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Seasonal diving behavior is described for the New Zealand fur seal, *Arctocephalus forsteri*, off the west coast of South Island, New Zealand. Eighteen female fur seals were successfully instrumented with microprocessor Time Depth Recorders (TDR). The maximum depth of dive recorded was to 274 m for a duration of 5.7 min and a bottom time of 1.0 min in May 1994. The longest recorded dive was for 11.17 min for a 237+ m dive in July 1992. The mean depth, duration and bottom time for all dives recorded were 38.0 m, 1.6 min and 0.63 min respectively (s.e. ± 0.26 m, ± 0.008 min, ± 0.004 min; n = 34,955 dives). The mean depth, duration and bottom time for dives ≥ 6 m depth were 53.4 m, 2.2 min, and 0.88 min respectively (s.e. ± 0.33 m, ± 0.01 min, ± 0.006 min; n = 24,319 dives). There was considerable variation in dive behavior between individual females foraging at the same time of year. Nevertheless, females tend to dive deeper and longer in autumn and winter as opposed to summer. Because of the individual variation in dive behavior observed, it would be difficult to identify changes in dive behavior caused specifically by the introduction of low frequency sound in the environment.

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INTRODUCTION

Our understanding of pinniped foraging ecology and dive behavior has increased rapidly over the past decade through the advent of microprocessor Time-Depth Recorders (TDRs). These instruments are physically attached to free-ranging seals (Gentry and Kooyman 1986; Costa 1991), and record time, ambient pressure (depth), ambient temperature, and light level at a predetermined rate. Because of the necessity to retrieve the instruments from experimental animals in order to retrieve the data, the majority of these studies have been limited to females with dependent pups (Kooyman *et al.* 1976; Kooyman 1981; Feldkamp *et al.* 1989; Le Boeuf *et al.* 1986; Kooyman 1989; Boyd and Croxall 1992; Lydersen and Kovacs 1993; Boyd *et al.* 1994) and more recently, to pups themselves (Lydersen and Hammill 1993). This is particularly true of sea lions and fur seals (Family: Otariidae), where females make regular foraging trips to sea between bouts of suckling their pup at the natal rookery. The average time from birth to weaning in otariids ranges from about four months for the northern fur seal (*Callorhinus ursinus*) to in excess of 36 months for the Steller's sea lion (*Eumetopias jubatus*). The same does not hold true for most of the earless or 'true' seals (Family: Phocidae) where females remain with their pup until they are weaned. The average time from birth to weaning in phocids can be as short as 10 days in the bearded seal (*Erignathus barbatus*) to about 68 days in the Baikal seal (*Phoca sibirica*; Riedman 1990). Once a pup is weaned, there is no guarantee that the female will return to the natal rookery, thus making it difficult if not impossible to retrieve the instrument. Consequently, little is known of seasonal pinniped diving behaviour, particularly for otariids. More recently there have been studies on elephant seal (Phocidae: *Mirounga* spp.) seasonal foraging behaviour (DeLong and Stewart 1991; Hindell *et al.* 1991). This often is undertaken with the use of satellite linked telemetry (McConnell *et al.* 1992), which was outside the scope of this study.

The New Zealand fur seal (*Arctocephalus forsteri*) offers an excellent system to investigate seasonal variation in foraging behaviour of a temperate otarrid. Considerable information exists on their general biology and natural history (e.g. Crawley and Wilson

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1976; Mattlin 1978, 1981, 1987; Miller 1975; Carey 1992). Pups do not leave their natal rookery prior to weaning and are nutritionally dependent on their mothers for about 10 months (Mattlin 1987). Females therefore are readily accessible at rookeries for most of the year.

This report represents part of a study investigating seasonal foraging ecology of the New Zealand fur seal in New Zealand. In it, seasonal diving behaviour of females resident at Taumaka, Open Bay Islands, Westland, New Zealand, is described, based on 19 different foraging bouts. This study provides the first data on seasonal diving behavior of free-ranging New Zealand fur seals. These data can be used as a baseline from which future studies and experimental manipulations, e.g. introduction of sound into the marine environment, can be compared.

