FEEDING BEHAVIOUR, OFFAL PREFERENCES AND TARSUS SHAPE OF *PUFFINUS* SHEARWATERS OFF CENTRAL NEW SOUTH WALES

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Between April 1985 and March 1987, 23 ocean cruises were made east of Wollongong (34°25′ S, 150°54′ E) to determine patterns of abundance of shearwaters and other procellariids (Wood 1990a, 1990b). Pieces of fish and animal fat were cut on board a 14 m chartered fishing boat and cast astern to attract the birds. Wedge-tailed (*P. pacificus*), Flesh-footed (*P. carneipes*) and Sooty Shearwaters (*P. griseus*) were boat followers. Short-tailed (*P. tenuirostris*), Fluttering (*P. gavia*) and Hutton's Shearwaters (*P. huttoni*) were generally non-followers.

These *Puffinus* shearwaters exhibit a wide range of food preferences and feeding techniques (Marchant & Higgins 1990). They are also morphologically different (Kuroda 1954). Wedge-tailed and Flesh-footed glide more and flap less than the other species. Short-tailed, Sooty, Fluttering and Hutton's have wings and legs which are adapted to underwater swimming. This report describes the feeding behaviour and food preferences of shearwaters observed off central New South Wales. It also analyses tarsus measurements to determine whether cross-sectional shape is related to underwater diving performance.

METHODS

Fish remains (including viscera and heads after filleting) and omental beef and lamb fat were sliced on the stern deck. Pieces c.30 mL in size were tossed towards the wake, landing 5-10 m from the vessel. On about 90% of cruises, fish species included gemfish (*Rexea solandri*), mullet (*Mulgil* spp.), blackfish (*Girella tricuspidata*) and flathead (*Platycephalus* spp.) in various proportions. Quantities of offal discarded per cruise were: fish 40-60 kg, fat 25-30 kg.

Measurements of tarsometatarsi were from dried adult skins collected in Australia or New Zealand. The major and minor axes (a and b) of one tarsus per bird were measured with vernier calipers at the mid-point between the ankle and the knee. Cross-section ratio (a/b) reflects the extent to which the tarsus is laterally compressed.

Definitions

Terms used to describe how shearwaters took food follow Harper et al. (1985)as closely as possible.

Surface seizing: A bird settled on the surface grasps items of food with its bill.

Contact dipping: A bird in flight pecks food from or just below the surface. Only the bill, head or breast makes momentary contact with the water.

Surface plunging: A bird "belly-flops" onto the water using the momentum of the fall to assist in catching food. It does not submerge completely.

Shallow diving: Bird submerges completely but penetrates $\prec$500 mm and swims very little to catch food.

Pursuit diving: Bird submerges completely and pursues food for a substantial distance ($\succ$1 m) by swimming underwater.

Pursuit diving and shallow diving may be preceded by a flying "belly-flop" or surface swimming.

RESULTS AND DISCUSSION

During the two-year period, 15 007 Wedge-tailed, 1617 Short-tailed, 1267 Flesh-footed, 346 Sooty and 375 Fluttering/Hutton's Shearwaters were censused within 250 m of the boat. At least six birds were Hutton's Shearwaters, but more may have been present ($\prec$50, refer Brandis *et al.* 1992). Although Short-tailed, Fluttering and Hutton's were essentially non-followers, some Short-tailed individuals followed on three cruises. One such cruise was in May 1986, when small numbers (1-7) scavenged in the wake for most of the day. Short-tailed and Sooty fed on the surface and underwater whereas Wedge-tailed and Flesh-footed scavenged only on the surface (Table 1). Of the five feeding techniques used, only surface seizing and surface plunging were common to these four *Puffinus* species. Contact dipping was used exclusively by Wedge-tailed and Flesh-footed Shearwaters.

Unlike some procellariids off Wollongong, the shearwaters observed clearly preferred fish offal to fat. Indeed they sometimes shunned pieces of fat on the water after inspection and smell. Wedge-tailed were often voracious, noisy and aggressive, occasionally approaching to about 4 metres from the stern as offal was being dissected. While foraging in the wake, they

TABLE 1 — Scavenging techniques and offal preferences of shearwaters off Wollongong, N.S.W.

