Proc. NIPR Symp. Polar Biol., 1, 166–174, 1987

CHICK GROWTH AND MORTALITY OF SHORT-TAILED SHEARWATERS IN COMPARISON WITH SOOTY SHEARWATERS, AS A POSSIBLE INDEX OF FLUCTUATIONS OF AUSTRALIAN KRILL ABUNDANCE

Nariko OKA[1], Naoki MARUYAMA[2] and Irynej SKIRA[3]

[1]*Yamashina Institute for Ornithology, Konoyama, Abiko 270–11*
[2]*Department of Environmental Science and Conservation, Faculty of Agriculture, Tokyo Noko University, 5–8, Saiwaicho 3-chome, Fuchu-shi, Tokyo 183*
[3]*Department of Lands, Parks and Wildlife, Hobart, Tasmania, Australia*

Abstract: A semi-lunar rhythm appeared to be in the chick weight-growth curve of the Short-tailed Shearwaters (*Puffinus tenuirostris*) and exactly found in feeding of the Sooty Shearwaters (*Puffinus griseus*) to their chicks before desertion by parents. These rhythms may be caused by periodicity in the availability of the krill, especially Australian krill (*Nyctiphanes australis*), the main food for chicks of both shearwaters. Comparing the chick growths in Tasmania with their mortality occurrences in Japan in over a four year study of the Short-tailed Shearwaters, the best growth year of 1980 corresponded to a low mortality year, while a poor growth year of 1984 was situated at the peak of a mass mortality period of 1983–1985 in Japan. In the worst growth year of 1986, the mass mortality did not occur along Japan but Australia and the island of Guam. Therefore, the growth of chicks at the breeding site in Tasmania and mortality occurrences in Japan, Australia and Guam have a mutual relation, and they could be governed by the annual fluctuations in abundance of krill in Australian regions.

1. Introduction

Short-tailed Shearwaters (*Puffinus tenuirostris*), estimated to number 23 million birds (I. SKIRA, unpublished), are trans-equatorial migrants; they breed in southeastern Australian and Tasmanian waters, and migrate to the northern North Pacific to 45°–70° latitudes for wintering. On the migration to the wintering waters in the North Pacific, a great number of hatching year birds occasionally die from exhaustion along the Pacific coast of Japan. This mass mortality occurred at about ten year intervals and, when it occurred, lasted for at least 1–3 years (OKA and MARUYAMA, 1986).

They are pursuit-plungers; their bills are developed especially for retaining concentrations of krill as a plankton-net (MORGAN and RITZ, 1982). At the breeding sites, their main diet is Australian krill (*Nyctiphanes australis*) (SKIRA, 1986), which usually occupies more than 80 percent of their stomach volume. This krill is a predominant species among the coastal krill in southeastern Australia and New Zealand (SHEARD, 1953; BARY, 1956; BLACKBURN, 1980).

The Sooty Shearwaters *Puffinus griseus*, the close relative of the Short-tailed

Shearwaters, breed in New Zealand and southeastern Australia (also southern South America) and may feed on the same krill around the western South Pacific breeding sites.

In this paper we analyze chick growth in the Short-tailed Shearwaters and feeding activity to chicks in the Sooty Shearwaters, the occurrence of their mass mortality along the Japanese coast, and how these may be related to the abundance of their main food, the Australian krill, in the waters around the breeding sites.

2. Rhythmicity in Feeding and Growth of Short-tailed and Sooty Shearwater Chicks

The chicks of the Short-tailed and Sooty Shearwaters were known to be starved for a few weeks ("desertion period") at natal sites after departure of their parents to the North Pacific from early to mid-April (SERVENTY, 1967; WARHAM *et al.*, 1982).

In the changes in body weight of Short-tailed Shearwater chicks obtained at ten colonies in Tasmania during the 1985 breeding season (OKA *et al.*, 1986), fluctuations are evident from late February to early April (desertion point), when most of the adults cease feeding their chicks (Fig. 1). Periodicity of these fluctuations was visually about 15 days and suggested a link to a semilunar rhythm. Full and new moons were located between peaks of these waves.

