shearwaters) to the time of sampling. Stranded birds sampled in mid June were compared to live-caught birds sampled in late July (Ronconi et al., 2010a ; Ronconi et al., 2010b), thus maximizing the overlap in sampling times and minimizing bias associated with continuous body feather molt during the non-breeding period. Surface contaminants and oils were removed by soaking feathers in a 2:1 chloroform:methanol solution for 24 hrs, followed by rinsing with the same solution, air drying, and cutting into small fragments with stainless steel scissors. Isotope analyses were performed as previously described (Ronconi et al., 2010a). Generalized linear models (SPSS 15.0) were used to compare isotope signatures between groups (stranded vs live-caught).

RESULTS

Twelve stranding events involving 4961 Great Shearwaters occurred along the eastern coast of the USA from 1993-2011 (Fig. 1). The number of Great Shearwaters stranding reported per year to the agencies included in the present study has increased since 1993. From 1993-2000 there were three mortality events with 296 individual birds compared with 2001-2011, during which there was a total of nine mortality events involving 4665 individual birds (Table 1). This latter period involved seven stranding events (n=4885) in the SE and three events (n=76) in the NE. Age-classes were determined from a subset of these strandings and revealed that most stranded Great Shearwaters were juveniles (47% in the NE, n = 33, and 79% in the SE, n = 27), as determined by feather plumage at necropsy. Tissue samples from 14 individual birds stranded in the SE in 2005 were tested for Newcastle Disease, West Nile Virus, and Avian Influenza. All results were negative. Heavy metal, organochlorine, and PCB analyses on liver and kidney tissues from the same 14 birds failed to yield significant results. The most common cause of death for Great Shearwaters stranded over the past 18 years was emaciation (Table 2).

Necropsy findings of stranded Great Shearwaters (n=60) also indicated geographical differences (Table 3). Plastics of various sizes and shapes were found in the ventriculus of 82% (n=27) of necropsied Great Shearwaters associated with mortality events, either stranded or bycaught, in the NE (n=33). No plastics were found on necropsy from Great Shearwaters (n=27) stranded in the SE.

The most common histologic lesions observed in the stranded birds examined from the SE (n=27) included pododermatitis (n=4), enteritis (n=4), gastritis (n=2), pneumonia (n=2), and hepatitis (n=3) (Table 3). Each case of pododermatitis was characterized grossly as 0.25 – 0.5cm diameter raised nodules on the plantar surface of one or both feet; histopathologically the pododermatitis was marked, acute, multifocal, necrotizing and heterophilic. The pododermatitis in all cases was consistent with trauma and secondary infection. The cases with gastritis were moderate to severe, acute with multifocal lymphoplasmacytic, histiocytic, and heterophilic infiltrates and serositis. Cases of enteritis were characterized by severe emaciation with moderate to severe, subacute, perivascular lymphoplasmacytic enteritis. The lungs from animals diagnosed with pneumonia were grossly wet and heavy; on microscopic examination they were lacey, pale, with eosinophilic material (presumably edema), and moderate infiltrates of hetrophils and red blood cells. Cases of hepatitis were characterized as mild, chronic, multifocal, with periportal lymphoplasmacytic infiltrates.

Comparisons of body feather stable isotopes should be interpreted carefully as we are comparing results from only 9 birds stranded in one mortality event in the SE in 2007 to healthy adult Great Shearwaters that successfully completed their northward migration in 2006-2008 (Ronconi et al., 2010a). Stable isotope values among groups (stranded vs. live-caught; Table 4) found significant differences among $\delta^{13}C$ values (ANOVA $F_{3,48} = 7.03$, $p = 0.001$) but not $\delta^{15}N$

values ($F_{3,48}$ = 0.73, p = 0.538). $\delta^{13}C$ values were lowest in stranded birds compared to live-caught birds in all other years (Tukey's post-hoc test: 2006, p = 0.005; 2007, p < 0.001; 2008, p = 0.085). It should be noted that without a prey library for comparison, lower $\delta^{13}C$ can only be interpreted to mean "different" prey sources since $\delta^{13}C$ can vary by prey species, inshore-offshore gradients, and over large spatial scales in oceans. Among the birds sampled for stable isotopes, mass (mean ± SD) varied significantly between stranded birds (458 g ± 28, excluding one individual of 836 g) and live-caught birds (2006 = 906 ± 44, 2007 = 844 ± 128, 2008 = 845 ± 92; ANOVA $F_{3,48}$ = 28.72, p < 0.001). Thus, stranded birds were emaciated and had different dietary stable isotope signatures than live-caught, healthy individuals.

