REFERENCES

BASKETT, T.S. 1975. Mercury residues in breast muscle of wild ducks, 1970-71. Pest. Monit. J. 9: 67-68.

BLUS, L.J., S.N. WIEMEYER, J.A. KERWIN, R.C. STENDELL, H.M. OHLENDORF & L.F. STICKEL. 1977. Impact of estuarine pollution on birds. Proceedings of a Conference Vol. I. 'Estuarine Pollution Control and Assessment'. U.S. Environmental Protection Agency.

FRITH, H.J. 1967. Waterfowl in Australia. Sydney: Angus and Robertson.

HART, B.T. 1974. A compilation of Australian water quality criteria. Aust. Water Resources Council Tech. Pap. No. 7. Aust. Govt. Publ. Service.

HARTUNG, R. 1976. The impact of environment pollutants on wildlife - an overview. *In* Wildlife Diseases. L.A. Page (Ed.). New York and London: Plenum Press.

HOWARTH, D.M., A.J. HULBERT & D. HORNING. 1981. A comparative study of heavy metal accumulation in tissues of the crested tern, *Sterna bergii*, breeding near industrialised and non-industrialised areas. Aust. Wildl. Res. 8: 665-672.

LAVERY, H.J. 1971. Lead poisoning as a possible cause of death in waterfowl in northern Queensland. Emu 71: 138-139.

LONGCORE, J.R., L.N. LOCKE, G.E. BAGLEY & R. ANDREWS. 1974. Significance of lead residues in mallard tissues. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 182.

MACKAY, N.J., R.J. WILLIAMS, J.L. KACPRZAC, M.N. KAZACOS, A.J. COLLINS & E.H. AUTY. 1975. Heavy metals in cultivated oysters (*Crassostrea commercialis = Saccostrea cucullata*) from the estuaries of New South Wales. Aust. J. Mar. Freshwat. Res. 26: 31-46.

NHMRC. 1981. Standards for metals in food. National Health and Medical Research Council 92nd session, October 1981.

NEUHAUS, J.W.G., M.N. BRADY, D.S. SIYALI & E. WALLIS. 1973. Mercury and organochlorine pesticides in fish. Med. J. Aust. 1: 107-110.

NORMAN, F.I. 1976. The incidence of lead shotgun pellets in waterfowl (Anatidae and Rallidae) examined in south-eastern Australia between 1957 and 1973. Aust. Wildl. Res. 3: 61-71.

OLSEN, P., H. SETTLE & R. SWIFT. 1980. Organochlorine residues in wings of ducks in south-eastern Australia. Aust. Wildl. Res. 7: 139-47.

STENDELL, R.C., R.I. SMITH, K.P. BURNHAM & R.E. CHRISTENSEN. 1979. Exposure of waterfowl to lead: a nationwide survey of residues in wingbones of seven species, 1972-73. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Wildl. 223.

SZYMCZAK, M.R. & W.J. ADRIAN. 1978. Lead poisoning in Canada Geese in Southeast Colorado. J. Wildl. Manage. 42: 299-306.

THROWER, S.J. & I.J. EUSTACE. 1973a. Heavy metals in Tasmanian oysters in 1972. Aust. Fish. 32: 7-10.

———. 1973b. Heavy metal accumulation in oysters grown in Tasmanian waters. Fd. Technol. Aust. 25: 546-53.

WHITE, D.H. & R.C. STENDELL. 1977. Waterfowl exposure to lead and steel shot on selected hunting areas. J. Wildl. Manage. 41: 469-475.

WILLIAMS, R.J., N.J. MACKAY, L.C. COLLETT & J.L. KACPRZAC. 1976. Total mercury concentration in some fish and shellfish from N.S.W. estuaries. Fd. Technol. Aust. 28: 8-10.

PENNY D. OLSEN, *Division of Wildlife and Rangelands Research, CSIRO, P.O. Box 84, Lyneham, A.C.T. 2602.*

21 March 1983

OLFACTORY EXPERIMENTS ON SOME ANTARCTIC BIRDS

Some ornithologists have suggested that certain Procellariiforms are able to detect the smell of fish or animal oil (Murphy 1936; Miller 1942; Kritzler 1948), and anatomists have noticed the highly developed olfactory bulbs and sensory epithelium in this group of seabirds (Bang 1960, 1965, 1966, 1971). Over the last ten years a few experimental studies have been carried out in this field. Grubb (1974) indicated the possibility of olfactory homing in Leach's Storm-petrel *Oceanodroma leucorrhoa* and (Grubb 1972) of foraging at sea by smell in both the Great Shearwater *Puffinus gravis* and Wilson's Storm-petrel *Oceanites oceanicus*. Similar experiments have also been recently carried out by Hutchinson & Wenzel (1980).

Since it is difficult to keep petrels in captivity and as they seem to show limited learning capacities, few laboratory tests have been performed. However, Jouventin (1977) showed that the Snow Petrel *Pagodroma nivea*, which has the largest olfactory bulbs (Bang 1965, 1966; Bang & Cobb 1968), was able to smell and to locate its food by olfactory cues alone.