The body weights of chicks on the days when not weighed were estimated from those actual body weights on the nearest weighing days. Using these actual and

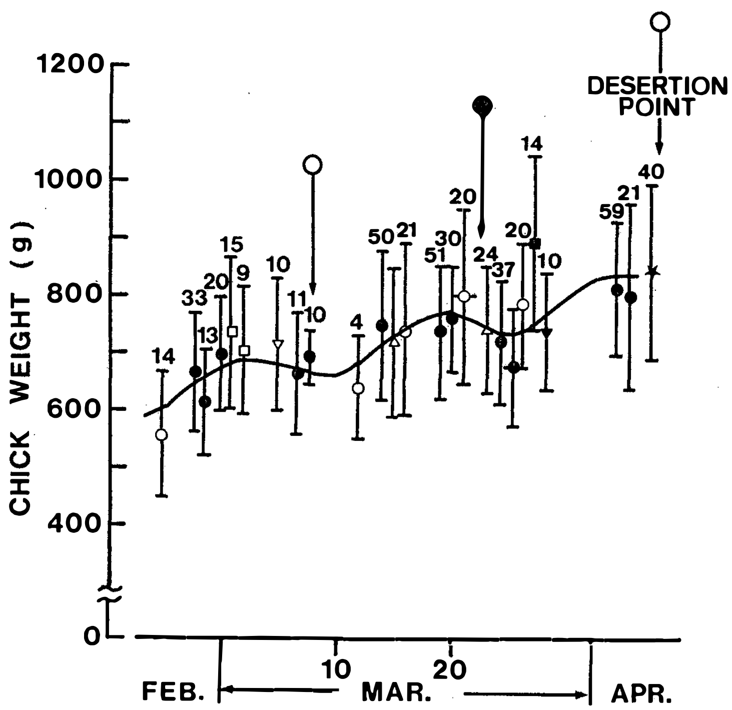

Fig. 1. Body weight growth of Short-tailed Shearwater chicks at various colonies in Tasmania in 1985. The trend line was drawn using running means. The large open and solid circles represent dates of full and new noons, respectively. Small symbols indicate the mean weight of different colonies with the sample size written above.

estimated values, a correlogram analysis was then made. However, we could not find any stable periodicity but only accidental ones. This may have been because of various interfering factors; different chicks were measured intermittently (not every day) at geographically remote colonies exposed to different weather and water conditions, and food abundance, etc.

RICHDALE (1945) measured the body weights of eight Sooty Shearwater chicks at one colony in New Zealand. Using his daily weighing data in changes of the food amounts in fresh weight fed to them, we obtained 13.3 days (12.8–14.2 days) of stable periodicity by correlogram analysis (Fig. 2-1). Full and new moons were located between peaks of these waves as were seen in the Short-tailed Shearwaters. RICHDALE

