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DIVING DEPTHS OF GENTOO *PYGOSCELIS PAPUA* AND ADELIE *P. ADELIAE* PENGUINS AT ESPERANZA BAY, ANTARCTIC PENINSULA

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SUMMARY

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During December 1987 and January 1988 10 Gentoo Penguins *Pygoscelis papua* and 20 Adélie Penguins *P. adeliae* were fitted with miniature depth gauges to determine the total time spent by each species at various depths underwater during foraging. The maximum depth reached per trip was significantly deeper in Gentoo Penguins than in Adélie Penguins and Gentoo Penguins spent a higher percentage of their time underwater at depths in excess of 50 m than did Adélie Penguins. Only two of the Adélie Penguins exceeded 100 m whereas seven of the Gentoo Penguins did so. Other results of diving depths of Gentoo and Adélie Penguins are considered to examine whether interspecific dive depth differences may act to reduce competition in areas of sympatry.

INTRODUCTION

The three species comprising the genus *Pygoscelis*, the Adélie *P. adeliae*, Gentoo *P. papua* and Chinstrap *P. antarctica* Penguins, have largely allopatric breeding areas (Watson 1975, Wilson 1983). However, areas of sympatry have promoted interest in mechanisms of interspecific ecological segregation (for review see Trivelpiece *et al.* 1987).

Terrestrial studies indicate that differences in nest site requirements and temporal interspecific

differences in nesting are important in reducing competition (Trivelpiece & Volkman 1979, Volkman & Trivelpiece 1981, Lishman 1985a, Moczydlowski 1986, Trivelpiece *et al.* 1987). All species do, however, rear chicks during the austral summer. Diets of the three species are broadly similar during breeding (Volkman *et al.* 1980) although Chinstrap Penguins appear to catch larger Antarctic Krill *Euphausia superba* than do Adélie Penguins (Lishman 1985b) and Gentoo Penguins take significantly more fish than either congener (White & Conroy 1975, Volkman *et al.* 1980). This

suggests that there are interspecific differences in foraging behaviour.

When foraging, all three species travel at similar speeds (Wilson *et al.* 1989) but telemetric studies indicate that larger species dive for longer periods. Gentoo, Adélie and Chinstrap Penguins, with mean masses of 5,9 kg, 5,0 kg and 4,5 kg, respectively (Stonehouse 1975), have mean feeding dive durations of 128 s, 114 s, and 98 s, respectively (Trivelpiece *et al.* 1986, Davis *et al.* 1988). Accordingly, it has been suggested that the larger species may dive deeper (Trivelpiece *et al.* 1986, 1987). The limited data available on Chinstrap Penguins indicate that they do not dive deep, with only 10% of all dives exceeding 45 m (Lishman & Croxall 1983). Gentoo and Adélie Penguins have highly variable maximum diving depths which appear dependent on locality. Gentoo Penguins at South Georgia (54S, 38W) regularly exceed 100 m (Croxall *et al.* 1988), whereas at Marion Island (46S, 37E) less than 20% of birds exceed 20 m (Adams & Brown 1983). Adélie Penguins at Name Island (69S, 39E) do not exceed 27 m (Naito *et al.* 1988), whereas penguins at Magnetic Island (68S, 77E) may dive to 180 m (Whitehead 1989). Thus, it may be premature to suggest that dive depths of a species at one locality are typical throughout the range. Differences in dive depth of *Pygoscelis* penguins may be particularly important in reducing competition where species occur together, but no study of diving depths has yet been conducted on different species in areas of sympatry.

Gentoo and Adélie Penguins breed sympatrically at Esperanza (63S, 57W) at the tip of the Antarctic Peninsula and, during late December and January, both species have chicks. I used a recently developed depth gauge (Wilson *et al.* in press a) to determine whether there were any differences in depth utilization of Gentoo and Adélie Penguins brooding chicks at Esperanza Bay. Differences would indicate a mechanism which could lead to exposure to different prey items and thus reduce interspecific competition.

MATERIALS AND METHODS

Field work was conducted at Esperanza Bay (63 23S, 57 00W), Antarctic Sound between 20 December 1987 and 18 January 1988. At the site there was a colony of c. 117 000 breeding Adélie Penguins (Wilson 1983) and 70 Gentoo Penguin nests.

