

At-sea distribution of waved albatrosses and the Galápagos Marine Reserve

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Abstract

Albatross populations worldwide are threatened by incidental takes in longline fishery operations. The recent establishment of the Galápagos Marine Reserve (GMR) is relevant to the longline bycatch issue, as it prohibits industrial longlining in the vicinity of the major nesting site of waved albatrosses (*Phoebastria irrorata*). However, the legality of the fishing protections is being challenged, highlighting a need for data on use of the GMR by albatrosses. We used satellite tracking over a total of four breeding seasons to determine the distribution of waved albatrosses inside and outside the GMR, and thereby assess the degree of protection that GMR provisions offer to this species. During the incubation period, breeding adults made commuting trips from the nesting island (Isla Española) to the Peruvian upwelling zone, traveling north, east, and south after leaving the nest. During the brooding period, the distribution contracted markedly, and most satellite fixes were within the GMR. During the rearing period, breeders performed both long trips outside the GMR and short trips within. The southeastern portion of the GMR is used throughout the incubation, brooding, and early rearing periods by breeding waved albatrosses. Indirect information from non-breeding adults indicates that they are likely to use the waters of the GMR extensively.

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1. Introduction

Dramatic incidental takes (“bycatch”) of albatrosses (Aves: Diomedidae) in human fisheries have occurred in the world’s oceans for over 50 years. At the time of the global moratorium on high seas driftnet fishing in 1993, tens of thousands of albatrosses were killed annually in the North Pacific alone after becoming entangled in nets (Johnson et al., 1993; Gould and Hobbs, 1993). Since the landmark paper of Brothers (1991) on the recent impacts of industrial longline fishing on albatrosses, longline bycatch has become the focus of interest of seabird ecologists and conservation

biologists (Gales, 1993; Robertson and Gales, 1998). The serious conservation status of the 24 species of albatrosses was emphasized by Croxall and Gales (1998) when they pointed out that the Diomedidae has the highest proportion of IUCN-threatened species of any bird family with more than one species. Gales (1998) further noted that “the best available evidence indicates that longline fishing is the most serious threat facing albatrosses today”.

Gales (1998) identified significant gaps in our understanding of threats to several albatross species, including the waved albatross (*Phoebastria irrorata*). Since that time, satellite-tracking studies of at-sea distribution of breeders of that species have been initiated (Anderson et al., 1998; Fernández et al., 2001), and a long-term perspective on population size is developing (Anderson et al., submitted for publication). The results confirmed several conclusions from earlier studies (e.g. Harris, 1973), indicating that virtually the entire breeding population nests on Isla Española (1°22'S, 89°39'W) in

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the Galápagos Islands, Ecuador, and that breeders forage within the Galápagos, in the Peruvian upwelling, and the ocean between those two areas. Anderson and Cruz (1998) noted that waved albatrosses received no conservation protection at sea from the governments of either Ecuador or Perú in their respective territorial waters, but on 18 March 1998, the Ecuadorian government enacted the sweeping Special Law for Galápagos. Among other provisions of this legislation was the creation of the Galápagos Marine Reserve (GMR), the second largest marine reserve in the world after the Great Barrier Reef Marine Park. Industrial, but not artesanal, longline fishing was prohibited within the GMR, which encompasses the waters within the archipelago and a 40 nautical mile buffer zone around it. Galápagos is a center of seabird endemism: of 19 taxa breeding in Galápagos, six are endemic species or virtually so (including the waved albatross), and six others are endemic subspecies (Huyvaert and Anderson, submitted for publication). The protection afforded to this seabird assemblage and other Galápagos biota contributed to the designation of the GMR as a Natural World Heritage Site on 13 December 2001.