MATERIALS AND METHODS

All dive records were collected from female New Zealand fur seals resident at Taumaka, the larger of the two Open Bay Islands, located about 5 km off the coast Haast, west coast, South Island, New Zealand (43°52'S 168°53'E). The nearest edge of the continental shelf is about 9 km to the north of the islands, where the water depth increases from 100 m to 500 m depth within a distance of about 3 km. Water depth in excess of 1000 m is within 30 km of the islands. Taumaka covers an area of about 12 ha, of which 10 ha is covered in vegetation, with 10-30 m vertical cliffs to the south. The rookery is found on the northern side of the island on a sloping beach consisting of irregular and broken limestone rocks. This site was chosen because it is readily accessible, supports a stable breeding population where about 1650 pups are born annually (pers. comm. H. Best, NZ Department of Conservation, Wellington), is relatively free from human disturbance, and is the best studied colony in New Zealand.

Females with pups were chosen because they regularly return to the rookery to feed their pups, which are weaned at about age 9-10 months (Mattlin 1987). Females weigh about 30-40 kg ($\bar{x}$=36.4 kg, s.e.=1.06, n=19) and will abandon their pup and run for the sea when approached. Experimental animals were caught in a hand held net of about 0.75 m diameter and physically restrained on a board modified after Gentry and Holt (1982). Chemical restraints were not used. Our handling of the seals did not appear to have any long-term negative effect on their behavior. All animals were resighted at least once, and occasionally a female would return to her pup immediately after release and lay down. Others went directly to sea upon release.

Each animal was instrumented with either a Mk3e (149 mm x 26.5 mm dia, 136 g; OBI01), Mk5 (64 mm x 38 mm x 13 mm, 50 g; OBI02-OBI10, OBI18 - OBI24) or Mk6 (69 mm x 57 mm at widest point x 35 mm at tallest point, 80 g; OBI11 & 13) Time Depth Recorder (TDR; Wildlife Computers, Seattle, WA, USA) and an individually tuned radio transmitter (70 mm x 27 mm x 15 mm minus antennae, 38 g; SirTrack, Havelock North, NZ). The transmitter was used to locate the animal once it had returned to the rookery. Individual signals were detected using a hand held three element yagi (SirTrack) and Merlin 12 radio receiver (Custom Electronics, Urbana, IL, USA). The Mk5 and Mk6 TDRs and radio transmitters were individually glued to a piece of neoprene wetsuit material slightly larger than the instrument, which in turn was glued to the pelage on the females' mid-dorsal area using a fast setting marine epoxy (Epiglue Quickset, Epiglass, Avondale, NZ). Upon recapture, the instruments were removed by cutting longitudinally through the neoprene, leaving half a neoprene patch attached to the instrument and half attached to the seal. The piece left glued to the seal either wore off, or was shed during the animal's moult in February-March. The Mk3e TDRs were held in place by hose clamps sewn to the neoprene. Care was taken not to burn the animals from the exothermic reaction of the two pot glue mix. The animals were removed to the shade when restrained, and occasionally water was poured over the epoxy while it was setting. We had no evidence of burning on any of our experimental animals. Animals were released immediately after the glue was set. The total time seals were restrained was about 20 minutes.

The TDRs were programmed to record depth, time and ambient temperature every 10 seconds early in the study (OBI01 - OBI10), and every five seconds later in the study (OBI11 - OBI24). Software provided by Wildlife Computers was used to download the data from the TDR to a laptop computer, and for initial analyses. Additional analyses were carried out using the commercial spreadsheet QuattroPro and statistical package SYSTAT. In the few cases where dive depth equalled or exceeded the maximum recording range of the TDR used, the data were taken at their recorded value for all analyses.