DISCUSSION

We present here a retrospective analysis of 18 years of stranding records for Great Shearwaters. There has undoubtedly been an increase in survey and monitoring effort over the past two decades; therefore there may be unpredictable variation in the reporting of strandings due to different surveillance efforts and potential bias from the different observers involved with the NWHC, SCWDS, SCDNR, and SEANET. These variations might result in an increased detection over the 18 years, not an actual increase in numbers of stranding events (or birds) over that time period. However, monitoring and observation efforts for stranding events have been equal and consistent between geographic regions (NE and SE) since 2004. Despite these limitations, these data are an invaluable indicator of historical stranding levels for pelagic seabirds, such as the Great Shearwater, and may lead to an improved ability to detect an increase in stranding events along the east coast of the USA.

Collectively, data from the present study indicate that emaciation was the most common and consistent finding among stranded Great Shearwaters, especially those stranded along the SE coast of the United States. The average body mass of Great Shearwaters in good body condition sampled as part of a different study in the North Atlantic, prior to the southward migration, was 908 g (n = 328) (Ronconi et al., 2010a). When arriving at the breeding grounds after southward migration, the average weight of Great Shearwaters was previously determined as 761 g (n=36) (Cuthbert, 2005). The stranded Great Shearwaters in the present study that were deemed emaciated had an average body mass of 460 g (+/- 69.6 g; n = 25) while those that drowned in fishing gear in the northeast had an average body mass of 853 g (+/- 141.5 g; n = 26). All weights presented here were from non-molting Great Shearwaters. The average body mass of the stranded Great Shearwaters was significantly less than that of healthy individuals that made successful migrations between the North and South Atlantic (Cuthbert, 2005 ; Ronconi et al., 2010a), supporting the diagnosis of cause of death as emaciation. The specific cause(s) of the severe emaciation in migrating Great Shearwaters remains unknown. Based on the data presented here, mortality due to infectious disease, heavy metals (arsenic and lead), organochlorines or PBCs can be ruled out for one major stranding event (n=1668) in the SE in 2005. We hypothesize that the emaciation in the stranded Great Shearwaters is the result of starvation. In some years poor foraging conditions in the South Atlantic, prior to northward migration, may be responsible for lack of body reserves required to complete the long-distance migration. Such conditions may be particularly detrimental to young, inexperienced birds (i.e. sub-adults) and contribute to the high stranding rates of emaciated juvenile Great Shearwaters along the east coast of the US during migratory periods.

In the South Atlantic, breeding Great Shearwaters forage as far as 4000 km away from their colonies in diverse marine habitats including deep pelagic waters, continental shelf and slope waters, sub-tropical frontal zones, and the Sub-Antarctic Front (Ronconi et al., 2010b), indicating adaptable foraging strategies of these birds to a wide range of oceanographic conditions. However, prior to northward migration, most Great Shearwaters reduce their forage area, focusing over the Patagonia Shelf (Ronconi unpubl. data). While the Patagonian Shelf is typically considered highly productive, pending physical oceanographic parameters such as upwelling and current shifts, productivity may be reduced in March and April (Rivas et al., 2006), when the Great Shearwaters would be focusing their foraging in this area. Therefore, foraging restricted to the Patagonia Shelf may not consistently provide adequate food for accumulation of body reserves prior to migration, especially in juvenile Great Shearwaters. The mechanisms driving the variability in prey availability for Great Shearwaters prior to migration are unknown, but may be related to changing oceanographic conditions. Other shearwater species are known to forage within the Polar Front, where oceanic upwelling occurs and results in the accumulation of prey species; however, alterations in weather and physical oceanographic parameters may change these foraging zones and result in increased energy expenditures needed to reach these areas (Raymond et al., 2010). Similar mechanisms may ultimately decrease the foraging success of juvenile Great Shearwaters (Lee, 2009), contributing to increased numbers of emaciated birds stranded along the SE coast of the United States as they undertake their northward migration.

The stable isotope analysis comparing the dietary signatures of stranded vs. live-caught (healthy) birds suggests that stranded, emaciated birds fed at a similar trophic level ($\delta^{15}N$) but on different prey sources ($\delta^{13}C$) than those of apparently "healthy" live-caught birds that completed their migration to the Bay of Fundy. We sampled body feathers which in some shearwater species are thought to molt primarily during chick-rearing (Ramos et al., 2009) and during subsequent non-breeding periods (Ginn and Melville, 1983). The timing of feather growth and observed differences in dietary signatures combined indicates a dietary dissimilarity in ingested prey between the apparently healthy live caught and dead stranded Great Shearwaters. These data do not provide an indication of prey quality, though they do indicate that the birds that survive the northward migration have been foraging on different prey items in the southern Atlantic Ocean than those that do not survive the northward migration. Thus we hypothesize that prey choices in the southern hemisphere prior to migration may influence the outcome of Great Shearwater northward migrations. However, the interpretation of these stable isotope data should be treated with caution since this assessment is based on samples from a single stranding event and information on pre-migratory prey availability and quality, which would impact the development of body-reserves necessary for long-distance migrations, are lacking.