In light of several legislative and constitutional challenges to the ban on industrial longline fishing in the GMR, we used satellite telemetry of breeding waved albatrosses at sea to assess the degree to which they use the protected GMR during foraging. Many albatross species mix local foraging trips of a few days with very long trips of up to several weeks, trading off frequent food deliveries to chicks from short trips with recovery of the parent's physiological condition during long trips (Weimerskirch et al., 1997). Trip lengths may be especially short during the brooding period, when the hatchling is attended by one parent and receives frequent meals (e.g. Fernández et al., 2001). With this pattern in mind, we assembled both published and unpublished satellite tracking data during incubation (Anderson et al., 1998, and this study), brooding (Fernández et al. 2001, and this study), and chick-rearing (when the chick is left alone at the nest; Fernández et al., 2001) to detect any temporal variation in activity within the GMR. In 1996 we also recorded the durations of trips of non-breeding adults to estimate their maximum foraging range.

2. Methods

2.1. Satellite tracking of breeders

All birds studied via satellite tracking were nesting in the same part of the breeding colony at Punta Cevallos, Isla Española, the eastern point of the island (Anderson and Ricklefs, 1987, give details of the area). In 1995 and 1996, 30 g Platform Transmitter Terminals (PTTs;

Microwave Telemetry Inc., Columbia MD USA) were glued to the dorsal feathers of birds at the nest (Anderson et al., 1998) and tracked using the satellites of the Argos System (Service Argos, Largo MD USA). In 2000 and 2001, a tape attachment method was used instead (Fernández, 1999). In 1995 and 1996, PTTs transmitted on an 8 h on:24 h off duty cycle to conserve battery power, limiting the frequency of contact with satellites. In 2000, five PTTs used this duty cycle, while two others transmitted continuously, and in 2001 all six transmitters transmitted continuously. The girth of the Earth at the equator further limited the number of satellite views of the PTTs (Service Argos 1988). These factors limit the number of contacts to 0.8–1.28 locations per PTT per day for the conservative duty cycle (Anderson et al., 1998; Fernández et al., 2001), so we used all six location quality classes provided by Argos (but not class Z), as in previous studies (Anderson et al., 1998; Fernández et al., 2001). Argos System ground-truthing conducted at the site in 1995 showed that the lowest quality locations, Class B, had a mean error of 17.8 km (9.6 nautical miles; Anderson et al., 1998).

A total of 44 birds making 55 trips provided the data reported here. The 21 birds tracked during incubation in 2000 and 2001 were part of a study of senses used in navigation; 10 and 9 of them had, respectively, small (3.5 g) magnets or brass sham magnets affixed to their heads during their trips (Mouritsen et al., unpublished data). All 19 of the magnet and sham birds showed the same “commuter” foraging behavior seen during incubation in 1995 and in the two unmanipulated birds in 2000 and 2001, traveling to the Peruvian upwelling in relatively straight flights, remaining in the upwelling for several days, and then returning directly to Española.

2.2. Trip lengths of non-breeders

In 1996 we color-banded 14 non-breeding adults resident in the Punta Cevallos breeding colony (non-breeders represent approximately 22% of adults resident in the colony; Anderson et al., submitted for publication). We searched the colony daily at 0600, 1000, 1400, and 1800 h, for these banded adults. Both breeding and non-breeding adults remain in small areas when on land (unpublished data), so we assumed that the non-breeders were at sea if they were not in the Punta Cevallos colony. Birds could perform two or more trips, but appear to be gone on a single trip, if they returned from one trip and departed on the next between two colony searches. Our searching method may, thus, overestimate some trip lengths. However, the searching method indicated that the median duration of non-breeder visits to the colony between trips was 16 h (range 0–260 h), so this overestimate is likely to be minor. From 29 April to 15 July we recorded 286 trips. This period spanned the incubation and brooding periods and the beginning of the rearing period.

2.3. Statistical methods

We considered the trips of incubation-stage birds bearing magnets and sham magnets in 2000 and 2001 to be comparable to those of unmanipulated incubation-stage birds tracked in 1995, 2000, and 2001, because all birds tracked during incubation showed directed, rapid, long-distance flight to and from the Peruvian upwelling, far from the GMR (Fig. 1). Similarly, birds at the brooding stage in 1996 and 2001 showed contracted foraging ranges (Fig. 1). With respect to the specific objective of this study (to assess how much activity is

inside the GMR), we combined data across years within breeding stage for some analyses, but also made comparisons within years when possible. Calculations of χ^2 values followed Zar (1999).