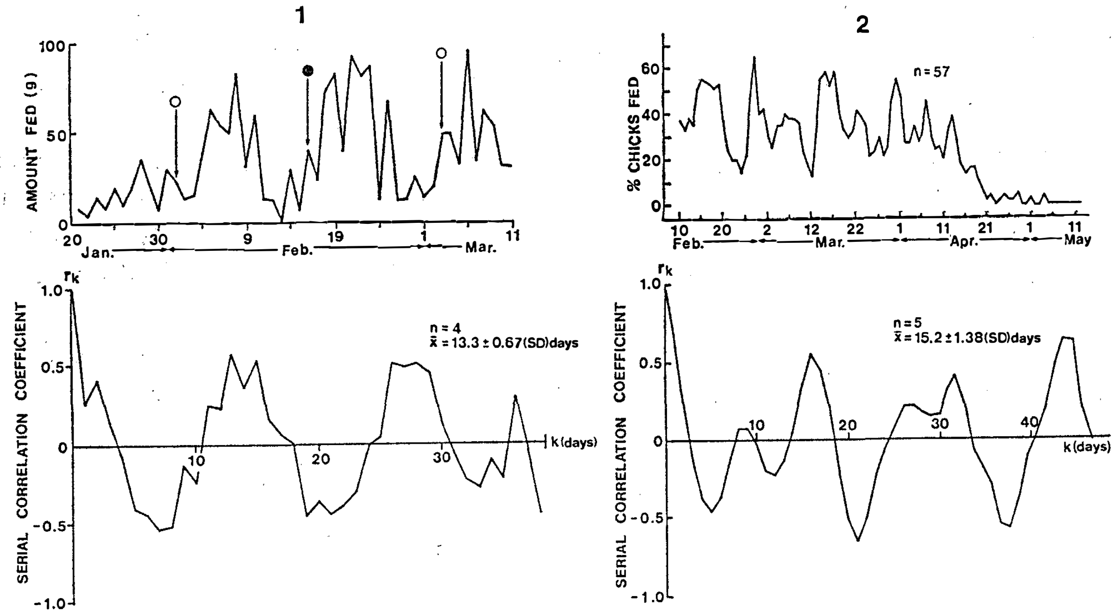

Fig. 2. *(1) Food amounts fed to 8 Sooty Shearwater chicks at Snares Island in New Zealand in 1944 (after RICHDALE, 1945) and its correlogram calculated by us. See Fig. 1 for open and solid circles.* x̄ *shows the average periodicity estimated,* r_k *shows serial correlation coefficients and* k *shows days. (2) Percent age of the chicks fed among the 57 chicks of Sooty Shearwaters at Snares Island in New Zealand in 1953 (after RICHDALE, 1954) and its correlogram during the period between 10 February and 5 April (desertion point), calculated by us.*

(1954) also shows the daily changes in the percentage of Sooty Shearwater chicks (n=57) fed at a colony in New Zealand in 1953 (Fig. 2-2). Since the chicks of this species have a long desertion period after mid-April, we made the correlogram up to the desertion point. Its periodicity was 15.2 days (13.0–16.6 days) (Fig. 2-2), showing a semilunar rhythm. RICHDALE (1954) found no correlation between weather and the percentage of parents returning to the colony, and no adequate explanation for this pattern was proposed.

Semilunar cycles in the chick growth curve and in the feeding activity of the chicks by the parents of these two shearwater species seemingly reflect a similar semilunar cycle of the Australian krill availability. Diving birds probably capture swarming krill near the sea surface (BROWN *et al.*, 1979). SKIRA (1979) described the Short-tailed

Shearwaters diving to about 12 m below the sea surface. This krill is most abundant in the upper surface layer 30 m in depth at night from October to June and aggregations reach densities of 200 inds$\cdot$m^{-3} (BLACKBURN, 1980). Some euphausiid species are known to surface-swarm even in daytime and their densities occasionally reach up to 1500000 inds$\cdot$m^{-3} in *Euphausia lucens* (NICOL *et al.*, 1987), 600000 inds$\cdot$m^{-3} in *Thysanoessa longicaudata* (FORSYTH and JONES, 1966), 30000 inds$\cdot$m^{-3} in *Euphausia krohnii* (BAKER, 1970) and 72 inds$\cdot l^{-1}$ in *Euphausia pacifica* (HANAMURA *et al.*, 1984). The Australian krill are also known to swarm at a density of 10000 inds$\cdot$m^{-2} at certain times of the year (O'BRIEN *et al.*, 1986).

BROWN *et al.* (1979) described that spring tides help the euphausiid *Meganyctiphanes norvegica* to swarm and their swarming did not occur during neap tide. This suggests the existence of their semilunar abundance in the surface water.