Of the Great Shearwaters stranded in the NE, 29% (22/76) were entangled and drowned in fishing gear. These birds were of comparable body mass to other healthy Great Shearwaters in the same geographical area (Cuthbert, 2005 ; Ronconi et al., 2010a). Interestingly, 82% of all Great Shearwaters carcasses necropsied from strandings in the NE had plastic within their gastrointestinal tract, yet no plastic was observed in the unhealthy, stranded Great Shearwaters in the SE USA. This may indicate that these birds ingest plastic as they forage in the northern North Atlantic. While plastic has been found in the proventriculus and ventriculus of Great Shearwaters in the western North Atlantic (Brown et al., 1981 ; Pierce et al., 2004), this is the first study to show a specific geographic distribution of plastics in the gastrointestinal tract of individuals foraging in the southern and northern portions of the western North Atlantic. Free-floating plastics are well documented in the North Atlantic subtropical gyre (Lavender-Law et al., 2010 ; Moret-Ferguson et al., 2010), supporting the hypothesis that Great Shearwaters may be exposed to plastics while foraging in more northern latitudes of the North Atlantic. However, there is currently no information regarding gastrointestinal transit time for foodstuff or plastics in pelagic seabirds. It is feasible that Great Shearwaters ingest plastic in the southern Atlantic prior to northward migration; plastics were found in 95% of 21 adult females sampled during incubation on Gough Island in the South Atlantic (Ryan et al., 1988). It should also be noted that the birds stranded in the SE USA were primarily juveniles while those in the NE USA were a mix of adults and juveniles: the young birds may not yet have foraged in as many areas as adults and therefore not encountered plastics while foraging. Alternately, foraging strategies or targeted prey specific to adults may predispose them to increased encounters with plastics.

Overall, there has been an increase in the reported Great Shearwater mortality events over the past two decades. At this time it cannot be ruled out that this increase in reports is due to an increased awareness, communication, and reporting between the involved agencies and the development of networks such as SEANET. In the 1990s only three events involving 296-stranded birds were reported. In contrast, from 2001-2011 a total of nine mortality events with an estimated 4665-stranded Great Shearwaters were reported. This three-fold increase in stranding events may be the result of increasing monitoring efforts over the past 20 years, but may also indicate a broad trend in pelagic bird mortality (Newman et al., 2007). The increase in mortality events involving Great Shearwaters correlates with high numbers of other species of emaciated or starved seabirds stranded along the east coast of the USA. The specific cause of the emaciation or starvation among Great Shearwaters and other pelagic bird species (Newman et al., 2007) remains unknown but may be related to changing environmental conditions (Newman et al., 2007 ; Raymond et al., 2010), food sources (Raymond et al., 2010), or underlying and undiagnosed infectious diseases.

The Great Shearwater, like many pelagic seabirds, serves as a useful indicator of oceanic health. It is thought that, similar to other shearwater species (Hedd et al., 2012), Great Shearwaters do not forage during their transequatorial (>15,000km), 3-week migration between the South and North Atlantic. Therefore, the observed increase in emaciated juveniles stranded along the east coast of the United States may indicate that these birds are not in sufficient body condition prior to their northward migration in April/May. This poses the question of whether the foraging success of juvenile Great Shearwaters is impaired in the South Atlantic? Are oceanographic conditions along the Patagonia Shelf changing such that the Great Shearwaters are not meeting their foraging needs and thus do not accumulate the nutritional reserves necessary to make the long-distance migration between the south and north Atlantic?

Long-term and collaborative data collections and analyses of mortality data improves our understanding of the threats to pelagic seabirds, marine wildlife conservation, and overall ecosystem health (Newman et al., 2007). The multi-institutional, interdisciplinary dataset presented here raises rather than answers questions about seabird mortality. Future research efforts with more thorough investigations of oceanic conditions will aid in the development of a predictive model for large-scale changes in the pelagic marine ecosystem and lead to improved management of fragile marine ecosystem health.

