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Incidence of Wing Deformities ('Angel Wing') Among Masked Boobies at Clipperton Island: Life History Consequences and Insight into Etiology

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ABSTRACT.—'Angel wing' is a developmental wing deformity among birds that can cause flightlessness; it is mostly known from domestic birds, especially waterfowl, and has only rarely been reported among wild bird populations. We estimated that 508 (4.9%) Masked Booby (*Sula dactylatra*) chicks on Clipperton Island (10° 18′ N, 109° 13′ W) in the eastern tropical Pacific Ocean exhibited angel wing during March 2005. Both hatching-year birds and after-hatching-year birds exhibited the condition; the latter included seven flightless birds in adult plumage (i.e., minimum 2 yrs of age) which were still being fed by their presumed parents. The angel wing outbreak coincided in time with high nestling mortality, apparently related to food shortage, and we speculate on causal linkages. *Received 8 December 2011. Accepted 19 March 2012.*

'Angel wing' is a musculoskeletal disorder that can result in permanent wing deformity and flightlessness in birds (Kear 1973). The proximate cause is a deformity of the distal end of the carpometacarpus, which at times causes the primary flight feathers to droop when the wing is folded next to the body, or it can result in a dorsolateral rotation of the primaries, causing them to twist and project outward (Kear 1973, Zsivanovits et al. 2006). The resulting appearance gives rise to the 20 or more common names for this condition, depending upon whether the primaries twist (e.g., flip, tilt, airplane, or angel wing), or droop (e.g., slipped, dropped, or drooped wing). Symptoms begin during the chick stage, apparently as primary feather growth exceeds the development of the supporting tissue of the carpus. The condition can occur unilaterally or, less commonly, bilaterally; unilaterally, it occurs much more commonly on the left than the right wing, and more commonly among males than females. It can be successfully treated in captive birds (Zsivanovits et al. 2006), but is probably mostly fatal among birds in the wild due to the consequences of flightlessness.

Angel wing has been reported far more commonly among domesticated birds or wild birds raised in captivity than among birds in the wild. The vast majority of reported cases have been of waterfowl, but it has also occurred among psittacines, raptors, bustards, herons, and cranes (Kear 1973, Serafin 1982, Naldo et al. 1998, Thompson et al. 2006, Zsivanovits et al. 2006). Other wild waterbirds diagnosed with angel wing have included Double-crested Cormorants (*Phalacrocorax auritus*) nesting in Canada (Kuiken et al. 1999) and American White Pelicans (*Pelecanus erythrorhynchos*) nesting in Minnesota (Drew and Kreeger 1986). To our knowledge, angel wing has not been reported among wild populations of any marine birds. We document a high incidence of angel wing among Masked Boobies (*Sula dacytylatra*) at Clipperton Island in the eastern Pacific Ocean, comment on its etiology, and discuss some life history consequences of its occurrence.

METHODS

Study Area.—Clipperton Island (10° 18′ N, 109° 13′ W) is an isolated, uninhabited, French-owned atoll in the middle of the eastern tropical Pacific Ocean, ~1,280 km west of the coast of Mexico (Fig. 1). It is ~4 km long and 3 km wide with a large central lagoon; it is tiny (1.7 km^2 of total exposed surface area), but is home to the largest Masked Booby colony in the world (Pitman et al. 2005).

Procedures.—We participated in a private French scientific expedition to Clipperton Island (Charpy 2009) where we studied the diet of Masked Boobies nesting there during 3–27 March 2005. Five weeks prior to our visit (3–28 Jan), and as part of the same expedition, H. Weimerskirch and M. Le Corre also conducted booby research on the island (Weimerskirch et al. 2008, 2009).