The semilunar cyclic rhythms in chick growth and feeding or food availability shown in these shearwaters seem to be peculiar to krill feeders and were not found in the fish-feeding shearwaters such as the Streaked Shearwaters (*Calonectris leucomelas*) (JIDA, 1987). However, to explore further the relationship between krill movements and shearwater feeding behavior, much more ecological information is required on the shearwaters feeding areas for chicks as well as for themselves, chick daily growth and the Australian krill, especially on their vertical movements related to lunar rhythm.

3. Mass Mortality and Chick Growth in Short-tailed Shearwaters

For many years it was believed that the Short-tailed Shearwaters migrated along a vast figure-of-eight trans-equatorial circuit of the Pacific. However, SHUNTOV (1972) proposed another theory that in northward migration most of the birds flew in temperate waters in a broad area between Japan and the Hawaiian Islands. In particular heavy concentrations of the shearwaters on their through flights can be observed between Honshu, mainland of Japan, and 160°E as the birds approach the Japanese shores from southern directions. GUZMAN (1981) had the same opinion as SHUNTOV (1972) and supposed the heavy concentrations approaching Japan to be hatching year birds.

Recently, we carried out eleven trans-North Pacific surveys to clarify their migration route. More than 99 percent of the birds found dead along the Japanese coast were hatching year birds. They were extremely emaciated due to complete exhaustion of body lipids (OKA and MARUYAMA, 1985, 1986). It is likely that the Short-tailed Shearwaters achieve their migration using the energy stored at the breeding places, as do the Manx Shearwaters (*Puffinus puffinus*) (PERRINS *et al.*, 1973). Therefore, migratory success in the Short-tailed Shearwaters must be determined before migration. The number of hatching year birds beach-washed along the Japanese coast varies among years (Fig. 3). In years of low mortality, about ten birds per km were recorded in late May and June (OKA *et al.*, 1985). However, mass mortalities far beyond the usual level occurred in wide range in 1964 (OZAWA, 1964; KAWAGUCHI and MARUMO, 1964; KURODA, 1967), in 1973–1975 (SUGIMORI *et al.*, 1976; TOYOHASHI WILD BIRD CLUB, 1973–1976, 1978) and recently in 1983–1985 (OKA and MARUYAMA, 1986). The number of dead birds was about 80/km in 1974 and 1975, but about 40/

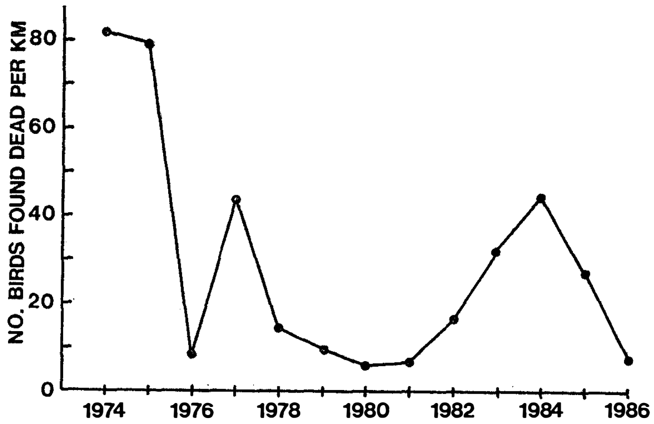

Fig. 3. *Numbers of dead Short-tailed Shearwaters found along Kujukuri-Beach, Central Honshu, Japan, 1974 to 1986 (data of 1974–1982 by* OKA *et al., 1985; 1983–1985 by* OKA *and* MARUYAMA, *1986; 1986 by* OKA *and* MARUYAMA, *unpublished). The occurrence of the mass mortality in 1977 was localized in the study area caused by the storm (*OKA *et al., 1986) and the mass mortality in 1974, 1975, 1983, 1984, 1985 occurred for several hundred to a thousand kms along the coast.*