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TABLE 1. Summary of all stranding events of Great Shearwaters on the east coast of the United States, 1993-2011. Dashes indicate no recorded observations of stranded Great Shearwaters. Bycatch mortalities (n=22) in the NE are not presented here.

Region	State	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	TOTAL
Northeast	ME	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	NH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20[c]	20
	MA	-	-	-	-	-	-	-	-	-	-	-	1[d]	-	-	-	21[b]	-	-	-	22
	RI	-	-	-	-	-	11[a]	-	-	-	-	-	-	-	1[c]	-	-	-	-	-	12
	CT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Southeast	NY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	NJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	DE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	MD	-	-	-	-	-	-	-	-	-	-	-	-	9[a]	20[a]	-	-	-	-	-	29
	VA	-	-	-	-	-	-	-	-	-	-	-	-	29[a]	-	-	-	-	-	-	29
	NC	55[a]	-	150[a]	-	-	-	-	-	-	-	-	-	81[a]	-	-	8[b]	-	3[a]	-	297
	SC	-	-	-	-	-	-	-	-	-	-	-	-	305[a]	-	-	-	-	-	-	305
	GA	-	-	-	-	-	-	-	-	-	-	-	-	503[a]	-	250[b]	-	-	1[b]	-	754
	FL	80[a]	-	-	-	-	-	-	-	-	-	-	-	741[a]	-	2500[b]	-	-	150[b]	-	3471
Totals	Northeast	0	0	0	0	0	11	0	0	0	0	0	1	0	1	0	21	0	0	20	**54**
	Southeast	135	0	150	0	0	0	0	0	0	0	0	0	1668	20	2750	8	0	154	0	**4885**
	Overall	135	0	150	0	0	11	0	0	0	0	0	1	1668	21	2750	29	0	154	20	**4939**

[a]Spring (22 March- 21 June)

[b]Summer (22 June - 21 September)

[c]Fall (22 September - 21 December)

[d]Winter (22 December - 21 March)

TABLE 2. Cause of death, as proportions, of Great Shearwaters along the east coast of the United States (n=4961), 1993-2011.

	Gross Observations		Necropsy	
	Northeast	**Southeast**	**Northeast**	**Southeast**
	n=43	**n=4858**	**n=33**	**n=27**
Fishing gear entanglement	NA[a]	NA	22 (67%)	NA
Trauma	0	0	0	0
Oiled	1 (2.3%)	0	0	0
Emaciation	25 (58%)	4858 (100%)	7 (21%)	27 (100%))
Foreign Body	NA	NA	1 (3%)	0
Infectious	NA	NA	0	0
Unknown	17 (40%)	0	3 (9.1%)	0

[a] NA = Not Applicable

TABLE 3. Secondary findings unrelated to cause of death of Great Shearwaters along the east coast of the United States. Numbers represent percentages of birds necropsied (n=60) from 1993-2011. Histopathology was not performed on birds necropsied in the NE. Some birds had multiple histopathologic findings.

		Northeast	**Southeast**
		n=33	**n=27**
Parasites		7 (21%)	10 (37%)
	Cestodes	6 (85%)	9 (90%)
	Nematodes	1 (14%)	2 (20%)
	Lice	0	4 (40%)
Plastics		27 (82%)	0
Infectious Disease		NA[a]	0
Histological Lesions		NA	13 (48%)
	pododermatitis		4 (31%)
	enteritis		4 (31%)
	gastritis		2 (15%)
	pneumonia		2 (15%)
	hepatitis		3 (23%)
	other		3 (23%)

