Mass Die-offs of Greater Shearwaters in the Western North Atlantic: Effects of Weather Patterns on Mortality of a Trans-equatorial Migrant

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Introduction

In June of 2007 thousands of dead and dying Greater Shearwaters, *Puffinus gravis*, were reported at sea in waters off the northern Bahamas; subsequently, significant numbers were found washed ashore along the Atlantic coast of the southeastern US that same season. Media reports suggested that scientists were alarmed and feared that these massive die-offs resulted from some unknown ecological disaster. These concerns were widely circulated over the Internet, and various research institutions encouraged people to salvage specimens so that they could be examined for contaminants and other factors that might explain the die-off. Many causes have been suggested, including mercury poisoning, bacterial infections, and H5N1 avian flu. Necropsies of the dead shearwaters revealed little more than that the birds were very emaciated.

Actually, spring migration die-offs of this species occur regularly and probably nearly annually. The magnitude of the die-offs, the degree of documentation, and the amount of media coverage are of course highly variable. Weather conditions, notably offshore winds, in this part of the western North Atlantic are not conducive to washing dead birds shoreward. The Labrador Current and long shore currents carry floating objects southward, while the Gulf Stream transports Outer Continental Shelf waters north and east. As a result, only a small portion of passive floating marine objects such as dead seabirds are actually beached; thus seabird mortality could go largely undetected.

I have been tracking these die-off events for about three decades. What follows is not so much a scientific study of the issue as it is a collection of facts that directly and indirectly may help explain this phenomenon. To give perspective, I also have added to this account various aspects of the marine biology of this Greater Shearwaters.

Life History and Migration

Greater Shearwaters are trans-equatorial migrants breeding in the Southern Hemisphere and, in our summer, "wintering" in the western North Atlantic. *Breeding:* This species' entire breeding range is restricted to two small islands of the Tristan de Cunha group, Gough Island and Kidney Island off the Falklands, but despite its limited breeding distribution the species is relatively abundant. The breeding population is estimated at be 5 million-plus breeding pairs (Williams 1984), and it is generally believed that the total adult population exceeds 6 million pairs. *Wintering:* In the western North Atlantic these shearwaters occur over cool pelagic waters both as summer visitors (during the Southern Hemisphere's winter) and as migrants. Most "winter" north of 45° N latitude (Stresemann and Stresemann 1970). Small numbers also occur in the Gulf of Mexico from May through October. *Migration:* Nearly the entire global population passes through waters off the southeastern US in the spring and early summer (Lee 1999), with a modest number of sub-adults remaining off of the southeastern coast during the summer through November (age based on North Carolina State Museum specimens and lack of observed flight feather molt in "wintering" shearwaters off North Carolina, pers. obs.). Off North Carolina they typically occur in waters from 180 to 300 meters in depth (Lee 1986, 1995). The bulk of southward fall migration appears to be more over the mid- to eastern Atlantic (Warham 1996).

Occurrence off the Southeastern United States and the Gulf of Mexico

While Greater Shearwaters are of common occurrence as migrants in the southeastern US, with, for example, sometimes thousands being seen on a single day in the Gulf Stream off North Carolina's Outer Banks (Lee 1995), as recently as 1963 there were only 22 records for the entire southeastern US (Kale 1963). The limited number of earlier reports reflects the sparse amount of information available prior to regular excursions' being made into offshore waters by dedicated bird watchers. The species occurs primarily along the edge of the outer Continental Shelf and along the inner edge of the Gulf Stream. Comparative studies by Haney and Lee (in ms) show that Greater Shearwaters make up 3.9% of the total annual marine bird fauna and 3.5% of the total annual marine bird biomass in the Gulf Stream off North Carolina's Outer Banks. To the south, in the Gulf Stream across the Georgia Embayment, these shearwaters are less abundant and represent a smaller percentage of the total annual avifauna (l.9%) and biomass (2.3%). They do not regularly occur in inshore waters and only during strong offshore winds within the period of peak migration are these shearwaters likely to be seen from shore.

Greater Shearwaters have been recorded from mid-April through late December off the southeastern US, but the principal period of occurrence is from mid-May through mid-November. The majority of the birds pass through offshore waters from mid-June through the first half of August (Clapp et al. 1982, Lee 1986, 1995). Modest to large numbers of Greater Shearwaters also "winter" off the southeastern US, but the return fall migration through this area is minimal, thereby supporting the belief that most southbound birds migrate further out to sea.