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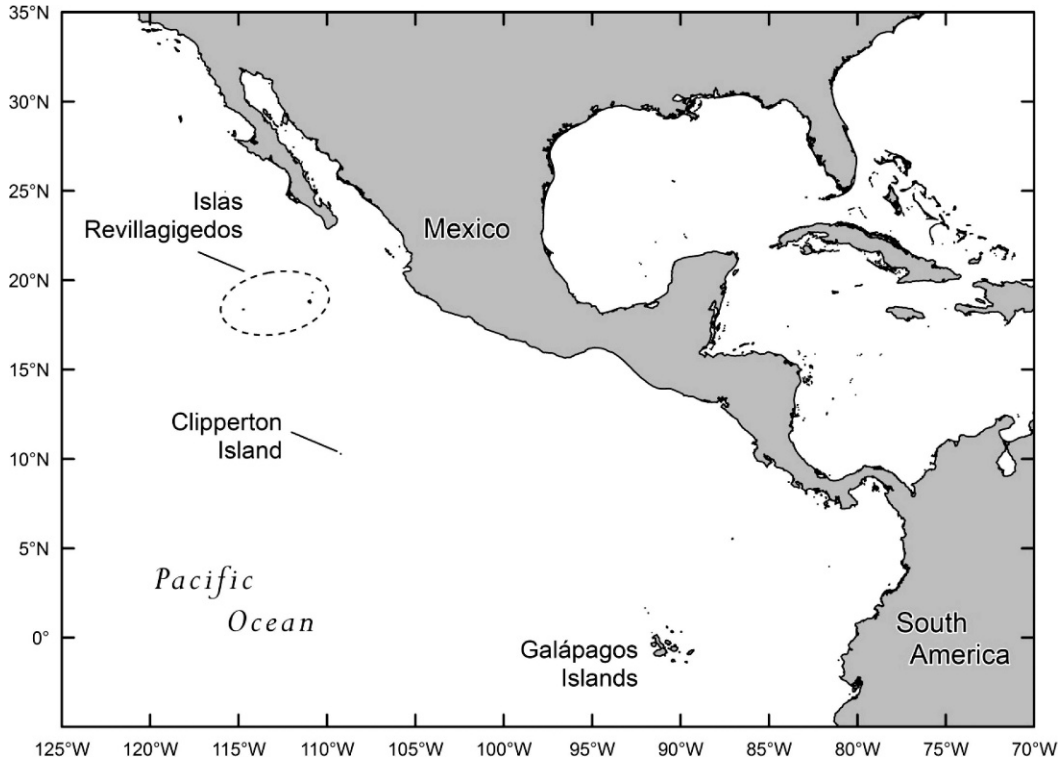

FIG. 1. Clipperton Island in the eastern tropical Pacific Ocean.

OBSERVATIONS

One of us (RLP), during eight previous visits to the island (from 1985 to 2003), had occasionally noticed Masked Booby chicks with deformed wings, but during March 2005 the number was much larger. This condition prevents affected chicks from ever flying or leaving the island.

We surveyed the entire atoll during 11–12 March 2005 and counted 10,375 individual Masked Booby chicks. Clipperton is a low, flat atoll with almost no vegetation and the entire population was counted easily. We subsampled the chick population on 11–12 March to ascertain the percentage of individuals with deformed wings. We used a stretched, 22-m length of polypropylene line and made a series of strip transects between pre-determined landmarks, zigzagging between the lagoon side and the ocean side, around the entire island. We had one person holding each end of the line and one person in the middle, which allowed us to count every chick within the transect, dead or alive, and note those with deformed wings. We sampled 1,019 live chicks using this method, corresponding to 9.8% of the total chick population; of those, 50 (4.9%) individuals had deformed wings, including 45 (4.4%) hatching-year (HY) and five (0.5%) after-hatching-year (AHY) individuals. We extrapolated to the total population and estimated that 508 chicks on the island at the time had wing deformities, including 456 HYs and 52 AHYs.

DISCUSSION

Birds with deformed wings exhibited three modal plumages and, because Masked Boobies breed synchronously at Clipperton Island (Weimerskirch et al. 2008; RLP, pers. obs.), we inferred these modes represented at least three separate year classes (plumage descriptions in Nelson 2005). HY had dark backs, heads, and necks (Fig. 2A), often with some downy plumage. Many HYs were flying around the colony during the daytime by the end of our stay (27 Mar), but still returning in the afternoon or evening to be fed by the parents. Some AHYs had white heads, necks, and upper backs, but still had residual dark flecking on the rump, lower back, and on the greater coverts of the upper wing (Fig. 2B); these

