Ornithol Sci 7: 29–35 (2008)

SPECIAL FEATURE Bio-logging science in the ecological study of seabirds in Japan

# Post-breeding movement and activities of two Streaked Shearwaters in the north-western Pacific

Akinori TAKAHASHI[1,#], Daisuke OCHI[2], Yutaka WATANUKI[2], Tomohiro DEGUCHI[3], Nariko OKA[3], Vsevolod AFANASYEV[4], James W. FOX[4] and Philip N. TRATHAN[4]

*[1] National Institute of Polar Research, Research Organization of Information and Systems, 1–9–10 Kaga, Itabashi, Tokyo 173–8515, Japan*
*[2] Graduate School of Fisheries Sciences, Hokkaido University, Minato-cho 3–1–1, Hakodate 041–8611, Japan*
*[3] Yamashina Institute for Ornithology, 115 Konoyama, Abiko, Chiba 270–1145, Japan*
*[4] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK*

**ORNITHOLOGICAL SCIENCE**


**Abstract** We used miniature light-level/immersion loggers (geolocators) to study the movements and behavior of two Streaked Shearwaters (*Calonectris leucomelas*) during their travel away from Japan, after the breeding season. During the period from late October until late December, the tracked shearwaters moved south over subtropical pelagic waters with low productivity. The birds traveled to the seas off northern New Guinea and the Gulf of Carpentaria, Australia, 3400–5200 km distant from Mikura Island, their breeding colony in Japan. During the wintering period (December–February), the birds were on the sea surface for 77–85% of their time on average. The migratory and wintering behavior of Streaked Shearwaters are discussed in relation to the physical and biological marine environment of the north-western Pacific.

**Key words** Animal tracking, Foraging range, Geolocation, Migration, Seabirds

The post-breeding movement and behavior of the majority of seabirds has been poorly documented, in contrast to the growing levels of information about their movements and behavior during the breeding season (Shealer 2002). Information on post-breeding movement of seabirds would help to identify key geographical areas and help to increase our understanding of population dynamics (Harris et al. 2005; Furness et al. 2006) and/or help to address conservation issues (Phillips et al. 2005, 2006). Satellite transmitters or Global Positioning System (GPS) devices have proved to be effective in determining the movement of relatively large-sized seabirds, yet these systems have limitations in terms of large device size (usually >20 g) and short recording durations (Phillips et al. 2003). Recently, miniature light-level loggers (geolocator) have been developed for tracking long-distance movements of marine animals (Afanasyev 2004; Phillips et al. 2004; Shaffer et al. 2005). Some studies using geolocators have shown that seabirds exhibit wide movement ranges and utilize habitats that are markedly different from those used during the breeding season (Weimerskirch and Wilson 2000; Croxall et al. 2005; Shaffer et al. 2006; González-Solís et al. 2007). Although bird positions derived from light-based geolocation have much lower accuracy (>186 km; Phillips et al. 2004) than satellite transmitters or GPS devices, the small device size and long recording durations of geolocators have provided opportunities to examine post-breeding movements and activities of small/medium–sized seabirds.

Streaked Shearwaters *Calonectris leucomelas* breed on islands around East and South-east Asia (Oka 2004). The breeding biology of this species has been studied at various breeding colonies in Japan and Korea (Yoshida 1962; Yoshida 1981; Oka et al. 2002; Lee & Yoo 2004). The species has been observed around the seas off New Guinea or northern Australia during winter (Marchant & Higgins 1990), but these at-sea observations do not differentiate among the numerous possible origins of the individuals observed. Information about bird movement and

(Received 12 June 2007; Accepted13 September 2007)
# Corresponding author, E-mail: atak@nipr.ac.jp

behavior after the breeding season at the individual level has been lacking, except for some occasional ring recovery records that suggests that some individuals spend their winter as far as the Philippines or northern New Guinea (Yoshida 1981). Therefore, the purpose of this study was to examine the movement and behavior of Streaked Shearwaters breeding on Mikura Island during the post-breeding period, using recently developed geolocation techniques.