Greater Shearwaters have been reported from the Gulf of Mexico during the warmer months on occasion but they are uncommon (Clapp et al. 1982).

Biology at Sea

Greater Shearwaters are found over open seas where they feed from the surface, by plunge diving, and by following fishing vessels to scavenge offal. Principal food items are fish and squid, and to some extent crustaceans. These shearwaters tend to concentrate along current edges, around floating mats of pelagic *Sargassum,* and over schools of foraging fishes. They often feed in mixed species flocks. Examination of the digestive tracks of 43 specimens collected off North Carolina (Lee unpublished) revealed mostly fish (50% occurrence, including Clupeids, Myctophids, and one jack, *Caranx hippos*), and squid or remains of squid beaks (100% occurrence: three families including *Histioteutius corona* and *Thysanoteuthis rhomus*). Many of the squid beaks that were in the birds' crops, based on wear, probably represent long-term accumulations.

Miscellaneous food items include one beetle, shrimp appendages, and one arthropod claw. Plastic ingestion by 35 Greater Shearwaters collected off the southeastern US was studied and compared to that of other pelagic marine birds occurring in the same region by Moser and Lee (1992). Despite the high incidence of plastic ingestion in Greater Shearwaters collected off North Carolina (100%) and reports of plastic obstruction starvation in Greater Shearwaters, they concluded that plastic ingestion, including secondary ingestion from the guts of prey items, is not a significant cause of mortality.

Die-offs and Mortality Factors

Mass die-offs of Greater Shearwaters are reported from waters of the southeastern US on a regular basis. While reporting is limited from outside of US waters, these events are known to occur as far south as the southern Caribbean (Surinam and Trinidad; Collins and Tikasingh 1974, Mees 1976). There are no reports of die-offs from the Gulf of Mexico where the species occurs less commonly. These events are restricted to late spring and early summer and often represent hundreds to thousands of dead and dying birds. Die-off events can easily go unnoticed because, as noted above, the currents along the southeastern US are not conducive to washing ashore birds dying in offshore waters, and the magnitude of mortality is probably often underestimated because the individual birds are widely scattered over various barrier islands and throughout different states. On several occasions I have had North Carolina charter boat captains comment on large numbers of dead and dying shearwaters they have seen in the Gulf Stream. Despite the regularity of this seasonal mortality, it has not been widely reported in the scientific literature, and the events are more likely to be reported by local media. While the scientific community is aware of the issue, and dead birds have been examined in attempts to determine the cause of these mass mortalities, nothing conclusive has been found, and as a result nothing has been published regarding these die-offs.

Timing of die-off events in relation to migration: Greater Shearwater die-offs occur mostly in June, but dates of documented occurrence extend from 28 May through 4 August. There is an 1893 report of many found dead on a South Carolina beach from sometime in late August, but this was storm-related. The peak time for die-off reports is between the third week of June and the first week of July. Beached salvaged birds are likely to have been dead and drifting at sea for days, and perhaps longer.

At these times, Greater Shearwaters are recently departed from their breeding grounds. Adults depart northward from their breeding grounds in April and May, and their fledglings leave the nest and begin to migrate north between May and August (Rowan 1952). The peak occurrence of Greater Shearwaters in the Grand Banks area does not occur until the second week of August (Murphy 1936).

In comparison, the Cory's Shearwater, *P. diomedea*, is a similar-sized seabird that occurs off the southeastern coast of the US more commonly and is more regularly encountered than the Greater Shearwater. It is present at the same season, and feeds on similar prey items. Some individuals tend to occur closer to shore than Greater Shearwaters, and they are considerably more abundant both as migrants and seasonal residents (Lee 1995, Haney and Lee in ms, pers. obs.). This species, however, is a bird of the North Atlantic and its migration patterns are trans-Atlantic. Because of their abundance and other factors Cory's Shearwaters should be encountered much more commonly in die-offs if the issues affecting the mortality were of local origin. However, they are seldom encountered as beach-cast birds and there have been no documented region-wide, or even local, die-offs of this species. I point this out, as it provides indirect evidence that the causes of regular die-offs of Greater Shearwaters need not be factors originating in the temperate or sub-tropical waters of the North Atlantic. Along similar lines, during die-off events other locally occurring seabirds are not affected, and non-storm-related mass die-offs in all reported cases have been specific to Greater Shearwaters.