The experiments reported here were designed to complement, in field conditions, the previous experiments on the Snow Petrel, as well as to extend our knowledge of the use of olfaction in other birds breeding in Terre Adelie (Antarctica). Our experiments were carried out during the austral summer of 1981-1982. The location was in Terre Adelie close to the French base, which is on the Petrels Island in the archipelago of Pointe Geologie, 1 km from the Antarctic continent.

During the summer Prevost (1963) estimated that, over an area of 1 km radius, there are breeding about 1000 Snow Petrels, 1000 Cape Petrels *Daption capense*, 1000 Wilson's Storm-petrels. Our most recent counts show that, in addition to these there is breeding by about 70 Antarctic Fulmars *Fulmarus glacialoides*, 30 Southern Giant-petrels *Macronectes giganteus* and 80

South Polar Skuas *Stercorarius maccormicki.*

Since the waters of the coastal and pack-ice zones are calm, there is little dispersion of odorous products. In our tests we used mineral oil and then sea-water as controls and, as a 'food source', untreated cod-liver oil. A piece of sponge (12 cm × 8 cm × 4 cm) attached to a string was soaked with one of these substances and thrown approximately 10 m from the shore. The soaked sponge floating on the surface of the water looked like seaweed.

The observer was hidden behind rocks approximately 50 m away. Observations were made with the naked eye or with binoculars. Only birds seen within 10 m of the sponge were counted because the birds that seemed to be attracted moved into that area. The experiments were carried out after 8 p.m. (local time), since a series of preliminary observations made at our site indicated that those bird species tested were more abundant at this time.

Each test with water, mineral oil, or cod-liver oil was 0.5 h long. The control tests with water or mineral oil were performed just before the tests with cod-liver oil when both types of tests were performed the same evening.

Our equipment was relatively inconspicuous and our zone of observation was restricted to the food source. We thus minimized the possibility of counting birds that had been visually attracted to the food source by equipment and this might explain why our results for the three most abundant species are so clear cut.

We have distinguished between birds that made a single flight a few metres over the sponge without changing their direction and birds that showed what we have called "special interest". "Special interest" involved the birds either flying over the sponge several times, or skimming, or circling over it.

Confidence intervals were calculated when comparing the percentages of the total number of birds attracted during the control and the cod-liver oil tests in the three species.

RESULTS AND DISCUSSION

Initially, when scoring the response of the birds by 5 min periods, we found that, whatever the stimulus, the birds paid similar attention at the beginning and later on in a series of observations.

To determine whether the birds were able to distinguish between sponges soaked in water or mineral oil a series of eight 0.5 h tests were carried out. Despite the conspicuous irridescence caused by the mineral oil on the water's surface, the birds were apparently less attracted to the mineral oil than to the water: 8 Wilson's Storm-petrels and one Skua were attracted to the mineral oil, 16 Wilson's Storm-petrels and 3 Snow Petrels to the water. However, these observations need to be confirmed by more data.

Wilson's Storm-petrels, Snow Petrels and Cape Petrels were able to distinguish, by olfaction, between a sponge soaked in cod-liver oil and a control sponge soaked in mineral oil or water ($p < 0.01$, Fig. 1). The category of behaviour called 'special interest' was more frequently observed in the tests involving cod-liver oil than in the control tests. If we cumulate the results obtained from the three species (N = 271), 90% of these birds were observed when the sponge was soaked in cod-liver oil. Of these, 77.9% showed 'special interest'. Among the remaining 10% that we observed during the control tests, only 18.5% showed 'special interest'.

These findings indicate that the Cape Petrel, the Snow Petrel and the Wilson's Storm-petrel, are able to

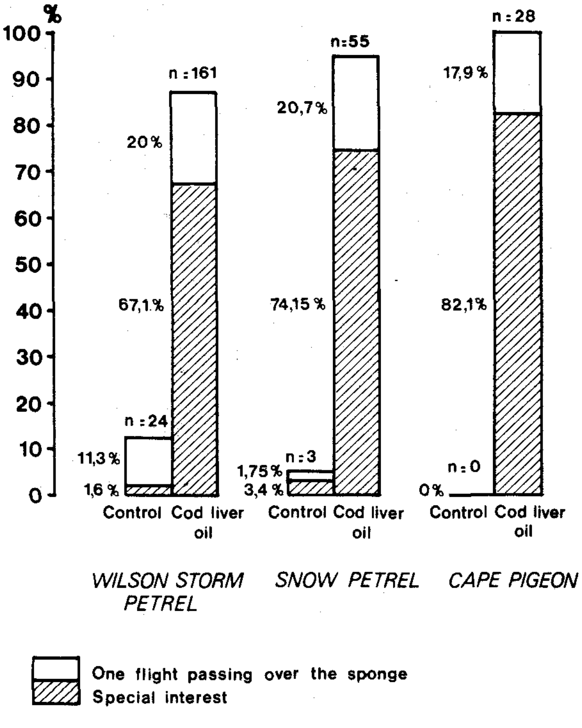

Figure 1. Histograms showing percentage of birds seen within 10 m of floating sponges soaked in water, or mineral oil (control) or cod-liver oil. The behaviour of birds seen within 10 m of sponges is divided into two categories (see text) and n is the number of birds seen in each trial.