## METHODS

The study was carried out on Mikura Island (33°52′N, 139°36′E), Izu, Japan, where approximately 1.75–3.5 million birds nest in burrows, comprising 68–81% of world population of the species (Oka 2004). Deployments of geolocators or Global Location Sensor loggers (GLS-Mk4, 25×18×7 mm, 4.5 g, built by the British Antarctic Survey; Afanasyev 2004) were conducted between 29 September and 1 October 2004. Loggers were attached to plastic leg rings (total mass 7 g; 1.3% of the average body mass of the study birds, 535±68 (SD) g) and the rings were placed on the tarsi of 11 Streaked Shearwaters captured from different nest burrows (Fig. 1). Bird sex was estimated from vocalizations (Arima & Sugawa 2004). A metal leg-ring was also attached on each bird for identification. Burrows were marked with bamboo stakes, and were visited in the following breeding seasons to retrieve devices.

The BAS geolocator records time, light intensity, immersion in seawater and water temperature. Light levels were measured every 60 s, and the maximum value over each 10 min recording interval was logged. Immersion in seawater was checked every 3 s and integrated at 10 min intervals, thereby providing a value from 0 to 200 representing the proportion of time in the water during that period. Temperature was recorded only after a 20 min period of continuous immersion, as it takes 10 min for the temperature sensor reading to stabilize (temperature sensor accuracy ±0.5°C, with a resolution of 0.0625°C).

**Fig. 1.** A geolocator attached on the right leg of a Streaked Shearwater.

Light data were analyzed with 'TransEdit' and 'BirdTracker' software developed by British Antarctic Survey. Sunset and sunrise times were estimated from thresholds in the light curves, latitude was derived from day length, and longitude from the time of local midday with respect to Greenwich Mean Time and Julian day, providing two locations per day (Phillips et al. 2004). During processing, locations derived from light curves with obvious interruptions around sunset and sunrise, or that required unrealistic flight speeds (>35 km/h sustained over a 48 h period) were identified and later excluded, following Phillips et al. (2004) (10.7% of total positions). Locations were unavailable for variable periods around the equinoxes when it is impossible to directly estimate latitude from daylight data (Wilson et al. 1992; Hill 1994). Simultaneous deployment of geolocators with satellite tags (ARGOS Platform Terminal Transmitters) on Black-browed Albatrosses *Thalassarche melanophyrys* around South Georgia have shown a mean location error of 186 km (Phillips et al. 2004), but location error may be higher in lower latitudes (Hill 1994). Maps were created with the Maptool program (Coyne & Godley 2005), with original data of monthly average Chlorophyll *a* concentration obtained by NOAA.

Data on immersion in seawater and water temperature were summarized daily to examine seasonal changes. Gaps in the data due to occasional corruption in the logger memory meant that immersion and temperature data were unavailable on a small number of days (4.6% of total recording duration).

## RESULTS

Of the initial 11 study birds (from 11 nest burrows) fitted with geolocators in September–October 2004, four birds were recaptured in their original nests and their geolocators retrieved in August 2005. For other seven nests, non-instrumented pairs (birds not fitted with geolocators) occupied three study burrows, and none occupied the remaining four. According to the results from another study in the same colony, the