3. Results

3.1. Satellite tracking of breeders

Fig. 1 shows all Argos locations of waved albatrosses at sea during this study. During the incubation periods

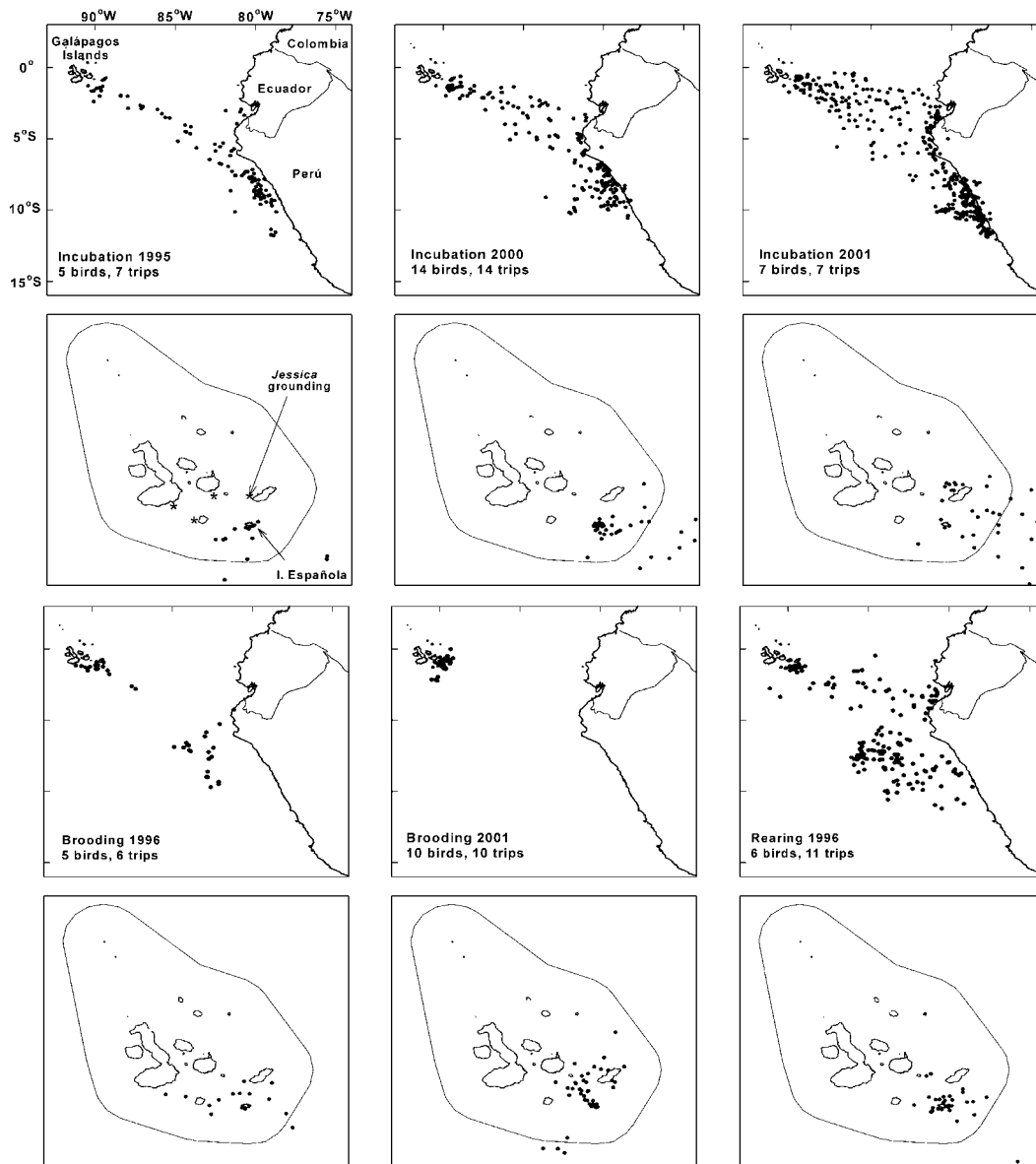


Fig. 1. Locations of breeding waved albatrosses in different periods of the reproductive cycle. Top panels show all points for a given year and period. Bottom panels show details of points in and near the Galápagos Marine Reserve, delimited by the polygon surrounding the archipelago. The first bottom panel shows the location of I. Española, locations of the four shipping ports (stars), and the site of the January 2001 grounding of the *Jessica* (see text). Points shown over land in Perú are Argos class B locations (with the highest degree of error) and probably do not represent actual presence over land.