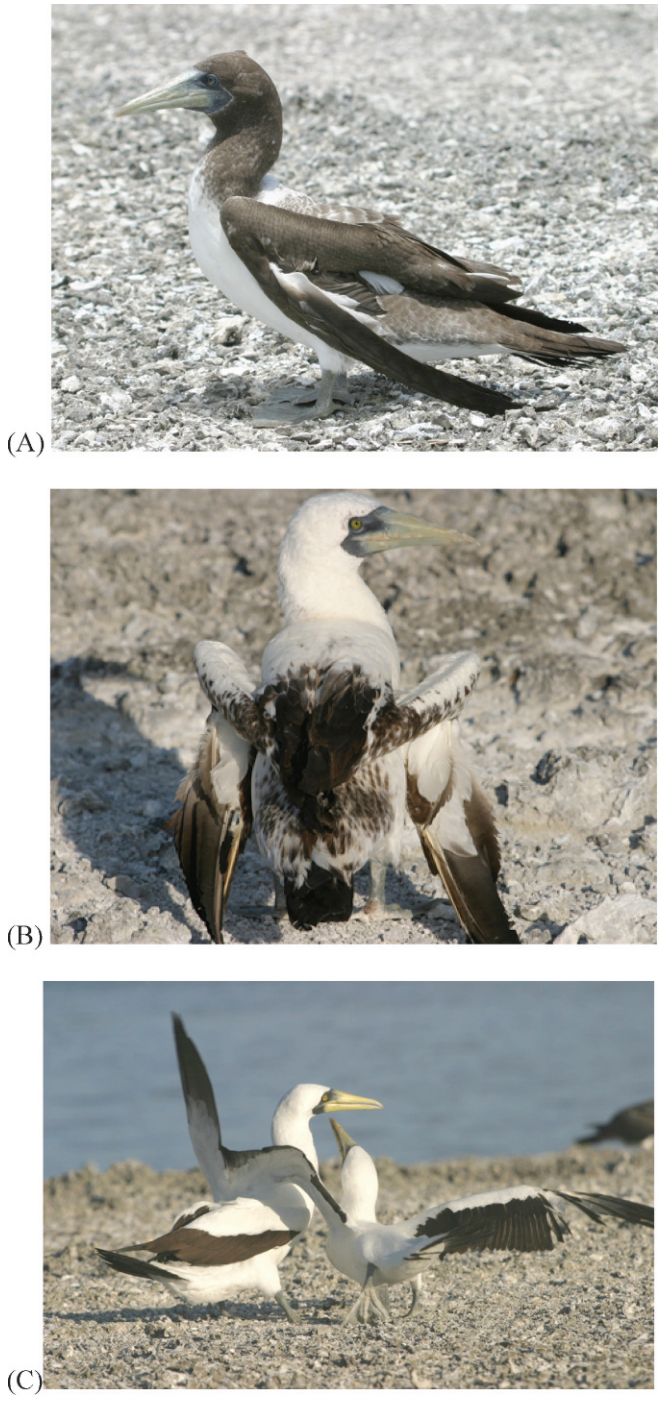

FIG. 2. Examples of angel wing deformities among Masked Boobies photographed at Clipperton Island during March 2005: (A) hatching-year bird with a dropped-wing condition, this bird would normally be of fledging age; (B) second-year bird with flecking on the upper wing coverts and rump, showing the twisted-wing condition; and (C) minimum 2-year old 'adult chick' (on the right) with all-white rump and upper wing coverts, begging the presumed parent for food. The slightly irregular feather development on the right wing of this bird has rendered it flightless; moments after this photograph was taken the chick was fed.

were 1–2 year old birds. Flying birds in this plumage are normally rare at Clipperton because most fledglings begin a nomadic phase and do not return to the colony until they are full adults (Kepler 1969, Nelson 2005). The third plumage was the full adult stage: all white except for black flight feathers and tail (Fig. 2C); birds in this plumage were in their third year or older.