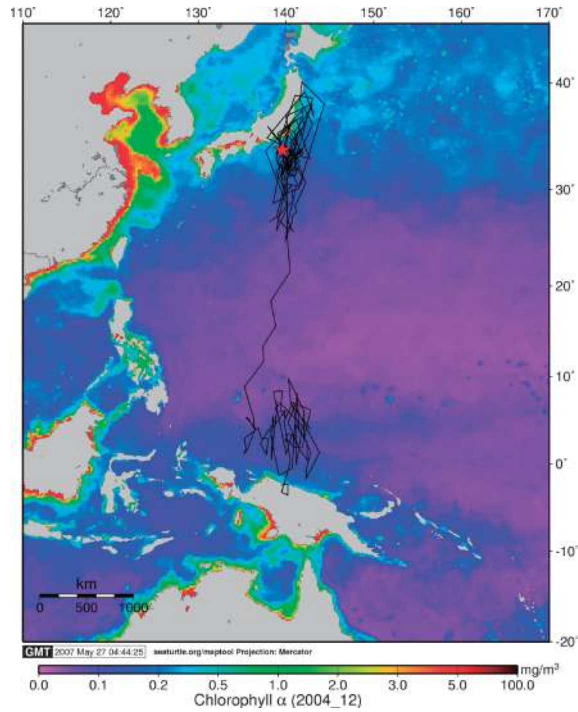


**Fig. 2.** Movement of a Streaked Shearwater (Bird A) from Japan to the sea north of New Guinea (21 Oct. 2004 to 21 Feb. 2005). The star indicates Mikura Island, where the breeding colony is located. Bird positions were obtained with a light-based geolocation device, and the location accuracy is estimated to be 186 km or lower. The base map shows the monthly average Chlorophyll *a* concentrations for December 2004, when Bird A started southern migration (see Methods).

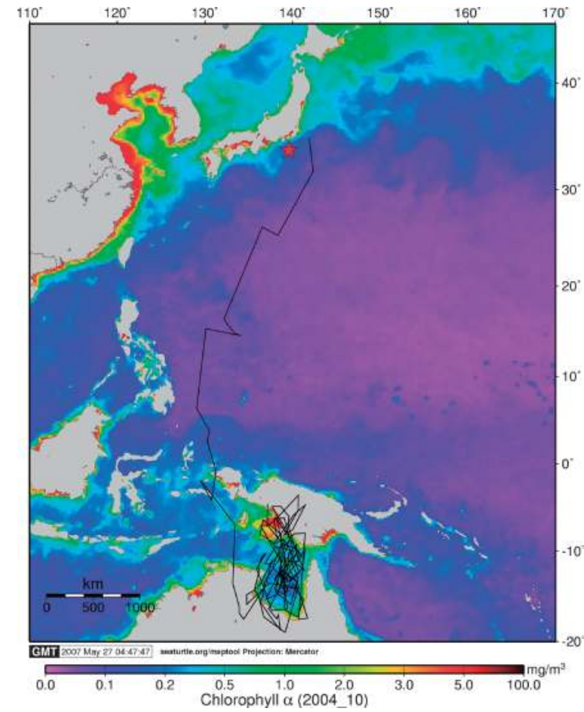


**Fig. 3.** Movement of a Streaked Shearwater (Bird B) from Japan to the Gulf of Carpentaria, Australia (16 Oct. 2004 to 13 Jan. 2005). The base map shows the monthly average Chlorophyll *a* concentrations for October 2004, when Bird B started southern migration (see Methods).

rate of non-instrumented birds returning to the same nests between 2005 and 2006 were 29.3% (or 17 returned in 2006 out of 58 birds ringed in 2005) (Daisuke Ochi unpublished data), which is comparable to the return rate of geolocator birds (36.4% or 4 out of 11 birds). The reason for the low return rates would be that some birds could not be recaptured possibly because they changed their nests to other burrows in the following year (Daisuke Ochi personal communication).

Of the four geolocators retrieved, data were download successfully only from two loggers due to problems of water incursion. The two loggers from Bird A (male) and B (female) provided light, immersion and water temperature data for 290 and 94 days respectively (Figs. 2–4.). Data for Bird A were full records until the recapture in August 2005, whereas those for Bird B were partial records until the logger failed in early January 2005 probably due to water incursion. Bird positions could not be determined from light data during the equinox periods, for 1–20 October 2004 (autumnal equinox) and 22 February-3 April 2005 (vernal equinox) for Bird A, and 1–15 October 2004 (autumnal equinox) for Bird B (Fig. 4).