of 2000 and 2001, all breeders commuted to the Peruvian upwelling, as they did in 1995 (Anderson et al., 1998). During the brooding periods of 1996 and 2001 the foraging ranges of breeders contracted markedly to the region around Española, with the exception of two parents that flew toward the continent. One of these parents left the nest 1.5 days before its egg hatched, and we classified the trip as occurring during the brooding period since most of the trip occurred after hatching, yet the parent may not have known that the brooding period had begun. The other parent began its trip on its infertile egg's day 61; since the median incubation period is 61 days (Harris, 1973), we classify the trip as during brooding, but the parent may not have received the necessary stimulus from the offspring to change its foraging trip length. During the 1996 rearing period parents mixed local and long-distance trips (Fernández et al., 2001).

The proportion of locations within the GMR varied with period in the breeding cycle (Table 1). Combining across years, the proportion of GMR locations during the incubation period (0.103) did not differ significantly from that of the 1996 rearing period (0.149; Yates' Corrected $\chi^2=2.65$, $df=1$, $P=0.10$), but both differed from the combined proportion of GMR locations for the brooding period (0.679; combined incubation vs. combined brooding, Yates' Corrected $\chi^2=78.30$, $df=1$, $P < 10^{-4}$; 1996 rearing vs. combined brooding, Yates' Corrected $\chi^2=33.46$, $df=1$, $P < 10^{-4}$). We found the same patterns within year when comparing the incubation and brooding periods of 2001 (Yates' Corrected $\chi^2=219.13$, $df=1$, $P < 10^{-4}$) and the brooding and rearing periods of 1996 (Yates' Corrected $\chi^2=14.17$, $df=1$, $P=0.0002$).

3.2. Trip lengths of non-breeders

Anderson et al. (1998) found that flights of commuters to the Peruvian upwelling, into the wind, lasted 3.4–6.8 days, and return flights to Española, with the wind, lasted 2.0–6.3 days. Most absences (90.6%) by non-breeders in 1996 were of 3 days or less (Fig. 2), apparently an insufficient period to travel to the Peruvian upwelling

Table 1
Proportion of Argos locations of breeding waved albatrosses falling within the GMR (raw numbers are in parentheses)

Year	Period in the breeding cycle		
	Incubation	Brooding	Rearing
1995	0.12 (11/91)		
1996		0.43 (17/40)	0.15 (28/188)
2000	0.17 (39/234)		
2001	0.06 (24/391)	0.93 (38/41)	

The proportion for the 1996 brooding period includes data from two birds that may be misclassified incubators (see text).

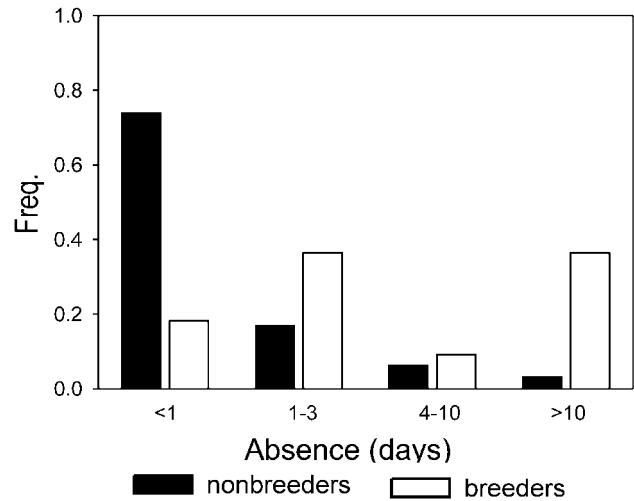


Fig. 2. Frequencies of trip lengths of breeding and non-breeding waved albatrosses in the incubation, brooding, and early rearing periods of 1996.

and back. During the same period, 36.4% of breeders with PTTs took trips of more than 10 days. Using the absence categories of Fig. 2, the distributions of trip lengths of breeders and non-breeders differed significantly (Yates' Corrected $\chi^2=40.88$, $df=3$, $P < 10^{-5}$).