locate food by using olfactory cues. These results have already been obtained with the Wilson's Storm-petrel (Grubb 1972) as well as the Snow Petrel (Jouventin 1977) in captivity. Certain occasional behaviours by these three species seen in the field make the difference between the tests and their controls even more obvious. For example, Cape Petrels and Snow Petrels were repeatedly observed to change their flight direction towards the piece of sponge impregnated with cod-liver oil. On other occasions, after circling over the sponge for a few minutes, several birds landed on the water's surface and some of these actually pecked at the sponge. These behaviours were never observed during the control tests.

The other breeding seabirds were seldom seen in our test area. The Skuas were less numerous than the three other species mentioned, but they belong to the Order Charadriiformes, which, as an order, has poorly developed bulbs (Bang 1971) and probably a poor sense of smell. On one occasion a Skua showed equal interest in the control and in the real test and later the same bird dragged the water-soaked sponge towards the shore.

The Southern Giant-petrel is a Procellariiform and a member of the fulmar group, as are the Snow Petrel, Cape Petrel and Antarctic Fulmar. Not a single Giant-petrel was attracted to the control sponge, but on four occasions several individuals came close to the sponge soaked in cod-liver. On one occasion a Giant-petrel made two swoops towards the sponge with its legs extended. It landed, took the sponge in its mouth and attempted to take off with it. Unable to do so, the bird remained close to the impregnated sponge for several minutes. On three other occasions we saw Giant-petrels circling over the food-odoured sponge. We need a fuller knowledge of Giant-petrel behavioural repertoire before a clearer idea of its olfactory capacity can be made.

Although 20 Antarctic Fulmars were observed over the experimental zone, none changed its flight path toward the sponge soaked in cod-liver oil. This result is surprising since it is known that the Antarctic Fulmar is attracted to whale blubber, suggesting a sensitive olfactory sense. Furthermore, this species is closely related to the Northern Fulmar *Fulmarus glacialis* and the Northern Fulmar ranks close to the Cape Petrel in its olfactory sense (Bang & Cobb 1968). It is possible that the Antarctic Fulmar failed to respond to the sponge soaked in cod-liver oil because our experiments were conducted outside its normal feeding range. The Antarctic Fulmar in Terre Adelie feeds out at sea, flying at high altitude, to and from its nest and feeding grounds and has never been seen foraging along coastlines.

This study was supported by 'Terres Australes et Antarctiques Francaises' and 'Expeditions Polaires Francaises'. We thank M. Bradbury and M. Berdoy for their translation, F. Bourliere and E. Wyndham for comments, and L. Ruchon for drawing the figure.

REFERENCES

BANG, B.G. 1960. Anatomical evidence for olfactory function in some species of birds. Nature 188: 547-549.
———. 1965. Anatomical adaptations for olfactory in the Snow Petrel. Nature 205: 513-515.
———. 1966. The olfactory apparatus of tubenosed birds (Procellariiformes). Acta Anat. 65: 391-415.
———. 1971. Functional anatomy of the olfactory system in 23 orders of birds. Acta Anat. Suppl. 58: 1-76.
———, & S. COBB. 1968. The size of the olfactory bulb in 108 species of birds. Auk 85: 55-61.
GRUBB, T.C., Jr. 1972. Smell and foraging in shearwaters and petrels. Nature 237: 404-405.
———. 1974. Olfactory navigation to the nesting burrow in Leach's Petrel (*Oceanodroma leucorrhoa*). Amin. Behav. 22: 192-202.
HUTCHINSON, L.V. & B.M. WENZEL. 1980. Olfactory guidance in foraging by Procellariiforms. Condor 82: 314-319.
JOUVENTIN, P. 1977. Olfaction in Snow Petrel. Condor 79: 498-499.
KRITZLER, H. 1948. Observations on behaviour in captive fulmars. Condor 50: 5-15.
MILLER, L.H. 1942. Some tagging experiments with Black-footed Albatrosses. Condor 44: 3-9.
MURPHY, R.C. 1936. Oceanic birds of South America. Am. Mus. Nat. Hist. New York.
PREVOST, J. 1963. Densites de peuplements et biomasses de vertebres terrestrers de l'archipel de Pointe Geologie, Terre Adelie. Terre et Vie 17: 35-49.

P. JOUVENTIN and J.P. ROBIN, *Institut des Sciences de l'Evolution Section Socioecologie U.S.T.L., Place E.-Bataillon 34060 Montpellier, France.*

21 March 1983