Bird A remained within the seas off Japan between 25°N and 40°N between October and December 2004 (Figs. 2, 4). Then, the bird moved south from 33°N to 5°N during a 6-day period (28 December–2 January), when the sharp rise in water temperature from 16.7 to 29.0°C was recorded (Fig. 4). From early January to late February, the bird stayed around the sea off northern New Guinea, around the area of 2°S–8°N, 139–143°E, about 3400 km away from Mikura Island, their breeding colony in Japan. Although bird positions could not be obtained subsequently from late February to early April due to the vernal equinox, water temperature showed a sharp decrease from 28.6 to 16.6°C (Fig. 4) during a 10-day period (26 February–8 March), suggesting northward migration. During April–July, bird A remained within the seas off Japan between 27°N and 41°N (Fig. 4). From the immersion records, the bird spent 77±17 (SD) % of time on water daily during the winter months (De-

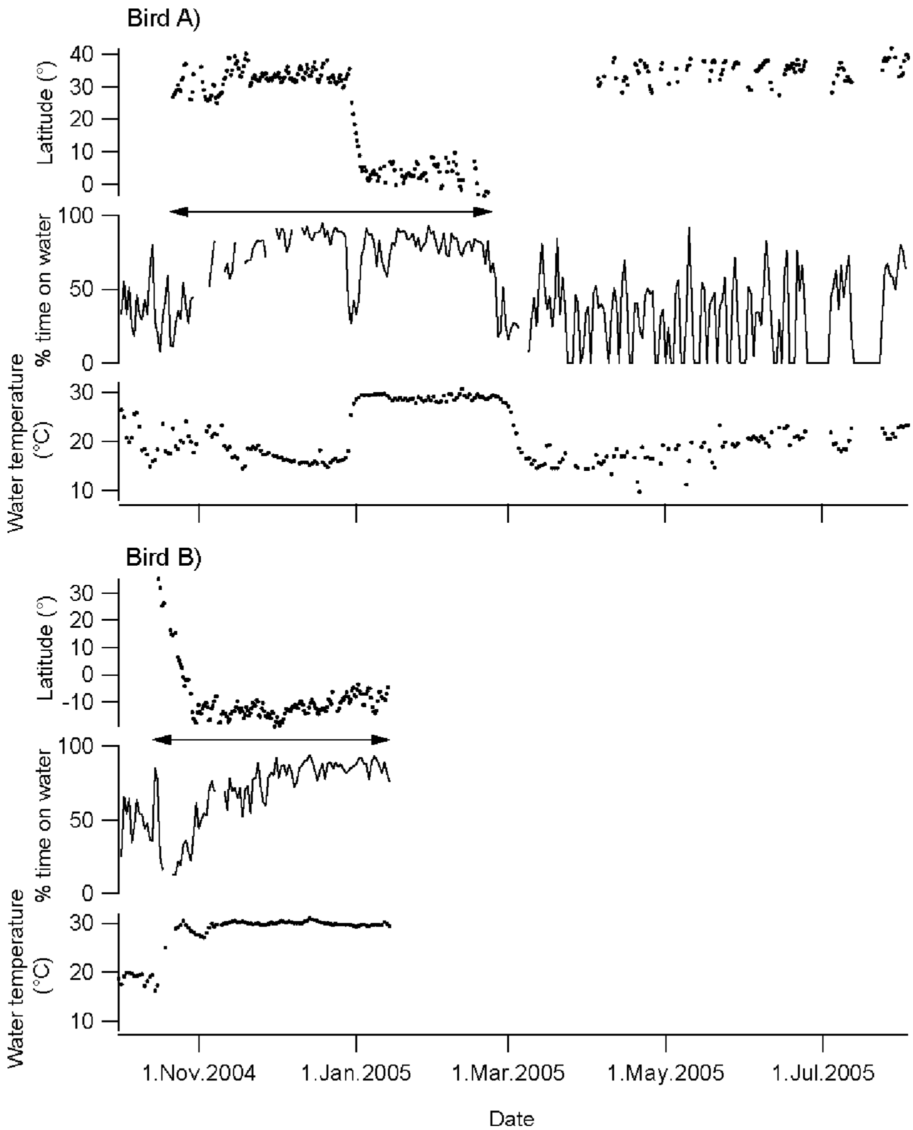


**Fig. 4.** Seasonal changes in latitudinal positions, percent time on water (per day) and water temperature recorded by a logger mounted on the leg of two Streaked Shearwaters (Bird A and B). The arrows indicate the periods where the data on the wintering movements (Figs. 2, 3) were shown. Increases in water temperature were associated with southern movements of the birds (28 Dec. to 2 Jan. for Bird A; 16–24 Oct. for Bird B). Bird positions could not be determined from light data during 22 February–3 April 2005 (vernal equinox period) for Bird A (see Methods).

cember–February), which is relatively high compared to 29±26 (SD) % after April (Fig. 4). The immersion and light data suggested that the bird was continuously in the nest burrow for 9 days (25 June–3 July 2005) and 11 days (13–23 July 2005), probably for two incubation shifts.