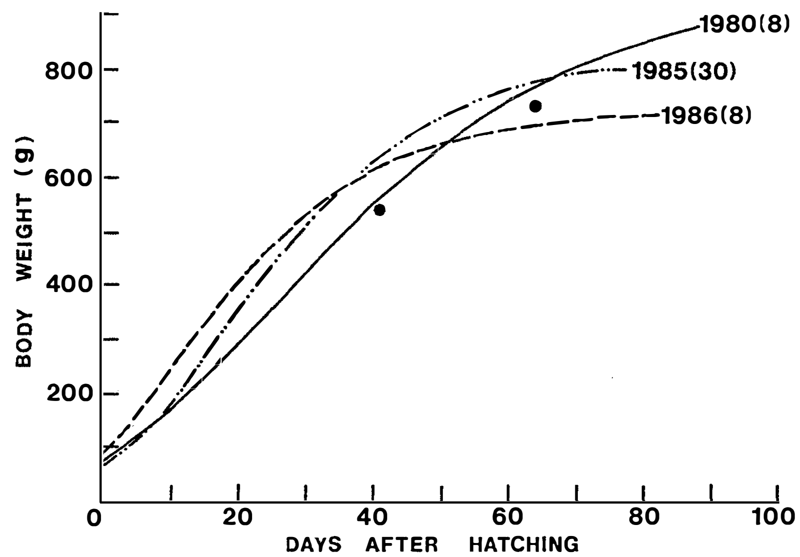

Fig. 4. *Regression growth curves in body weight for Short-tailed Shearwater chicks in 1980, 1985 and 1986 fitted by the von Bartalanffy equation. The number in parentheses shows the weighing frequency. Solid circles show weight values for 1984. Regression equations and the mean squared sums of deviations (MSD) of each year are as follows. An average chick weight of 57 g at hatching in 1985 was treated as a constant for these regression calculations.*

1980: $y=958.2(1-0.732e^{-0.0308t})^3+57.0$

$MSD=1591.1$

1985: $y=784.1(1-0.763e^{-0.0504t})^3+57.0$

$MSD=4965.7$

1986: $y=667.0(1-0.636e^{-0.0593t})^3+57.0$

$MSD=3777.5$

Data were cited from NAARDING, *1980;* LILL *and* BALDWIN, *1983;* OKA *and* MARUYAMA, *1985;* OKA *et al., 1986.*

km in 1984. Those in 1983 and 1985 were very low, 30 and 25/km, respectively. Mass mortalities seem to occur at intervals of 10 years, and once they occur, they may continue at least for 1 to 3 years (OKA and MARUYAMA, 1986). SERVENTY (1967) reported the same interval in occurrences of mass mortality in southeastern Australian waters.

Chick growth curves in weight between hatching and desertion points from three breeding seasons, 1980, 1985 and 1986 (NAARDING, 1980; LILL and BALDWIN, 1983; OKA and MARUYAMA, 1985; OKA *et al.*, 1986), most closely fitted von Bertalanffy equation of the three regression formulae; logistic, Gomperz and von Bertalanffy. An average chick weight of 57 g at hatching in 1985 was used as a constant for the regression calculations. The three year von Bertalanffy regression curves for chick body weight are shown in Fig. 4. Two values from 1984 are also shown and compared with curves of other years. The body weight reached its maximum at the desertion point.

The south Tasmanian chicks in mid-April, 1980, showed an excellent growth, probably affected by the greatest attentiveness of their parents at the later feeding stage (Fig. 4). This best chick growth of 1980 coincided with a low mortality along the Japanese coast, and an intermediate growth in Tasmania and a moderate mass-mortality in Japan were found in 1985. Although chicks were weighed only twice before desertion point in 1984, these values were low and showed a poor chick growth. This was also supported by the information from mutton-birders in the Bass Strait. The poor growth of chicks in 1984 corresponded to the occurrence of big mass-mortality in Japan. In 1986 when the chick growth in Tasmania was extremely poor, mass mortality occurred along the coast of Guam, in the tropical waters far south of Japan (WILES, pers. commun.), as well as along the east coast of Australia and failed fledgelings unable to fly were found on many colonies even in late May (NAARDING, pers. commun.).