Fur seals OBI01 - OBI10 were instrumented with 250m TDRs, which have a maximum depth recording capability of about 237 (±1) m depth. Because of the resolution of these instruments, only dives ≥ 2m depth were analysed. Fur seals OBI11 - OBI24 were instrumented with 500m TDRs, which have a maximum recording capability of about 474 (±2) m depth. For these instruments, only dives ≥ 4 m depth were analysed. For consistency, only dives ≥ 6 m depth were used when data collected by the two different TDR types were compared.

The effect TDRs and transmitters may have had on New Zealand fur seal diving behavior is unknown. The presence of TDRs attached by a harness was shown to reduce swimming speed in California sea lions from an estimated 3.0 ms^{-1} to 2.5 ms^{-1}, or by about 17% (Feldkamp *et al.* 1989). These were early model instruments which were considerably larger in size, weight and cross section area than those used in this study (50 mm x 200 mm, 500 g). Boyd *et al.* (1991) found no significant difference in foraging-attendance cycles of Antarctic fur seals with and without Wildlife Computer's Mk3 TDRs or radio transmitters attached to their backs. Considering the size and weight of the TDRs and radio transmitters used in this study, and considering that they were attached using glue and not by a harness, any adverse effect on diving behavior probably was minimal.

RESULTS

A total of 19 females was successfully instrumented with microprocessor TDRs between May 1991 and August 1994. Deployment information and a summary are given for all data in Table 1, and for dives ≥ 6 m in Table 2. What is immediately clear from these tables is that there is considerable individual variation in dive depth between animals, and to a lesser degree, variation between seasons of the year. In every case, there was a significant difference in the pattern of dive depths between individual seals instrumented during each field trip (Kruskal-Wallis one-way analysis of variance; $p<0.0005$). The mean depth of dive, duration and bottom time for all recorded dives was 38.0 m, 1.6 min and 0.63 min respectively (s.e. ± 0.26 m, ± 0.008 min, ± 0.004 min; n=34,955), though the range of mean dive depth of the 19 experimental animals ranged from 6.1 - 89.1 m. The mean depth, duration and bottom time for dives ≥ 6 m was 53.4 m, 2.2 min and 0.88 min respectively (s.e. ± 0.33 m, ± 0.01 min, 0.006 min; n=24,319), with mean dive depth ranging from 17.4 - 100.8 m.. The maximum recorded dive depth of 274 m was recorded by OBI21 in May 1994 for a duration of 5.7 minutes and a bottom time of 1.0 minutes. Of the 19,272 dives recorded from seals carrying 250 m TDRs, 89 dives were at or exceeded the maximum depth capability of the instruments (237±1 m). The maximum dive duration was made by OBI02 for 11.2 minutes during a 237+ m dive in July 1992. As might be expected, minimum dive duration increased with depth in all cases. A random sample of these data is shown graphically for all dives in Figure 1. About 55% of all dives recorded were to depths shallower than 20 m. When only dives ≥6 m depth were analysed, about 35% were shallower than 20 m. The majority (78%) of all dives ≥6 m were shallower than 100 m depth, but there was increased diving activity around the 120-139 m range (Figure 2). Individual variation in the time of day when the seals dove was common, with some diving activity taking place round the clock. The fewest dives were made between 0800 and 1600 h. (figure 3). As an example of the extremes encountered in diving activity, OBI09 (winter, July 1993) dove throughout the 24 hours, with peak diving activity during mid-day, while OBI11 (summer, February 1994) made about 96% of her dives between 1800 and 0600 h (Figure 4).

A random sample of average rate of assent and descent is plotted against dive depth in Figure 5. It is clear from this that these fur seals have an maximum average rate of ascent and descent of about 2 $msec^{-1}$ regardless of dive depth.

Dive data are analysed in greater detail by month and year of deployment, and by season bellow.

May 1991

The one successful deployment in May 1991 (OBI01; autumn) was on a female who consistently was a shallow diver, with an average dive depth of 6.1 m (Table 1). Over 95% of her recorded dives were shallower than 20 m depth (Figure 6a). OBI01 had an average dive duration of 0.54 min, with a maximum dive duration of 6.00 min. About 87% of her dives were made between 1800 and 0400 h (Figure 7a). The deepest dives were made between 1800 and 0400 h (Figure 8a).