Bird B moved south from 35°N to 13°S during a 14-day period (16–29 October) (Figs. 3, 4), passed through the Arafura Sea then to the Gulf of Carpentaria, Australia. Water temperature gradually increased from 17.3 to 28.4°C during this period (Fig. 4). Thereafter, the bird stayed in the Gulf of Carpentaria, around the area of 8–15°S, 137–141°E, approximately 5200 km away from Mikura Island, until the end of the period when data were recorded on 13 January. During the winter months (December–January), the bird spent 85±5 (SD) % of the time on the water.

## DISCUSSION

Although the sample size is limited and thus these initial results have to be confirmed by future studies, the present study revealed some new aspects to the migratory and wintering behavior of Streaked Shearwaters breeding in Japan. This included new information on the timing and route of southern migration, and wintering areas.

The two tracked Streaked Shearwaters moved from the seas off Japan to tropical waters, but with different timing of the southern migration: one migrated in late October (Bird B: female) and the other in late December (Bird A: male) (Fig. 4). Although we do not have data on the timing of breeding for our study birds, Bird A appeared to stay around Japan at least for a month after breeding. This is because 1) it showed a relatively high proportion of time spent on water during December, though apparently there were no regular visits back to the colony, and 2) a previous study on Mikura Island showed that parents cease chick provisioning by 7 November (range=29 October–22 November) (Oka et al. 2002). This suggests that at least some breeding adults may stay around the seas off Japan after their breeding season, though the factors affecting timing of southern migration is uncertain.

Recent studies on post-breeding migration of Sooty Shearwaters *Puffinus griseus* (Shaffer et al. 2006) and Cory's Shearwaters *Calonectis diomedea* (González-Solís et al. 2007) suggested that the migration route of the birds may be associated with global wind circulation patterns over the Pacific and Atlantic Oceans, respectively. During migration, the heading of our Streaked Shearwaters was south or south-southwesterly. Generally, northerly or northeasterly winds blow in this region of the north-western Pacific during winter (Spear & Ainley 1999; Liechti 2006), thus we hypothesize that the birds might be able to use northerly tail winds during their southern migration.

The two tracked birds utilized the seas north of New Guinea or the Gulf of Carpentaria during the winter months (Figs. 2, 3), which is consistent with previous ship-based surveys reporting relatively large flocks of Streaked Shearwaters in both areas (Marchant & Higgins 1990; Blaber & Milton 1994). The relatively high proportion of time spent at the sea surface during winter months (Fig. 4) suggests that both birds did not need to fly for long periods to search for new prey patches, thus possibly they stayed in favorable areas for foraging. The Gulf of Carpentaria is a shallow (<70 m) continental shelf known to have high primary productivity due to the supply of nutrients from land drainage (Motoda et al. 1978), which may provide suitable foraging habitat for shearwaters. In contrast, the seas north of New Guinea lie within the 'Western Pacific Warm Pool' biome, which is characterized by very low chlorophyll concentrations (Longhurst 1998). However, this region supports the highest fishery catches of Skipjack and other tuna in the Pacific Ocean (Lehodey et al. 1997), an enigma difficult to explain (Longhurst 1998). In tropical seas, surface-feeding seabirds, including shearwaters, often accompany subsurface feeders such as tunas and dolphins (Au & Pitman 1988). We hypothesize that feeding association with tuna may be a possible explanation for the distribution of Streaked Shearwaters north of New Guinea.