The degree of wing deformity varied among birds, from relatively slight in one wing (Fig. 2C), to major deformities in both wings (Fig. 2B). The majority of affected birds had only one deformed wing; relatively few had both. The outward appearance of the deformity was also variable. Some birds had the classic outward rotation of the primaries when the wing was folded against the body, presenting the angel wing appearance (Fig. 2B), while others (the majority) displayed only drooping primaries; the so-called slipped or dropped wing condition (Fig. 2A).

We saw at least seven Masked Boobies in adult plumage during our stay that, because of wing deformities, were flightless and still being fed by their presumed parents (Fig. 2C). This is, to our knowledge, the longest period of time (min = 2 yrs) that parents of any bird species have been recorded feeding dependent young. The only remotely comparable situation of which we are aware involves another seabird, the Great Frigatebird (*Fregata minor*), which has a fledging period of up to 169 days with post-fledging feeding by the parents for up to an additional 428 days (total 587 days; Schreiber and Burger 2002:670). Our observations also suggest the time and age at which Masked Boobies terminate parental care is, at least in some cases, affected by the chick and not by the adults.

The etiology of angel wing is unknown but some of the suggested causes have included vitamin or nutrient deficiency or imbalance (Zsivanovits et al. 2006), elevated protein concentration in the diet (Kear 1973), elevated levels of contaminants (polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans; Thompson et al. 2006), or a genetic effect, perhaps due to inbreeding after a bottleneck event (Kreeger and Walser 1984, Drew and Kreeger 1986). Some specifics about the outbreak at Clipperton shed some light on these factors.

The sheer isolation (Fig. 1) and lack of human inhabitants at Clipperton almost certainly precludes the possibility of contaminants having a role in the occurrence of the observed angel wing. Under normal conditions during the chick-feeding stage, foraging adults depart the island in the morning, feed and return to the nest by dusk; on average they range only 103 km off the island with a maximum of 242 km (Weimerskirch et al. 2008). Thus, it seems unlikely that chicks raised at Clipperton were exposed to any significant sources of anthropogenic contamination.

A direct genetic effect is a possibility but also seems unlikely (Kear 1973), at least in part because none of the afflicted individuals would ever successfully breed. Kreeger and Walser (1984) documented nine cases of angel wing in a population of Giant Canada Geese (*Branta canadensis maxima*) breeding in and around Minneapolis-St. Paul, Minnesota. That subspecies was once thought to be extinct and, because current stocks were derived from very small populations (as few as 1 pair in some cases), Kreeger and Walser (1984) suggested the angel wing condition may have been a genetic disorder resulting from inbreeding. Masked Boobies at Clipperton Island also experienced a bottleneck event, although perhaps not as extreme as in the case of Giant Canada Geese. Pigs were introduced on Clipperton in 1917 and by 1958 the once massive Masked Booby population had collapsed to an estimated 150 individuals (Stager 1964). The pigs were eliminated, and by 2003 the population had rebounded to >100,000 individuals (Pitman et al. 2005). The prevalence of angel wing at Clipperton based on our visits to the island seems to vary considerably from year to year, which suggests it is more likely linked to some factor(s) other than genetics. We also saw at least one Brown Booby (*S. leucogaster*) chick with this condition in 2005, perhaps further evidence the condition is not inherited.

Excess protein in the diet has often been cited as a possible cause of angel wing (Kear 1973, Serafin 1982, Zsivanovits et al. 2006, Meredith and Keeble 2011). However, Masked Boobies at Clipperton normally feed on a high protein diet comprised almost exclusively of flyingfish (*Exocoetidae*), and smaller amounts of ommastrephid squid (*Ommastrephidae*) and other fish (Weimerskirch et al. 2008; R. L. Pitman and L. T. Ballance in prep.). Angel wing has also been reported in wild populations of Double-crested Cormorant and White Pelicans (Drew and Kreeger 1986, Kuiken et al. 1999), two species that also feed almost exclusively on fish. The only

dietary changes that could possibly have contributed to the development of this condition at Clipperton would have been either a change in the ratio of fish and squid consumed, or an overall food shortage.