4. Discussion

4.1. Distributions at sea in 2000 and 2001

Foraging trips of incubating birds in both 2000 and 2001 were similar to those of incubating birds in 1995 (Anderson et al., 1998). In all three years, every trip made by incubating breeders began by movement directly, or nearly so, from the nest to the continental shelf, and ended by direct movement from that area back to the nest, a round trip of 1200–1600 km. During the brooding period of 2001, foraging ranges contracted markedly, as occurred in 1996 (Fernández et al., 2001) and as is known in other albatross species (Fernández et al., 2001). During the single rearing period that we have studied, we documented both long trips, often reaching the Peruvian upwelling again, and local trips. We have not studied the consequences for parents and chicks of this cycle of trip lengths, but the satellite tracking data are consistent with the hypothesis that parents make long-range trips to preferred, productive areas except during the brooding period, when the chick requires frequent food deliveries (e.g. Weimerskirch et al. 1997; Fernández et al., 2001).

4.2. Use of the Galápagos Marine Reserve

Waved albatrosses breed on a predictable schedule on Española, with egg laying from April to June, and fledging

from October to January. Breeders, fledglings, and non-breeders vacate the Galápagos from late January to mid-March (Harris, 1973; Huyvaert and Anderson, unpublished data). The area around Española, unsurprisingly, has a high density of breeding waved albatrosses throughout the months that we have conducted satellite tracking (April–July). The focus of foraging activity during much of the breeding season appears to be feeding opportunities in and near the productive continental shelf waters, a trait they share with their two Hawaiian congeners [Laysan (*P. immutabilis*) and black-footed albatrosses (*P. nigripes*); Fernández et al., 2001; Hyrenbach et al., 2002]. When making these trips, breeders typically exit and enter the GMR through a corridor including waters northeast, east, southeast, and south of Española. Occasional birds about to begin trips to the continental shelves first spend time within the GMR (e.g. Male 8 shown in Fig. 1G of Anderson et al., 1998). Thus, the southeastern portion of the GMR represents an area of high density of breeding birds in the process of making long trips to continental shelf waters.

During the brooding period, waved albatrosses appear to forage mostly within the GMR. Our data indicate that the highest densities extend west from Española to the eastern coast of I. Fernandina, north to waters north of I. San Cristobal, and especially within 70 km of Española. The brooding period lasts from mid-June to late August (Harris, 1973; Huyvaert and Anderson, unpublished data). Thus, our data indicate that foraging waved albatross breeders use the southeastern part of the GMR from April through July annually, and use is especially high in June and July. This period of intensive use likely extends through the latter part of the brooding period, until late August.

4.3. Foraging range of non-breeders

Merlen (1996) reported substantial aggregations of hundreds of waved albatrosses in the western part of Galápagos during the chick rearing period, especially around I. Fernandina, the westernmost island in the main part of the archipelago. Our satellite tracking data indicate that breeders are not likely to account for these aggregations, even during the brooding period. In 2001, approximately 22% of the adults present on Española did not breed in either 2000 or 2001 and were classified as non-breeders by Anderson et al. (submitted for publication). Band recapture data indicate that many of these birds are pre-breeding young adults (Huyvaert and Anderson, unpublished data). In 1996, most non-breeder trips away from Española were of short durations of 3 days or less, consistent with the hypothesis that much of the habitat use by this substantial component of the adult population, representing future breeders, was either within the GMR or in waters just

outside the GMR (Anderson et al., 1998). At straight-line flight speeds of up to 24.9 km/h (Anderson et al., 1998), the approximately 250 km roundtrip from Española to Fernandina could be accomplished within 24 h. As a body, these preliminary data suggest that the GMR and nearby waters are the principal foraging areas of the resident population of pre-breeding adults and breeding age adults skipping one or more breeding seasons due to mate loss or costs of reproduction.