Therefore, we find links between the mass mortalities in Japan or in the southern waters on their migration and the growth of chicks in Tasmania, and between the chick growth and the fluctuations of the Australian krill abundance. No mass mortality of the Sooty Shearwaters, however, has been found along the Japanese coasts except in a few localized areas (SUGIMORI *et al.*, 1976; OKA *et al.*, 1985), although they probably take the same krill around the breeding sites in New Zealand and southeastern Australia. It is because the Sooty Shearwaters have developed a better adaptation to diving than the Short-tailed Shearwaters (KURODA, 1954), and they are more efficient in capturing krill, squid and fish than Short-tailed Shearwaters. In the northern North Pacific, they mainly take fish rather than krill (CHU, 1984; OGI, 1984). Their population is thus likely to remain more stable, compared to the Short-tailed Shearwaters, which depend mainly on krill populations which are situated at lower trophic levels than small fish. In addition, their wintering area is located more south (40°–50°N) than that of the Short-tailed Shearwaters (45°–70°N). The combination of these factors may help them to complete their migration and to capture food more easily than the Short-tailed Shearwaters. However, if they should meet an extreme shortage of krill in their breeding waters, mass mortality will also occur amongst them. In 1942, a mass mortality of the Short-tailed Shearwaters and poor growth of the Sooty Shearwater chicks were recorded in southeastern Australia, Tasmania and New Zealand (RICHDALE, 1945; SERVENTY, 1967).

4. Conclusion

The Australian krill is an important food source for chicks of Short-tailed Shearwaters and probably for the Sooty Shearwaters. Accordingly, semilunar cyclic rhythms of the growth curve for both shearwater chicks and chick-feeding by the parent Sooty Shearwaters possibly reflect the availability of the krill and its ecological movement may be synchronized with the semilunar cycle. Fluctuations in krill abundance probably affect chick growth in both shearwaters and may cause mass mortalities in the Short-tailed Shearwaters every ten years or so. Thus, chick growth in both shearwaters may be a biometer for fluctuations of the Australian krill population. The dead bird count along the coast for the Short-tailed Shearwaters in Japan may be a remote bio-censor of the annual abundance of krill populations at least in Australian waters. However, more ecological studies are required, especially on krill populations if those biometers are put to practical use, because we have only limited information on them at present.

Acknowledgments

We would like to thank Dr. ENDO, Far Seas Fisheries Research Laboratory of Ministry of Agriculture, Forestry and Fisheries of Japan, for giving us valuable advice on krill. We also thank Mr. ICHII of the above for sending us literature on krill. We are grateful to Mr. JIDA, Faculty of Agriculture, Tokyo Noko University for his help in the systematic analysis. We are indebted to Toyota Foundation for its financial sponsorship of this study.

References

BAKER, A. DE C. (1970): The vertical distribution of euphausiids near Fuerteventura, Canary Islands. J. Mar. Biol. Assoc. U. K., **50**, 301–342.

BARY, B. M. (1956): Notes on ecology, systematics, and development of some Mysidacea and Euphausiacea (Crustacea) from New Zealand. Pacific Sci., **10**, 431–467.

BLACKBURN, M. (1980): Observations on the distribution of *Nyctiphanes australis* Sar (Crustacea, Euphausiidae) in Australian waters. Div. Fish. Oceanogr. Rep., **119**, 1–10.

BROWN, R. G. B., BARKER, S. P. and GASKIN, D. E. (1979): Daytime surface swarming by *Megacyctiphanes novegica* (M. Sars) (Crustacea, Euphausiacea) off Brier Island, Bay of Fundy. Can. J. Zool., **57**, 2285–2291.