Another possible cause of angel wing could be adult boobies acting aggressively toward other chicks. For example, non-breeding adult Nazca Boobies (*S. granti*) have been documented to attack nestlings of Blue-footed (*S. nebouxii*), Red-footed (*S. sula*), and other, nonfamilial Nazca boobies, resulting in lacerations on the chicks' bodies, broken wings at times, and occasionally death (Nelson 1978, Townsend et al. 2002, Anderson et al. 2004, Müller et al. 2011). These interactions have purportedly resulted in 'twisted wings' among the chicks, but for three reasons, we do not believe such aggression is the cause of angel wing. First, nearly all documented cases of angel wing have involved domesticated waterfowl and the explanations that have been offered for its occurrence have not included aggression towards nestlings by adults, which should be fairly evident among birds raised in captivity. Second, angel wing has also been documented among hand-reared birds in a variety of species, more evidence that it is not aggression-induced. Third, we have seen no evidence of other damage (e.g., lacerations to the head and body) to chicks, including those with angel wing, which is commonly evident when adult Nazca Boobies attack chicks (Anderson et al. 2004). We conclude adult aggression is not the cause of angel wing on Clipperton, although we cannot rule it out entirely.

Evidence suggests there was a food shortage at Clipperton, which resulted in a major chick die-off, and this clearly coincided with and may have contributed to the high incidence of angel wing. We counted 167 dead chicks during our strip transect survey. These birds appeared to have died fairly recently (we estimated within the previous 3–4 wks) and were from the current cohort of chicks still alive on the island. We divided the number of dead chicks by the total number of live plus dead chicks on our transects, minus the AHY chicks ($167/1{,}019 + 167 - 5$) to estimate the number of chicks that had died recently. We extrapolated the resulting 14.1% mortality rate to the entire island and estimated a minimum of 1,703 Masked Booby chicks had died during the recent event.

This was apparently part of an even greater die-off. Weimerskirch et al. (2009) counted 19,686 active Masked Booby nests (36% with eggs, 64% with chicks) on the island in January 2005; thus, the 10,375 chicks we counted 2 months later represented a loss of 9,311 nests, a 47.3% reduction. The die-off occurred mainly during February because Weimerskirch et al. (2009) reported 'normal' feeding during January and, when we were there in March, adult Masked Boobies were bringing heavy loads to feed chicks. We infer the die-off was due to a food shortage because pre-fledging mortality among chick boobies is usually due to starvation (Anderson 1993). All previous large-scale nesting failures and chick die-offs documented at booby colonies have also been attributed to food shortages (e.g., Dorward 1962, Schreiber and Schreiber 1984, Anderson 1989). We know of no records of epizootic disease causing large scale mortalities in any sulid species (Nelson 2005:115).

There are at least two reasons why boobies might have experienced reduced foraging success at Clipperton in early 2005. Masked Boobies, like many other seabirds in the eastern tropical Pacific (ETP), depend heavily on feeding schools of yellowfin tuna (*Thunnus albacares*) to drive prey to the surface and make it available (Au and Pitman 1986, Ballance et al. 1997). Catch rates for yellowfin tuna in the ETP in 2005 were lower than average, and fish caught were of smaller size (IATTC 2006); this alone could have resulted in reduced feeding opportunities at Clipperton. In addition, commercial fishermen in the ETP not only target the same tuna schools that boobies rely on, but often use feeding bird flocks to help them locate tuna schools (Perrin 1969, Au and Pitman 1986). It may be significant that Weimerskirch et al. (2009) reported that up to seven tuna purse seiners were present at Clipperton Island during their visit in January 2005. That a fleet of tuna purse seiners was operating in the waters around the island just prior to the time when the colony suffered a major, probably food-related, chick die-off, further emphasizes the possible negative impact that tuna fishing can have on seabird foraging in the ETP (Ballance et al. 1997, Ballance and Pitman 1999, Weimerskirch et al. 2008). Further research at Clipperton Island could provide not only key information on the etiology of angel wing among bird populations, but could also shed some light on the possible impact of industrial-scale tuna fishing on a globally important tropical seabird population (Weimerskirch et al. 2008).

Prepared skeletons of two Masked Boobies and the one Brown Booby with angel wing from

Clipperton in 2005, along with radiographs of all three specimens, are housed at the San Diego Museum of Natural History (SDNMH 51044, 51046, and 51045, respectively).

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