Age of birds salvaged from die-offs: While major components of the biology of Greater Shearwaters are unknown due to the remoteness of their breeding colonies, a general understanding of key aspects can be inferred from better-studied species. Lee and Haney (1996) summarized the life history of Manx Shearwaters, *Puffinus puffinus*, the most studied of the shearwaters. Average age of maturity and first breeding is between 6 and 7 years for this species. Mortality is highest in their fledgling year, and survivorship from hatching to first breeding age is 25–35%. Thus the number of immature birds at any given time is likely to be far greater than the total adult population. Using Manx Shearwater demography as a crude tool for a conservative population estimate, the total Greater Shearwater population could be greater than 20–24 million birds, with over 10–12 million individuals being sub-adults, juveniles, and immatures.

It appears that all of the Greater Shearwaters salvaged from die-off events are non-breeding birds (fledgling year, immature, and sub-adult individuals). Collection of live healthy specimens in the Gulf Stream off North Carolina indicates that the majority of the individuals migrating through and "wintering" in waters off the southeastern US are likewise not adult birds. This finding is based on plumage, molt sequence, gonad size, and the presence of bursas. (The presence of bursas in petrels confirms birds of hatching to one-year-old birds, but some, while still immature, may be older.) While the plumage of adult and younger birds is similar in overall appearance, adults are distinguishable in having dark caps and white necks that appear to be more contrasting because the white neck collar is wider and more defined. While "wintering" in the North Atlantic, adult Greater Shearwaters undergo a rapid molt of flight feathers between July and August. Adults collected (n=2) and observed at sea off North Carolina were in early to mid-molt sequences of primary feathers between mid-June and early July. While many non-adult individuals exhibited some molt of body feathers, none of our series (April through December) of pre-breeding-age birds were in the process of molting flight feathers. Specimens collected at sea were nearly all non-breeding age individuals. The presence of a bursa indicates birds are not of breeding age. All die-off event specimens examined for the presence of bursas had them (n=20), and nearly all of the specimens collected at sea off North Carolina also had bursas (n=50 out of 52). While many of the die-off individuals, based on feather wear and body feather molt sequences, were not first-year birds, none were mature adults. At this time it is not clear what proportions of the different immature age groups are represented in the mortality events.

Weights: Body mass of 18 healthy Greater Shearwaters collected in the Gulf Stream off North Carolina ranged from 503.7 to 870.0 grams and averaged 666.0±89.2 grams (Lee and Grant 1986). Weights of 14 adults collected on their breeding grounds ranged from 715 to 950 grams, while 50 adults collected on "wintering" grounds off Nova Scotia averaged 833±77.6 grams (Hagen 1952, Brown et al 1981). Dead and dying Greater Shearwaters salvaged from North Carolina beaches (n=20) ranged from 337.9 to 432.5 grams (mean=379.5 g). These weights are well below those of breeding and "wintering" adults and are only 50.7 to 77% (mean=56.9%) of that of healthy individuals collected off North Carolina.

Mercury loads: Whaling, et al. (1980) examined total natural-source mercury loads in 51 species of marine birds collected off the North Carolina coast between 1979 and 1982. They found that Greater Shearwaters had some of the highest mercury loads of any of the species studied (surpassed only by Black-capped Petrels, *Pterodroma hasitata*, Royal Terns, *Thalasseus maximus*, and Herring Gulls *Larus argentatus*). Twenty-nine healthy Greater Shearwaters collected at sea had the following average mercury loads in tissues and various feathers: muscle 0.50 ppm, liver 2.28 ppm, kidney 0.89 ppm, feathers 0.95 ppm. The birds were regulating and excreting mercury through liver and kidney tissues, and by entrapping it in molting feathers. If natural mercury is used as a proxy for the potential of accumulation of other types of contaminants, then Greater Shearwaters are expected to be also vulnerable to exposure through absorption and accumulation. Necropsies of shearwaters salvaged from die-off events have not indicated high contaminant levels to be a cause of mortality. The degree to which mercury is retained in fat tissue is unknown, but it is logical that its release into other tissues during the starvation process would place additional stress on the shearwaters.