I caught 20 Adélie and 10 Gentoo Penguins, brooding or guarding chicks, by hand or by catching them around the leg with a long hooked pole. Depth gauges were attached to feathers in the centre of the birds' backs with black waterproof tape (Wilson & Wilson 1989) before the birds were released at the nest. The complete procedure from capture to release of the device-fitted bird took less than two minutes. Subsequently, nests were checked at least once daily (between 10h00 and 16h00) to check for the presence of device-fitted birds. Any absence from the nest was taken to indicate a foraging trip. Returned birds were captured in the same manner as first caught and the devices removed.

The depth gauges (64 X 11 mm diameter) weighed approximately 6 g and consisted of a transparent cylinder enclosing a volume of air, nominally at 1,2 atmospheres pressure, bounded by a movable bung. In this system, changes in external hydrostatic pressure are balanced by an increase in pressure of the air in the cylinder with a concomitant reduction in volume (Boyle's Law) brought about by changes in bung position. Thus, when the device is lowered in the water column the bung moves to a specific position dependent on depth. Bung position is recorded on photographic film by a bung-attached light emitting diode (LED) which is positioned to shine through the transparent cylinder wall. The film is taped over the outside of the cylinder. Increased exposure time of the film to the LED in any specific position results in increased optical density. Thus, the total time that the bung spends at any particular position can be determined by densitometric analysis of the trace. Overall, the

depth gauges record the total time that they spend at each depth underwater (Wilson *et al.* in press a).

Recovered devices were taken back to the base and immediately separated from their films. The films (HP 5) were developed for 15 min in a 1:5 solution of Neofin Blue and water at 20°C and then fixed for 5 min. Other films were then used to make exposure time/ optical density calibrations for each device. The optical densities of the traces and calibration films were determined with a modified Uvikon 810 P spectrophotometer set at 600 nm with a detection window of 1 mm (vertical) X 0.05 mm (longitudinal) at a film scan speed of 20 mm/min. The optical density, assessed continuously, was plotted directly onto paper (speed 200 mm/min) and then read off at 5-mm intervals (equivalent to 1-mm intervals on the film) by using an overlay. The optical density values were converted to time estimates by reference to calibration curves and then corrected for errors due to the spread function of the light (cf. Wilson & Bain 1984) by multiple iterative deconvolution (50 iterations) (Wilson *et al.* in press a). Reading intervals of 1 mm on the film correspond to overall depth intervals of e.g. c. 0,5 m (at 1 m), c. 10 m (at 50 m) and c. 50 m at 125 m. The relatively coarse analysis was intended to determine major differences in depth utilization by the two penguin species rather than differentiate fine detail. Nominally, small film reading intervals (0,2 mm) lead to errors in time estimation of less than 10% (Wilson *et al.* in press a). The total error in the analysis described here could be as high as 25% with a tendency to underestimate small time values. The depth gauge has a depth estimation error of less than 14% (Wilson *et al.* in press a).

All time at depth data from individual birds were converted to percentages with 100% representing the total time spent at all depths greater than 2 m. This eliminates much time accumulated due to travelling (cf. Trivelpiece *et al.* 1986, Croxall *et al.* 1988) and simplifies complications due to variations in time spent foraging. Monospecific results were lumped to derive mean percentage time spent per 5-m depth interval.

In order to assess potential effects of attached devices on penguin diving depth, I looked at variability in the maximum dive depth of birds from different localities in relation to the cross-sectional area of the attached device. Dive depth records were taken from this study and from the literature. Results from both Gentoo and Adélie Penguins were treated together. In cases where birds had devices attached with harnesses, strap thickness was taken to be 1,7 mm and both Gentoo and Adélie Penguin body diameters taken as 200 mm (Wilson *et al.* in press b). Calculations cannot be expected to be very accurate since precise details on the size of the attachment method are not always stated. This approach does, however, serve to identify general trends.

RESULTS

I believe that the depth gauge-fitted penguins that went to sea did so to forage because I saw six recently returned birds (two Gentoo and four Adélie Penguins) feed chicks. Adélie Penguins ($n = 20$) spent less time at deeper depths. More than 50% of the total time underwater was spent shallower than 20 m, 80% shallower than 35 m and 95% shallower than 50 m (Fig. 1). Although Gentoo Penguins also spent less time at deeper depths and spent a similar proportion of their time between 0 and 20 m (53%), overall, they spent more time deeper than Adélie Penguins; 20% of their total time was spent deeper than 50 m and 10% deeper than 75 m (Fig. 1). The sum of the difference in percentage time spent at different depths by the two species was 44%, indicating an appreciable difference in depth utilization (Fig. 1).