July 1992

The two females successfully instrumented in July 1992 (OBI02, 03; winter) dove, on average, to 69.0 m depth for 2.38 min with a bottom time of 0.93 min (Table 3). Both of these seals were deep divers. OBI02 dove to depths that equalled or exceeded the maximum recording range of the TDR ($\geq$ 237 m) on 41 occasions. Approximately 41% of their combined dives were shallower than 20 m depth (Figure 6b). The frequency of dives to depths between 20 and 100 m was relatively constant at about 4-6%, but increased to about 18% for dives in the 120 to 139 m depth range. The percentage of dives in the 200-219 m range decreased to less than 1% of the total, then increased to about 4% in the 220-239+ m depth range. Dive duration increased with dive depth, with times ≥ 5 minutes recorded on 178 occasions (6.1%). The maximum dive duration recorded was 11.17 minutes for a 237+ m dive by OBI02. Most dives were made during hours of darkness (Figure 7b). The deepest dives were made between 1800 and 0800 h, with the shallowest around mid-day (Figure 8b).

March 1993

The three females from whom data are available for March 1993 (OBI04, 05, 07; late summer) dove on average to 24.4 m for 1.16 min with a bottom time of 0.35 min (Table 3). None of these seals dove as deeply as the two females in July 92. Approximately 52% of their dives were shallower than 20 m. The percent frequency of dives by 20 m increment decreased to the point where fewer than 2% of their dives were to depths ≥ 100 m (Figure 6c). The deepest dive recorded in March 1993 was to 199 m. The maximum duration recorded was for a 5.67 min dive to 37 m depth. Only five of the 7003 dives made were ≥5 minutes duration. The timing of dives was similar between the three females. Most of their dives were taken between 2000 and 0600 hours, where the diving effort was relatively evenly distributed for each two hour time block (Figure 7c). The same did not hold true with dive depth by time block, where the average dive depth between 0600 and 0800 h and between 1400 and 1800 h was at least double that at other times (Figure 8c).

July 1993

July 1993 (OBI 08, 09, 10) is another mid-winter data set like July 1992, but is totally different in terms of overall dive pattern. The average dive depth for the combined data was 27.55 m, with a dive duration of 1.42 min and a bottom time of 0.62 min (Table 3). This is less than half the average dive depth seen in July 1992. Of the three animals instrumented, one (OBI09) was a shallow diver, with an average dive depth of 13.4 m and a maximum dive depth of 165 m. The other two tended to be deeper divers. OBI08 had an average dive depth of 58.4 m, and 38 were to depths ≥ 236 m, the maximum recorded range for the TDR used

(237±1 m). Similarly, OBI10 had an average dive depth of 40.7 m, and a maximum dive of 226 m. Even though two of the seals were deep divers, in all three cases, greater than 50% of their dives were to depths shallower than 20 m. Approximately 70% of their combined dives were to depths shallower than 20 m (Figure 6d). These seals dove round the clock and did not show the lack of mid-day diving as seen in May 1991 and March 1993 (Figure 7d). As in the other cases, these seals dove deeper at night, with average dive depth in excess of 55 m between 0400 and 0600 h, and again between 2200 h and midnight (Figure 8d).

February 1994

Two seals successfully instrumented mid-summer (February 1994: OBI11, OBI13) had a combined average dive depth of 19.8 m for 0.97 min with a bottom time of 0.37 min (Table 3). With the exception of the one animal instrumented in May 1991, they were the shallowest divers overall. Both dove to depths shallower than 20 m over 70% of the time. Approximately 93% of their combined dives were shallower than 60 m, while 4.7% were deeper than 100 m (Figure 6e). While most of their dives were between 1800 and 0400 h, their deepest dives were between 0600 and 1000 h (Figures 7e and 8e). Only 10% of their combined dives were between 0600 and 1800 h.