Evidence for the Influence of the Doldrums on Mass Die-offs

The weights of the beached dead and dying Greater Shearwaters are consistent with birds that have died of starvation. The molt sequence and plumage of these birds suggest many are young-of-the-year individuals, and bursa-based age determination suggest all birds to be of hatching and second-season age classes. The timing of the die-offs indicates that birds have recently arrived from the Southern Hemisphere. All of these factors lead to the conclusion that the birds associated with the die-off events are migrants and that the mortality is linked to stress related to the northward migration. Watson (1970) first proposed that the cause of these events is the result of the difficulty of migrants crossing the Doldrums in certain years. For reasons unknown, Watson's paper has continued to be overlooked by people concerned with the die-off events. Here I am simply supporting his earlier conclusions with additional information that has accumulated since the late 1960s.

The Doldrums, the same equatorial windless seas that stranded large sailing ships for weeks on end, are a barrier to the wind-dependent migration of Greater Shearwaters. A belt of low barometric pressure that often remains unaffected by both the northeast trade winds and the southeast trade winds of the Southern Hemisphere creates a virtual no-fly zone for some seabirds. The influence of the trade winds in equatorial regions can be seen in, or measured by, decreased salinity, seawater density, surface evaporation, and barometric pressure; and increased precipitation, and air and water temperature. Combinations of these factors can increase or decrease the extent of the area affected. In the western Atlantic the northern trade winds seldom extend south of northern South America. The trade winds of the Southern Hemisphere shift from south to north as the Northern Hemisphere spring changes into summer. At their peak the northern extent of these winds occasionally influences the Northern Hemisphere seas as far north as coastal Venezuela. However, they typically blow briskly only as far north as the equator (and mouth of the Amazon) from June to January, and during the remainder of the year this region is under a prevailing calm. The axis of the calm zone that separates the trade winds of the two hemispheres is actually a few degrees above the equator. In that the shift of the southern winds to the north does not begin until the northern migration of Greater Shearwaters is already underway, any variation in timing or magnitude could result in many of the birds being forced to cross the Doldrums while the calm zone is still wide.

The problem of the seasonally enhanced low-latitude no-fly zone is made worse by a general lack of food resources for surface-foraging seabirds in this region. The warm surface waters of the tropics hold little oxygen. Accordingly, measurements of plankton in the upper 50 meters of the western Atlantic are at their lowest between latitude 10° N and 20° S. Combined with the loss of wind-driven wave action, this scarcity results in limited marine productivity and opportunity for these shearwaters to effectively feed when they are in this area. The westward-flowing Atlantic Equatorial and Brazilian Currents sharply turn, respectively, to the north and south in this same general area, thereby eliminating current edges and other opportunities for the formation of oceanic fronts along which the birds could feed. These windless conditions deplete energy reserves as the combination of limited food resources, extra energy demands needed for flight, and increased time needed to travel through the area take their toll on the shearwaters. The result is shearwaters in stressed and starved conditions when they reach the patchy resources of the temperate North Atlantic. While it is not unusual to have high mortality in hatching-year seabirds, the seasonal mass die-offs reported here suggest that for this species low recruitment rates are the result of timing of migration as it relates to equatorial weather patterns.

Discussion

At first the evidence suggests that the spring migration die-off is a natural phenomenon, and indeed it is. The real question, however, is "Have these events increased in magnitude or frequency as a result of human activity?" It is interesting to note that despite the current regularity of mass die-offs of this shearwater, by the early 1960s Kale (1963) was only able to document 22 records, most of which were of individual birds, for the entire southeastern US. While the majority of these records were of beached birds, the dates of occurrence do not seem to be a result of spring die-offs as would be expected from our current assemblage of reports and salvaged specimens. Many of the individuals Kale reported were hurricane driven and a number of others are of late fall records. Of Kale's 22 records for the entire southeastern US obtained between 1879 and 1962, only seven are of beached birds that could have resulted from the die-off events. This species was considered to be very rare in the southeast up through the 1950s and 60s (e.g., Burleigh 1958), so it would seem that many more spring migrant die-off specimens would have found their way into museums and other sources of record if the spring die-offs were as regular an event 50 years ago as they are today. The first records of late spring/early summer dead beached shearwaters are mostly from 1911 and the late 1930s (GA, Burleigh 1958; NC, Person et al. 1959) and these all are of individual birds. Records of single individual beached specimens were still the norm even through the 1950s and 60s (Kale 1962, Tomkins 1959 and various reports in Audubon