CHU, E. W. (1984): Sooty Shearwaters off California; Diet and energy gain. Marine Birds; Their Feeding Ecology and Commercial Fisheries Relationships, ed. by D. N. NETTLESHIP *et al.* Ottawa, Minister of Supply and Services Canada, 78–85.

FORSYTH, D.C.T. and JONES, L.T. (1966): Swarming of *Thysanoessa longicaudata* (Kroyer) (Crustacea, Euphausiacea) in the Shetland Islands. Nature, **212**, 1467–1468.

GUZMAN, J. R. (1981): The wintering of sooty and short-tailed shearwater (genus *Puffinus*) in the North Pacific. Ph. D. thesis, Alberta, Univ. Calgary.

HANAMURA, Y., ENDO, Y. and TANIGUCHI, A. (1984): Underwater observations on the surface swarm of a euphausiid, *Euphausia pacifica* in Sendai Bay, Northeastern Japan. La Mer, **22**, 63–68.

JIDA, N. (1987): Breeding biology of streaked shearwater, *Calonectris leucomelas* on Mikura Island in Japan. M. thesis, Tokyo, Tokyo Noko University.

KAWAGUCHI, K. and MARUMO, R. (1964): Suruga Wan ni okeru hashibosomizunagidori no tairyôshi ni tsuite (Mass mortality of slender-billed shearwater *Puffinus tenuirostris*, in Suruga Bay). Yamashina Chôrui Kenkyûjo Kenkyû Hôkoku (Misc. Rep. Yamashina Inst. Ornithol.), **4**, 106–113.

KURODA, N. (1954): On the classification and phylogeny of the Order Tubinares, particularly the shearwaters (*Puffinus*), with special considerations on their osteology and habit differentiation (Aves). Published by the author. Tokyo, 179.

KURODA, N. (1967): Miyazaki-ken no hashibosomizunagidori no tairyôshi oyobi kôsatsu (A note on the mass mortality of *Puffinus tenuirostris* in Miyazaki, Kyushu). Tori (Bull. Ornithol. Soc. Jpn.), **18**, 198–199.

LILL, A. and BALDWIN, J. (1983): Weight changes and the mode of depot fat accumulation in migratory short-tailed shearwaters. Aust. J. Zool., **31**, 891–902.

MORGAN, W. L. and RITZ, D. A. (1982): Comparison of the feeding apparatus in the muttonbird, *Puffinus tenuirostris* (Temminck), and the fairy prion, *Pachyptila turtur* (Kuhl) in relation to the capture of the krill, *Nyctiphanes australis*, Sars. J. Exp. Mar. Biol. Ecol., **59**, 61–75.

NAARDING, J. A. (1980): Study of the Short-tailed Shearwater, *Puffinus tenuirostris*, in Tasmania. Nat. Parks Wildl. Serv. Tas., 78 p.

NICOL, S., JAMES, A. and PITCHER, G. (1987): A first record of daytime surface swarming by *Euphausia lucens* in the Southern Benguela region. Mar. Biol., **94**, 7–10.

O'BRIEN, D. P., RITZ, D. A. and KIRKWOOD, R. J. (1986): Stranding and matting behaviour in *Nyctiphanes australis* (Euphausiidae: Crustacea). Mar. Biol., **93**, 465–473.

OGI, H. (1984): Feeding ecology of the Sooty Shearwater in the western subarctic North Pacific Ocean. Marine Birds; Their Feeding Ecology and Commercial Fisheries Relationships, ed. by D. N. NETTLESHIP *et al.* Ottawa, Minister of Supply and Services Canada, 78–85.

OKA, N. and MARUYAMA, N. (1985): Visual evaluation of tibiotarsus and femur marrows as a method of estimating nutritive conditions of short-tailed shearwaters. Yamashina Chôrui Kenkyûjo Kenkyû Hôkoku (J. Yamashina Inst. Ornithol.), **17**, 57–65.