The western equatorial Pacific region, where Streaked Shearwaters winter, is currently experiencing substantial changes in the marine environment due to atmospheric forcing (Lehodey et al. 1997; Sugimoto et al. 2001) and/or fisheries impacts (Harris & Poiner 1991; Evans & Wahju 1996). The two tracked birds did not move between local wintering areas, rather they stayed in one area (north of New Guinea or the Gulf of Carpentaria) for relatively long periods (Figs. 2, 3), suggesting their susceptibility to local conditions. If individual shearwaters utilize certain wintering areas repeatedly over years as in found in some albatross species (Weimerskirch & Wilson 1990; Phillips et al. 2005), then the effects of environmental changes in local wintering area on birds may be important. Further studies on inter-annual and individual variations in migration and wintering behavior would be required to assess how environmental changes in southern wintering area affect Streaked Shearwater populations in Japan via migratory connectivity (Webster et al. 2002).

## ACKNOWLEDGMENTS

The authors wish to acknowledge use of the Maptool program for analysis and graphics in this paper. Maptool is a product of SEATURTLE.ORG. (Information is available at www.seaturtle.org). The work was supported in part by Grant-in-Aid from Transdisciplinary Research Integration Center, Research Organization of Information and Systems (No. A9930), COE program (Neo-Science of Natural History, led by H Okada) and JSPS research grant (19651100).

## REFERENCES

Afanasyev V (2004) A miniature daylight level and activity data recorder for tracking animals over long periods. Mem Natl Inst Polar Res 58: 227–233.

Arima H & Sugawa H (2004) Kanmurijima de hansyoku suru oomizunagidori no nakigoe to taisaizu ni okeru soukansei (Correlation between the pitch of calls and external measurements of Streaked Shearwaters *Calonectris leucomelas* breeding on Kanmuri Island). Jpn J Ornithol 53: 40–44 (in Japanese with English abstract).

Au DW & Pitman RL (1988) Seabird relationship with tropical tunas and dolphins. In: Burger J (ed) *Seabirds and Other Marine Vertebrates: Competition, Predation and Other Interactions*. pp 174–212. Columbia University Press, New York.

Blaber SJM & Milton DA (1994) Distribution of seabirds at sea in the Gulf of Carpentaria, Australia. Aust J Mar Freshwater Res 45: 445–454.

Coyne MS & Godley BJ (2005) Satellite tracking and analysis tool (STAT): an integrated system for archiving, analyzing and mapping animal tracking data. Mar Ecol Prog Ser 301: 1–7.

Croxall JP, Silk JRD, Phillips RA, Afanasyev V & Briggs DR (2005) Global circumnavigations: year-round ranges of nonbreeding albatrosses. Science 307: 249–250.

Evans SM & Wahju RI (1996) The shrimp fishery of the Arafura Sea (eastern Indonesia). Fish Res 26: 365–371.

Furness RW, Crane JE, Bearhop S, Garthe S, Käkelä A, Käkelä R, Kelly A, Kubetzki U, Votier S & Waldron S (2006) Techniques to link individual migration patterns of seabirds with diet specialization, condition and breeding performance. Ardea 94: 631–638.

González-Solís J, Croxall JP & Ruiz X (2007) Transequatorial migration and mixing in the wintering areas in a pelagic seabird. Fontier Ecol Environ 5: 297–301.

Harris AN & Poiner IR (1991) Changes in species composition of demersal fish fauna of Southeast Gulf of Carpentaria, Australia, after 20 years of fishing. Mar Biol 111: 503–519.

Harris MP, Anker-Nilssen T, McCleery RH, Erikstad KE, Shaw DN & Grosbois V (2005) Effect of wintering area and climate on the survival of adult Atlantic Puffins *Fratercula arctica* in the eastern Atlantic. Mar Ecol Prog Ser 297: 283–296.

Hill RD (1994) Theory of geolocation by light levels. In: Le Boeuf BJ & Laws RM (eds) *Elephant Seals: Popuation Ecology, Behavior and Physiology*. pp 227–236. University of California Press, Berkley.

Lee KG & Yoo JC (2004) Variation in chick provisioning of Streaked Shearwaters (*Calonectris leucomelas*) during the early nestling stage. J Yamashina Inst Ornithol 35: 105–119.

Lehodey P, Bertignac M, Hampton J, Lewis A & Picaut J (1997) El Niño Southern Oscillation and tuna in the western Pacific. Nature 389: 715–718.