Field Notes). Clapp et al. (1982) summarize all records of Greater Shearwaters from the southeastern US between 1893 through 1979. Of 113 records only 20 (18 %) are of beached birds and only four of these suggest mass die-off events. One of these occurred in South Carolina (1893, Wayne 1910) and three in Florida (1969, 1975, 1978; Ogden 1969, Ogden 1975, Ogden 1978). The first suggestion that reports of mass die-offs formed a pattern was by Watson (1970), who reported massive strandings of Greater Shearwaters along the Carolina coast in 1969. Various news accounts showed the die-off extended from Georgetown, SC to the Delmarva Peninsula and totaled 1000 to 2000 shearwaters. Subsequently the reports have been increasing in number, in the geographic area over which the die-offs have been documented, and perhaps also in the numbers reported per mortality event. A tally of all reported stranding events for the southeastern US and the Bahamas shows a marked recent increase in these events. While to some degree this increase should be interpreted as a result of an increased amount of coverage in recent decades, the value of beached birds was well known to people interested in ornithological investigations prior to the 1900s, and mass strandings were not likely to have been overlooked. The number of reported mortality events tallied per decade is as follows: 1890s, 1; 1900–1950s, 0; 1960s, 1; 1970s, 2; 1980s, 2; 1990s 6; 2000–2007, 5. The 1893 report is from late August and was stated to have occurred after a storm (Wayne 1910). Thus, the first documented occurrence of a non-storm-related die-off event is from 1969. Could the tropical, Doldrums-induced, starvation leading to the shearwaters' mass stranding be a result of climate change related to our current global warming?

While the Greater Shearwater is an abundant species with an estimated population of over 5 million breeding pairs (Williams 1984) making these die-off events insignificant, there may be increasing conservation concerns for this Atlantic endemic shearwater. The NOAA Fisheries National Seabird Program identified Greater Shearwaters to be the species most commonly encountered as by-catch in the US Atlantic pelagic long line fishery (Hata 2006). All of the by-catch was north of latitude 35° N. Charter boat captains working off North Carolina in the early summer commonly catch Greater Shearwaters while trolling for sport fish. This is the one time of year that by-catch is reported and these shearwaters are the only species that are regularly hooked. The birds aggressively go after the baits and most of the ones hooked and captured are in near-starved condition. Another conservation concern is that at one of their breeding sites, Gough Island, introduced house mice, *Mus musculus*, have recently been documented as important predators of nesting seabirds (Wanless et al. 2007). Another major concern is the potential impact of oil spills on this species. Greater Shearwaters are highly gregarious, often feed while swimming and diving and are attracted to oil slicks, hence are likely to be extremely vulnerable to oil spills. Spills during their peak migration in June and July off the Bahamas and southeastern US could jeopardize a large portion of the total population (Lee 1999). Concerns regarding frequency of by-catch are enhanced if the spring mortality of young-of-the-year and immature birds is indeed an event accelerated by an increase in global warming.

Other logical explanations for the increased die-offs, such as that they are a result of an expanding population or a decrease in their prey base, are unlikely. While there have been no comparative surveys of Greater Shearwater populations at any of their nesting sites prior or subsequent to those of Williams (1984), there is nothing to suggest an increase in the population. The presence of introduced predatory rodents on one of the nesting islands, mortality from fisheries by-catch, and possible competition for food resources with expanding commercial pelagic fisheries operations would negate the likelihood of a significant population increase during the last three decades. There is no regional evidence of Greater Shearwaters or other seabirds shifting foraging behaviors or changing marine foraging zones, nor of changes in relative abundance as would be expected if the local prey base moved or became inadequate (1975–present, pers. obs. North Carolina‘s Outer Continental Shelf). However, some dying shearwaters apparently move into continental shelf waters prior to expiring, as otherwise currents and wave actions would not be able to wash them ashore.

Conclusions

Based on patterns of beach stranding of other species of pelagic birds off the southeastern US, the May–July timing of dead and dying shearwaters is unique. It is not related to storms or known problems resulting from human activities such as oil spills, or contamination from heavy metals or other pollutants. As in other seabirds, isolated strandings of individual Greater Shearwaters occur on a regular basis, but non-storm-related mass stranding and die-offs seem limited to this single species and confined to this one season. While the influence of the Doldrums on the North Atlantic die-offs may have been an occasional natural event in the past, the factors driving the event may now be increasing as a result of global warming. While die-off records have never consistently been recorded, available evidence suggests that these events are increasing and for the last few decades have become of regular occurrence. Gradual increased heating of the earth’s atmosphere and oceans would be expected to directly drive the duration and extent of the temperature-driven Doldrums’ influence on sea conditions, and thereby have an increased impact on the migration and foraging ability of Greater Shearwaters.

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