4.4. Risks to waved albatrosses within the GMR

Waved albatrosses apparently lack the boat-following tendency that is typical of the other members of the Diomedidae, which may lower their risk of bycatch on longlines (Anderson and Cruz, 1998). Nonetheless, the species is known to scavenge dead items on the surface (Merlen, 1996), so the baited hooks of longline sets probably represent attractive food. A local artesanal fishery for tuna, baiting single-hook lines with live sardines within the GMR, reportedly catches up to five waved albatrosses per boat per day (G. Merlen, personal communication), indicating that a serious bycatch risk exists within the GMR if longlining occurs there. Additional relevant evidence was provided by Jahncke et al. (2001), who estimated that several thousand waved albatrosses were caught annually in small-scale longline fisheries in Perú, and our own recovery of a waved albatross carcass on Española in 2001 that washed up with a hook embedded in its esophagus and 2 m of line trailing from its mouth (Huyvaert, personal observation). Industrial longline fishing activity has continued within the GMR since its establishment, leading in some cases to the seizure of illegal vessels. Vigorous enforcement of the GMR fishing prohibitions by the Galápagos National Park Service, in cooperation with the Ecuadorian Armed Forces and non-governmental organizations, promises to lower bycatch risk within the GMR while the prohibitions are in place. However, bycatch mortality risks for both breeding and non-breeding waved albatrosses are likely to increase if recent legal challenges to the fishing prohibitions succeed.

A significant amount of national and international shipping passes through Galápagos, including freighters commuting between Galápagos and continental Ecuador and tourist vessels, raising the possibility of contaminant spills. On 16 January 2001, the fuel tanker *Jessica* grounded off the western point of Isla San Cristobal, 54 km north of Española, as it entered the port town of Puerto Baquerizo Moreno. Approximately 180,000 gallons of diesel and bunker fuel oil escaped from the ship over the next two weeks, moving primarily to the northwest, west, and especially southwest of the grounding site (Lougheed et al., 2002). The spill occurred at the beginning of the non-breeding season, after most of the population had left the GMR, and no

oiled albatrosses were reported at that time (Lougheed et al., 2002; Anderson, unpublished data). Our research team was present on Española from October 2000 until August 2001, and during that period we documented five oiled Nazca boobies (*Sula granti*) in January 2001, one oiled waved albatross in June 2001, and two oiled Nazca boobies in November 2001. Whether these foulings were due to residual contamination from the *Jessica* spill, or from other spills, is unknown, but clearly seabirds from Española interacted with spilled petroleum from some source. A variety of information, including oceanographic models and the actual movement of the *Jessica's* slicks (Snell et al., 2002), indicates that future contaminant spills from port areas and shipping lanes will occur in or move through the areas identified by our satellite tracking as critical foraging habitat for waved albatrosses.

4.5. Future research needs

Our results are preliminary in several respects. First, the low frequency of data acquisition from the Argos System at the equator limits our ability to make fine-grained assessments of habitat use within the GMR. Clearly breeding waved albatrosses travel within the GMR on foraging trips, especially during the brooding period, but at present we cannot be more specific about the areas of use than to identify the region of Española, and the southeastern portion of the GMR in general, as areas of frequent use. Implementation of GPS tracking, with higher cost-effective sampling rates and lower sampling error, can resolve this problem. Second, we have studied marine habitat use of breeders in the incubation, brooding, and early chick rearing periods, but not through the latter part of the rearing period. Finally, the largest gap in our understanding of habitat use in the GMR is the distribution of non-breeders. Non-breeders constitute a significant proportion of the resident population, and our indirect data suggest that most or all of their foraging is in or near the GMR. Priority should be given to simultaneous tracking studies of non-breeders and breeders throughout their period of residence on Española.

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