[a] NA = Not applicable

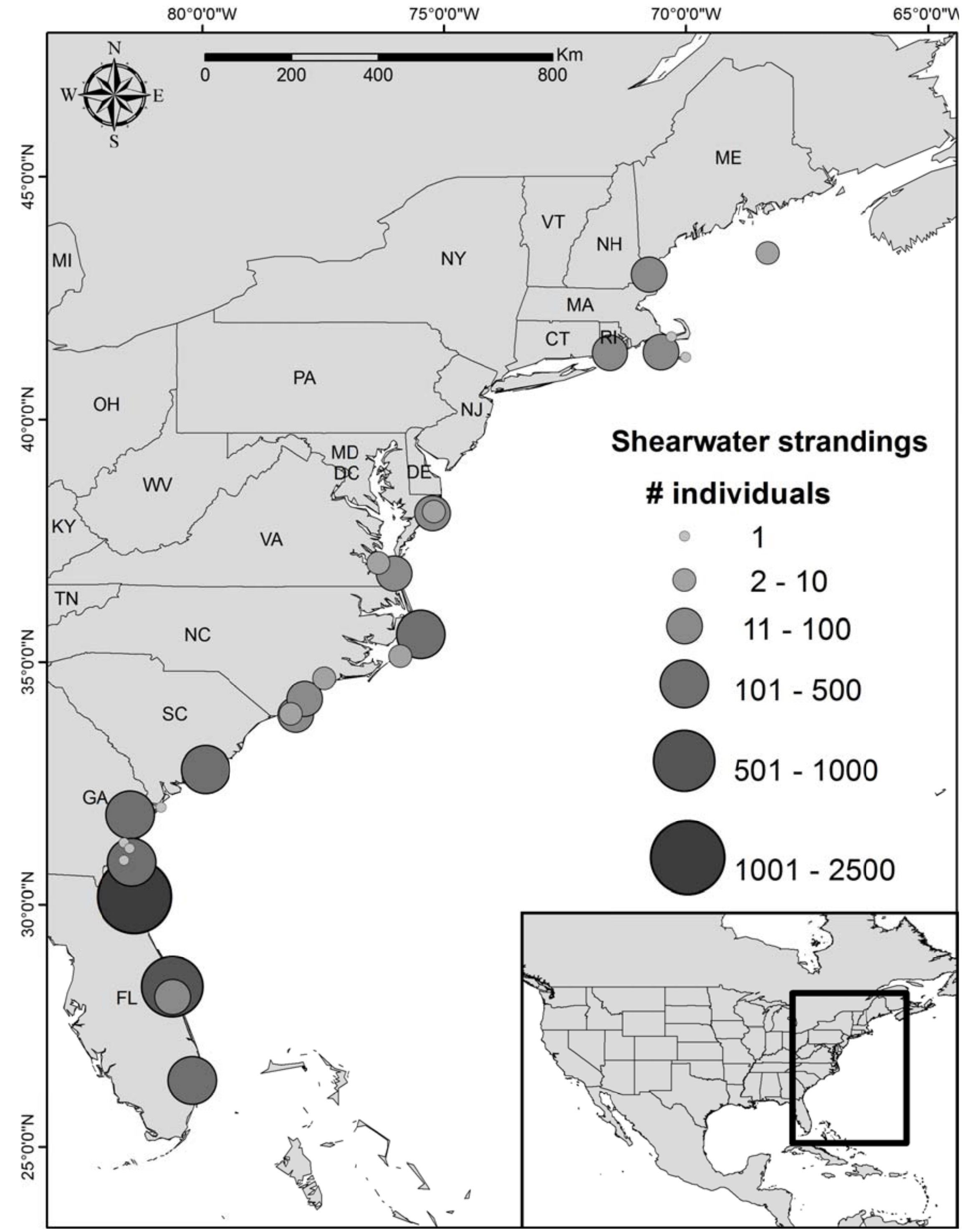
TABLE 4. Comparison of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope signatures from ventral body feathers of Great Shearwaters stranded in Florida (26-22 June 2007) and live-caught birds sampled in the Bay of Fundy (late July, 2006 to 2008). Subscript "str" refers to stranded birds.

			mass (g)	$\delta^{13}C$		$\delta^{15}N$	
Year	**Condition**	**n**	**mean ± SD**	**mean**	**SD**	**mean**	**SD**
2006	live-caught	11	906 ± 44	-16.8	1	16.1	1.7
2007	live-caught	20	844 ± 128	-16.6	0.7	16.3	1.7
2007	stranded	9	458* ± 28	-18.1	1.1	16.3	1.1
2008	live-caught	12	845 ± 92	-17.2	0.7	15.6	1
ANOVA		$F_{3,48}$	28.72	7.03		0.73	
		p-value	<0.001	0.001		0.538	
Posthoc tests (results p < 0.1)			2007_{str} < other yrs	2007_{str} < other yrs		n/a	

*mean value excludes one individual of mass 836g

FIGURE 1. Location and number of stranded Great Shearwaters along the eastern coast of the United States, 1993-2011. Division between northeast and southeast regions occurs at latitude 41°N, approximately at the most southeastern point of Massachusetts.

FIGURE 1.


80°0'0"W
75°0'0"W
70°0'0"W
65°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
25°0'0"N
Km
0
200
400
800
N
S
W
E
ME
VT
NH
NY
MI
MA
CT
RI
PA
OH
NJ
MD
DC
DE
WV
KY
VA
TN
NC
SC
GA
FL
Shearwater strandings
individuals
1
2 - 10
11 - 100
101 - 500
501 - 1000
1001 - 2500