The maximum recorded depth per foraging trip was also significantly higher in Gentoo than in Adélie Penguins (Gentoo Penguins; 0-50 m - 2 birds (20%), 51-100 m - 1 bird (10%), 101-150 m - 7 birds (70%); Adélie Penguins; 0-50 m - 12 birds (60%), 51-100 m - 6 birds (30%), 101-150 m - 2 birds (19%); $X^2 = 11,43$; $df = 2$; $P < 0,01$) (Fig. 2).

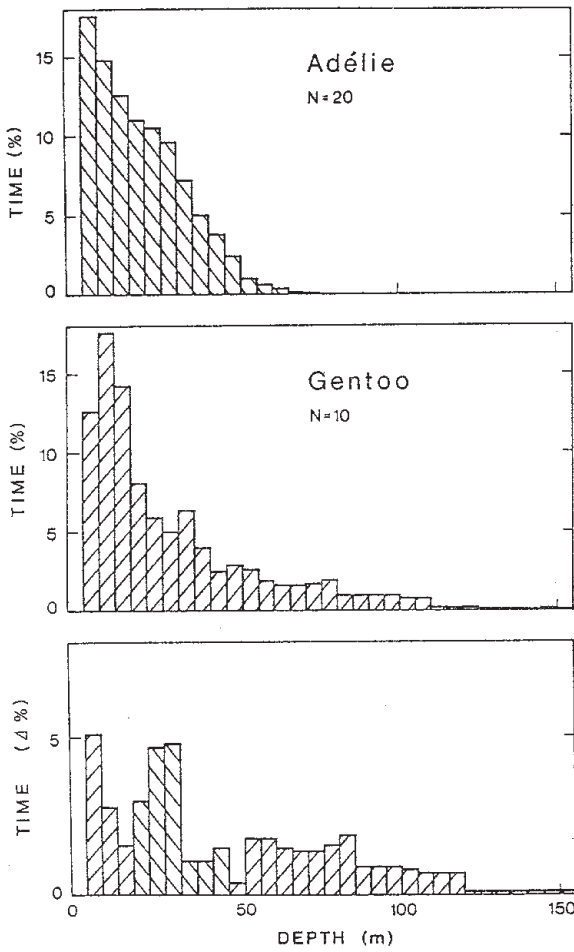


Figure 1

Total time spent per 5-m depth interval for Adélie (upper figure) and Gentoo (centre figure) Penguins foraging from Esperanza Bay, December 1987 - January 1988. The bottom figure shows the interspecific difference in time in relation to depth

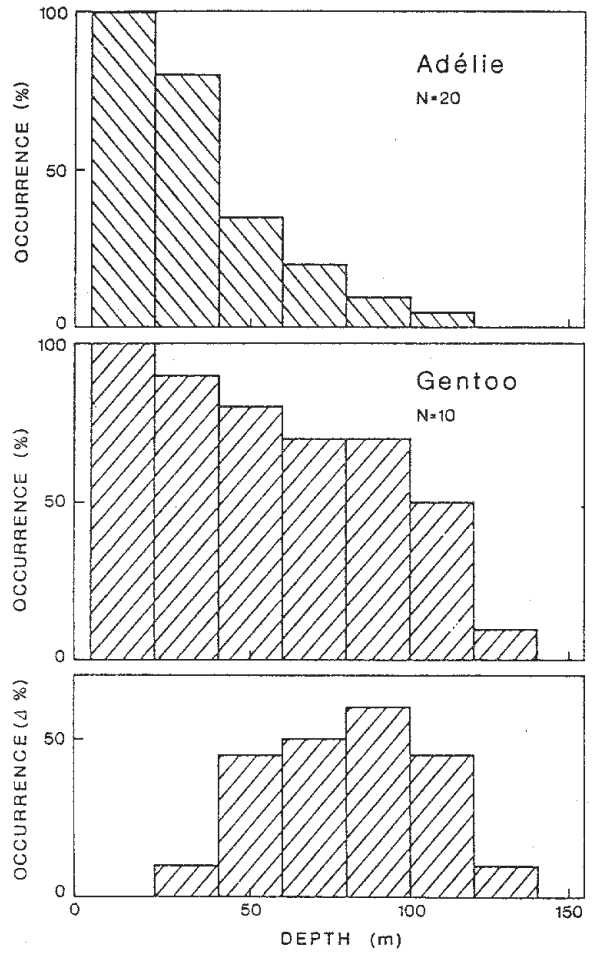


Figure 2

Percentage of device-fitted Adélie (upper figure) and Gentoo (centre figure) Penguins that attained specific maximum depths during foraging trips. The bottom figure shows the interspecific difference in maximum depths attained

Consideration of dive depth in relation to package size showed that for Gentoo and Adélie Penguins, maximum dive depth, D (m), was closely correlated with the cross sectional area of the attached device, XS (mm^2); $D = 166,5 - 0,08XS$ ($r^2 = 0,92$; $F = 56,0$; $P < 0,005$) (Fig. 3).