OKA, N. and MARUYAMA, N. (1986): Mass mortality of short-tailed shearwaters along the Japanese Coast. Tori (Bull. Ornithol. Soc. Jpn.), **34**, 97–104.

OKA, N., SUGIMORI, F. and ISHIBASHI, Y. (1985): Mortality counts of short-tailed shearwater *Puffinus tenuirostris* at Shiinauchihama of Kujukuri-beach, 1976–1982. Yamashina Chôrui Kenkyûjo Kenkyû Hôkoku (J. Yamashina Inst. Ornithol.), **17**, 113–117.

OKA, N., MARUYAMA, N., JIDA, N. and KURODA, N. (1986): Hashibosomizunagidori no hina no seichô patân (Growth of short-tailed shearwater chicks in Tasmania). Hashibosomizunagidori *Puffinus tenuirostris* no Tairyôhenshi ni kansuru Sôgôteki Kenkyû (Synthetic Study of the Mass-mortality of Short-tailed Shearwater *Puffinus tenuirostris*), Abiko, Study Group Short-tailed Shearwater, 13–25.

OZAWA, K. (1964): Tôkaidô okiai ni okeru hashibosomizunagidori no tairyôshi ni tsuite (Records and observations of unusual wreck of slender-billed shearwater on the Pacific coast of Japan, end of May, 1964). Yamashina Chôrui Kenkyûjo Hôkoku (Misc. Rep. Yamashina Inst. Ornithol.), **4**, 114–117.

PERRINS, C. M., HARRIS, M. P. and BRITTON, C. K. (1973): Survival of manx shearwaters *Puffinus puffinus*. Ibis, **115**, 535–548.

RICHDALE, L. E. (1945): The nestling of the sooty shearwater. Condor, **47**, 45–62.

RICHDALE, L. E. (1954): Duration of parental attentiveness in the sooty shearwater. Ibis, **96**, 586–600.

SERVENTY, D. L. (1967): Aspects of the population ecology of the short-tailed shearwater *Puffinus tenuirostris*. Proc. XIV I. O. C., ed. by D. W. SNOW. Oxford, Blackwell Sci. Publ., 165–190.

SHEARD, K. (1953): Taxonomy, distribution and development of the Euphausiacea (Crustacea). B. A. N. Z. A. R. E. Rep. Ser. B, **8**, 72 p.

SHUNTOV, V. P. (1972): Sea birds and biological structure of the ocean. Nat. Tech. Inf. Serv., U. S. Dept. Comm., **1974**, 74–92.

SKIRA, I. J. (1979): Underwater feeding by short-tailed shearwaters. Emu, **79**, 43.

SKIRA, I. J. (1986): Food of the short-tailed shearwater, *Puffinus tenuirostris*, in Tasmania. Aust. Wildl. Res., **13**, 481–488.

SUGIMORI, F., OKA, N. and IWASE, Y. (1976): Ankêto chôsa ni yoru mizunagidori-rui no henshi ni kansuru hôkoku; Shu to shite hashibosomizunagidori ni tsuite (An questionnaire survey of shearwater mortality, especially of *Puffinus tenuirostris*). Yamashina Chôrui Kenkyûjo Kenkyû Hôkoku (Misc. Rep. Yamashina Inst. Ornithol.), **8**, 113–131.

TOYOHASHI WILD BIRD CLUB (1973–76, 1978): Atsumi Hantô no Taiheiyô engan ni okeru hashibosomizunagidori no tairyôshi (A mass mortality of Short-tailed Shearwaters in the Pacific coast of Atsumi Peninsula). Toyohashi (mimeo from 1973 to 1976).

WARHAM, J., WILSON, G. J. and KEELEY, B. R. (1982): The annual cycle of the Sooty Shearwater *Puffinus griseus* at the Snales Islands, New Zealand. Notornis, **29**, 269–292.

(Received July 8, 1987; Revised manuscript received October 12, 1987)