Liechti F (2006) Birds: blowin' by the wind? J Ornithol 147: 202–211.

Longhurst A (1998) *Ecological Geography of the Sea*. Academic Press, San Diego.

Marchant S & Higgins PJ (1990) *Handbook of Australian, New Zealand and Antarctic Birds*. Oxford University Press, Melbourne.

Motoda S, Kawamura T & Taniguchi A (1978) Differences in productivities between the Great Australian Bight and the Gulf of Carpentaria, Australia, in summer. Mar Biol 46: 93–99.

Oka N (2004) Ohmizunagidori no hansyokutou to hansyokukotaisuukibo oyobi kaiiki, hyoumen suion tono kankei (The distribution of Streaked Shearwater colonies, with special attention to population size, area of sea where located and surface water temperature). J Yamashina Inst Ornithol 35: 164–188. (In Japanese with English abstract)

Oka N, Suginome H, Jida N & Maruyama N (2002) Chick growth and fledging performance of Streaked Shearwaters *Calonectris leucomelas* on Mikura Island for two breeding seasons. J Yamashina Inst Ornithol 34: 39–59.

Phillips RA, Silk JRD, Croxall JP & Afanasyev V (2006) Year-round distribution of white-chinned petrels from South Georgia: relationships with oceanography and fisheries. Biol Conserv 129: 336–347.

Phillips RA, Silk JRD, Croxall JP, Afanasyev V & Bennett VJ (2005) Summer distribution and migration of non-breeding albatrosses: individual consistencies and implications for conservation. Ecology 86: 2386–2396.

Phillips RA, Silk JRD, Croxall JP, Afanasyev V & Briggs DR (2004) Accuracy of geolocation estimates for flying seabirds. Mar Ecol Prog Ser 266: 265–272.

Phillips RA, Xavier J & Croxall JP (2003) Effect of satellite transmitters on albatrosses and petrels. Auk 120: 1082–1090.

Shaffer SA, Tremblay Y, Awkerman JA, Henry WR, Teo SLH, Anderson DJ, Croll DA, Block BA & Costa DP (2005) Comparison of light- and SST-based geolocation with satellite telemetry in free-ranging albatrosses. Mar Biol 147: 833–843.

Shaffer SA, Tremblay Y, Weimerskirch H, Scott D, Thompson DR, Sagar PM, Moller H, Taylor GA, Foley DG, Block BA & Costa DP (2006) Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. Proc Natl Acad Sci USA 103: 1279–12802.

Shealer DA (2002) Foraging behavior and food of seabirds. In: Schreiber EA & Burger J (eds) *Biology*

*of marine birds*. pp 137–177. CRC Press, Florida.
Spear LB & Ainley DG (1999) Migration routes of sooty shearwaters in the Pacific Ocean. Condor 101: 205–218.
Sugimoto T, Kimura S & Tadokoro K (2001) Impact of El Niño events and climate regime shift on living resources in the western North Pacific. Prog Oceanogr 49: 113–127.
Webster MS, Marra PP, Haig SM, Bensch S & Holmes RT (2002) Links between worlds: unraveling migratory connectivity. Trends Ecol Evol 17: 76–83.
Weimerskirch H & Wilson RP (2000) Oceanic respite for wandering albatrosses. Nature 406: 955–956.
Wilson RP, Ducamp JJ, Rees G, Culik BM & Niekamp K (1992) Estimation of location: global coverage using light intensity. In: Priede IM & Swift SM (eds) *Wildlife Telemetry: Remote Monitoring and Tracking of Animals*. pp 131–134. Ellis Horward, Chichester.
Yoshida N (1962) Maizurushi Kanmurijima ni okeru ohmizunagidori no seitai (Breeding ecology of the streaked shearwater at Kanmurijima I., Maizuru in Kyoto). Tori 17: 83–108. (In Japanese with English abstract)
Yoshida N (1981) *Ki ni noboru umidori–Kityo ohmizunagidori* (Climbing the trees–streaked shearwaters with interesting behavior). Chobun sya Co. Ltd., Tokyo. (In Japanese)