DISCUSSION

The results for depth utilization for Gentoo Penguins from this study are similar to those of Croxall *et al.* (1988) and D. Costa (cited in Trivelpiece *et al.* 1987) in that birds regularly exceed depths of 100 m. This contrasts with results obtained by Adams & Brown (1983) who found that at Marion Island, of 19 birds that went to sea for periods of up to eight days, only one individual dived to 70 m and only three (16%) exceeded 20 m. Similar variability occurs in maximum depth records of Adélie Penguins. The maximum dive depth of 58 birds at Magnetic Island, wearing devices up to four days, was 175 m (Whitehead 1989), whereas for four birds breeding at Name Island, wearing recording devices up to twelve days, maximum dive depth was 27 m (Naito *et al.* 1988). In both species it appears that there is substantial variation on depth utilization according to locality. However, foraging parameters in penguins may change when the birds are fitted with devices. Penguins are documented as swimming slower (Wilson *et al.* 1986) and spending longer at sea (Wilson *et al.* in press b) when fitted with larger devices. It is, therefore, not surprising that dive depths also appear to be affected by device size. However, the magnitude of depth change with relatively small changes in device cross-sectional area is substantial.

It would appear that potential interspecific variation in depth utilization over time and space cannot be examined unless device effects are considered. Studies which utilize remote-sensing devices to confirm interspecific mass-related differences in dive durations and dive depths (Trivelpiece *et al.* 1986, Davis *et al.* 1988) should be interpreted with care since smaller species are

more likely to be affected by devices of a specific size than larger species. Swimming speeds and foraging ranges (Wilson *et al.* 1989) may be similarly affected. It is clear that devices should be as small as possible, but perhaps, before results from large devices storing complex information are interpreted, birds should be fitted with capillary depth gauges (Burger & Wilson 1988) which, if attached with tape, have a cross-sectional area of less than 10 mm^2 . Although these devices only give information on the maximum depth reached per foraging trip, device-invoked changes in foraging behaviour would probably be minimized and results would be correspondingly more meaningful.

In the study reported here, devices were relatively small (Fig. 3) and only one device size was deployed on both species. Although southern Gentoo Penguins are approximately 0,5 kg heavier than Adélie Penguins (Stonehouse 1975), I tentatively suggest that the apparently deeper diving behaviour of the Gentoo Penguin at Esperanza Bay is not just an artefact resulting from differential bird size/device size ratios. Gentoo Penguins feed on crustaceans and nototheniid fish (Croxall & Prince 1980, Volkman 1980, La Cock *et al.* 1984, Jablonski 1985, Adams & Wilson 1987, Adams & Klages 1989). Since nototheniids are predominantly benthic/demersal (Burchett *et al.* 1983, Duhamel & Hureau 1985), when Gentoo Penguins feed on fish they dive deeper than when they feed on crustaceans (Croxall *et al.* 1988). I was unable to ascertain for certain that any of the device-fitted Gentoo Penguins at Esperanza Bay were feeding on fish because stomach-pumping would have further stressed the small and timid colony. However, much of the Gentoo Penguin faeces at Esperanza was grey, which I interpret as being indicative of a fish diet. In contrast, Adélie Penguins at Esperanza had markedly pink faeces and were feeding exclusively on Antarctic Krill (N.R. Coria pers. comm. for 30 stomach samples). Antarctic Krill is pelagic, generally occurring in the top 50 m of the water column (Ichii 1988). The deep dives exhibited by Adélie Penguins at Magnetic Island (Whitehead 1989) indicate that the