Species	Offal Type		Scavenging Technique				
	Fish	Fat	Surface Seizing	Contact Dipping	Surface Plunging	Shallow Diving	Pursuit Diving
Wedge-tailed *P. pacificus*	XX	O	XX	X	XX	O	O
Flesh-footed *P. carneipes*	XX	O	XX	X	XX	O	O
Short-tailed *P. tenuirostris*	XX	O	X	O	X	X	X
Sooty *P. griseus*	XX	O	X	O	X	X	X

XX indicates highest preference or usage
O indicates no preference or usage

were able to change direction at considerable speed or suddenly stall and "belly-flop" onto the ocean from a height of 3-4 metres. If the landing position of tossed offal was misjudged, they swam to it on the surface after alighting. A similar technique was used off Johnston Atoll, in the Pacific Ocean, to hunt live fish "about three inches long" at night (Gould 1967). Wedge-tailed were able to compete successfully with all other boat-following seabirds except Silver Gulls (*Larus novaehollandiae*). These gulls often followed close to the stern (<20 m) and maintained a steady altitude of 10-20 metres. From this position, they were able to take offal before most other scavengers by contact dipping and surface plunging. Silver Gulls did not dive but their lower wing loading (Pennycuick 1987) allowed them to use flapping flight to outmanoeuvre the stiff-winged shearwaters at low boat speeds (7-8 knots).

By comparison with Wedge-tailed, Flesh-footed were less manoeuvrable, less noisy and rarely foraged close to the stern (within 4 metres). Sooty and Short-tailed were similar to each other in feeding behaviour. They often dived for submerged offal, using skills which have been previously described off north-western USA (Brown *et al.* 1978), Japan (Ogi *et al.* 1980) and Tasmania (Skira 1979, Morgan 1982). On 25 October 1986, when Silver Gulls followed closely, Short-tailed Shearwaters continually zig-zagged across the wake under the gulls and "belly-flopped" on the surface close to fallen offal, diving for it if it sank. This was the only successful technique used by any of the *Puffinus* shearwaters to compete with Silver Gulls.

During the Wollongong study, Fluttering or Hutton's Shearwaters did not follow the *Sandra K* and were not seen in pursuit of natural prey. Indeed, there are few reported observations of either species feeding in Australian seas. On 27 August 1983, I was aboard the *MV Kariong* 6-8 km east of Sydney heads when the boat was deliberately steered into a foraging flock of c.300 Fluttering/Hutton's Shearwaters (probably >80% Fluttering). Some birds were sitting on the water, others were taking off from the front of the flock and flying downwind to the rear. Birds in flight wheeled to face the wind before landing on their bellies. On landing, they hesitated momentarily, then dived in pursuit of natural prey, swimming underwater towards the front of the flock. I could not detect their prey, but for birds which dived close to the bow (<10 m), submersion times and depths were about 10 seconds and 2-3 metres.

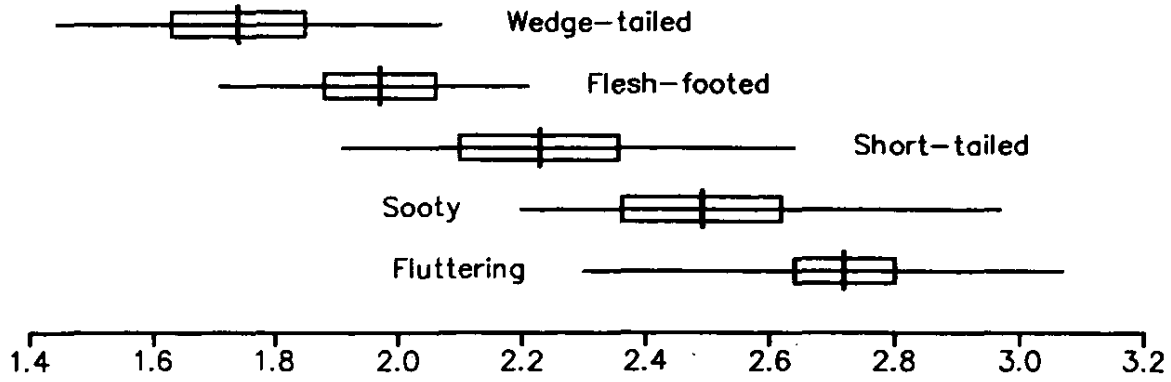

FIGURE 1 — Shearwater tarsometatarsus section ratio (a/b) indicating mean, ± 99% confidence limits of mean (rectangle) and range (horizontal line).

TABLE 2 — Shearwater tarsometatarus measurements (mm). Symbols a and b are major and minor axes of the transverse section. Values are mean ± SD, (range).

Wedge-tailed	**a**	**5.9 ± 0.38**	**(6.6 - 5.3)**
n = 19	**b**	**3.4 ± 0.27**	**(4.0 - 2.9)**
	a/b	**1.74 ± 0.16**	**(2.07 - 1.43)**
Flesh-footed	**a**	**7.4 ± 0.3**	**(8.0 - 6.85)**
n = 21	**b**	**3.77 ± 0.28**	**(4.3 - 3.3)**
	a/b	**1.97 ± 0.14**	**(2.21 - 1.71)**
Short-tailed	**a**	**6.8 ± 0.51**	**(7.5 - 5.7)**
n = 22	**b**	**3.1 ± 0.26**	**(3.5 - 2.5)**
	a/b	**2.23 ± 0.21**	**(2.64 - 1.91)**
Sooty	**a**	**8.55 ± 0.53**	**(10.0 - 7.6)**
n = 22	**b**	**3.44 ± 0.2**	**(3.8 - 3.1)**
	a/b	**2.49 ± 0.21**	**(2.97 - 2.2)**
Fluttering	**a**	**5.97 ± 0.4**	**(6.9 - 5.3)**
n = 41	**b**	**2.2 ± 0.13**	**(2.55 - 1.9)**
	a/b	**2.72 ± 0.2**	**(3.07 - 2.3)**

Flying and feeding methods used by *Puffinus* shearwaters have been described previously (Kuroda 1954). Diving species are characterised by laterally compressed (streamlined) tarsometatarsi, which lessen resistance to water during the recovery strike of the foot. Comparative measurements of five *Puffinus* species show that Fluttering and Wedge-tailed have the most and least streamlined tarsi respectively (Table 2, Figure 1). There is no overlap in 99% confidence limits of the mean section ratio of these five species. Indeed, the adjacent species shown have section ratios which are very similar in variance (F-tests) yet very significantly different (t-tests):

Wedge-tailed v Flesh-footed	($F = 1.3, P = 0.05$ $t = 4.7, P = 0.01$)
Flesh-footed v Short-tailed	($F = 2.2, P = 0.01$ $t = 4.6, P = 0.01$)
Short-tailed v Sooty	($F = 1.0, P = 0.05$ $t = 4.0, P = 0.01$)
Sooty v Fluttering	($F = 1.1, P = 0.05$ $t = 4.2, P = 0.01$)

These statistical results, together with the feeding techniques described, suggest that diving skills of the large *Puffinus* shearwaters are closely linked to their tarsus shape. The maximum recorded diving depths are 20 m for the Short-tailed (Morgan 1982) and 10 m for the Sooty Shearwater (Brown *et al.* 1981). In the breeding season off Lord Howe Island, Flesh-footed regularly dive to 5 metres for hooked pieces of fish bait and discarded fish offal (Clive Wilson pers comm.). Further studies may show that diving performance of all the large *Puffinus* shearwaters is ranked in the order of their tarsus section ratio.

CONCLUSIONS

Over the continental shelf east of Wollongong, Wedge-tailed, Flesh-footed and Sooty Shearwaters consume large quantities of fish offal; Short-tailed Shearwaters consume much smaller quantities. These four species take very little animal fat. Fluttering and Hutton's Shearwaters rarely scavenge behind fishing boats; presumably their diet consists almost entirely of live prey. The feeding methods used by all the above species appear to be related to the extent to which the tarsus is streamlined. Diving species have the most streamlined tarsi.

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