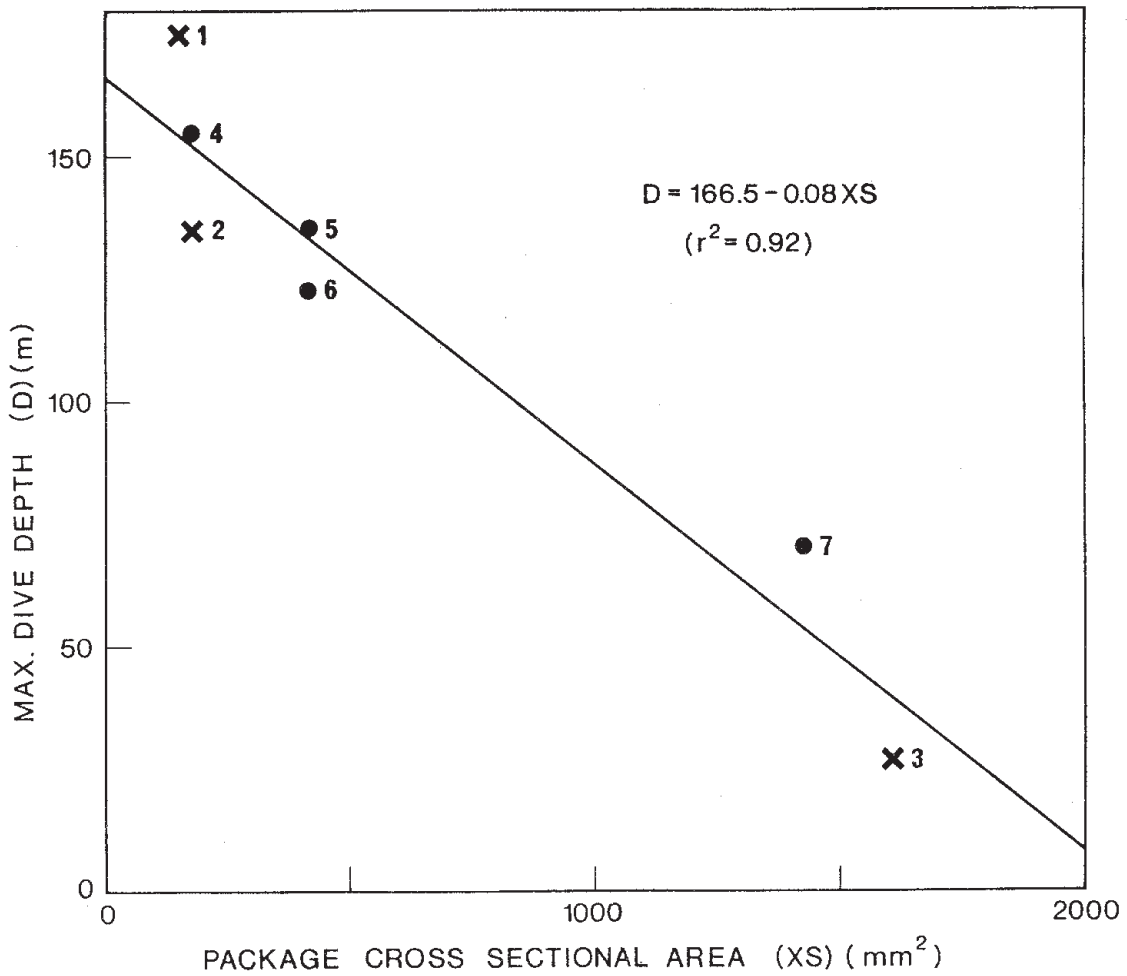


Figure 3

Maximum recorded dive depth as a function of calculated package cross-sectional area for Adélie (crosses) and Gentoo (circles) Penguins. Data from: (1) Whitehead (1989), (2) this paper, (3) Naito *et al.* (1988), (4) this paper, (5) D. Costa, cited in Trivelpiece *et al.* (1987) (6) Croxall *et al.* (1988), (7) Adams & Brown (1983)

birds are probably capable of exploiting prey this deep.

At present, it seems of little use to consider whether Gentoo Penguins can more easily exploit deeper prey than Adélie Penguins by virtue of their greater size (Stonehouse 1967) or Adélie Penguins more easily exploit deeper prey by virtue of their greater anaerobic muscle capacity (Baldwin 1988). Both Gentoo and Adélie Penguins are capable of diving in excess of 150 m although prey distribution presumably rarely necessitates that they do so. The physical ability to dive to particular depths probably does not constitute a valid interspecific difference realised in normal foraging by Adélie and Gentoo Penguins. In any event, thus far, the quality of the data collected on the diving abilities of the two species does not warrant extensive speculation. Observed interspecific differences in this study may be solely due to the depth distribution of the prey exploited and, as suggested by Trivelpiece *et al.* (1987), interspecific area differences may account for the type of prey encountered. Much more work with small remote-sensing systems is required in areas where *Pygoscelis* penguins occur in sympatry and allopatry before conclusions can be reached regarding interspecific foraging differences which lead to differential prey ingestion.

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