May 1994

The four seals instrumented in May 1994 (OBI18, 19, 20, 21; autumn) had a more typical winter diving pattern, in that they tended to be deep divers. The deepest dive recorded throughout this study was made by OBI21, who dove to 274 m with a dive duration of 5.7 min. They had a combined average dive depth of 67.9 m for 2.58 min with a bottom time of 1.14 min (Table 3). While the greatest percentage of dives was to depths shallower than 20 m, they were actively diving to depths well in excess of 150 m (Figure 6f). About 51% of their dives were to depths in excess of 60 m, and 33% were in excess of 100 m. Although these seals dove throughout the day and night, particularly around dawn and dusk (Figure 7f), most daytime dives (between 0800 and 1759 h) were either shallower than 20 m depth (21.9%) or ≥ 100 m depth (66.0%; Figure 8f). Only 12.1 % of the dives were to depths ≥ 20 < 100 m depth.

August 1994

Two of the three seals successfully instrumented in August 1994 (OBI22, 23; winter) were deep divers, with average dive depths of slightly over 73 m (Table 1). The third (OBI24) was a shallow diver, with an average dive depth of about 30 m (Table 1). Their combined average dive depth was 45.8 m for 1.73 min duration and a bottom time of 0.66 min (Table 3). As has been the case at the other times, the majority of dives were shallower than 60 m, though there was diving activity to depths in excess of 160 m (Figure 6g). As was the case in July '92, July '93, and May '94, there was an increase in diving activity around 120-140 m depth. There was decreased diving activity between 1000 and 1600 h, and slightly increased diving activity around dawn and dusk (figure 7g). These data show an increase in average dive depth from mid-day on through the night, with a concomitant decrease in average dive depth from about 0800 to 1200 h (Figure 8g).

Season

When these data are further grouped into seasons (summer: February 1994; late summer March 1993; autumn: May 1991, May 1994 and winter: July 1992, July 1993, August 1994), a definite pattern begins to emerge (Figure 9a-c). Mean dive depth was significantly deeper in autumn and winter than in summer and late summer, as was dive duration. There was little difference in bottom time between summer and late summer, but both were significantly shorter than during autumn and winter. The deepest and longest dives recorded were in autumn and winter in all cases (Table 4).

DISCUSSION

What is immediately clear from this study is that there is considerable variation in dive behavior between individual fur seals foraging at the same time of year. As pronounced as this may be, it does not totally mask a seasonal variation in dive behavior , where females tend to dive deeper and longer in autumn and winter as opposed to summer. The New Zealand fur seal has the deepest recorded dive depths of the eight southern fur seal species and the northern fur seal. Dives in excess of 150 m depth were common, with some dives exceeding 200 m depth. Maximum dive depth recorded for other fur seal species for which there are data give maximum depths of 100-200 m, with mean dive depths of about 30 - 68 m (see Gentry and Kooyman 1986). Dives in excess of 150 m depth were recorded only during the austral autumn and winter, which suggests a possible change in diet from the warmer summer months.

Theoretically, a fur seal of about 30 - 40 kg mass has an aerobic dive limit (ADL) of about 3.4 - 3.5 minutes (Gentry *et al.* 1986). New Zealand fur seals not only are deep divers, but are able to stay submerged for times well in excess of the theoretical ADL. Dives in excess of the ADL, particularly repetitive dives, would cause the animal to go anaerobic with a concomitant lactic acid build-up. This in turn would require extended surface intervals for the animal to recover. If prey species are difficult to find, then the fur seals will have to work harder, either by making more dives, longer dives, deeper dives, or a combination of all three. This in turn could cause individual fur seals to approach or exceed their ADL on a regular basis. If prey abundance is indeed a factor forcing seals to dive deeper and/or longer, then it can be hypothesized that prey abundance decreases in winter as opposed to summer. For example, fur seals actively prey upon arrow squid (*Nototodarus* spp.), which support a major commercial fishery during the New Zealand summer (Mattlin *et al.* 1985). Arrow squid are not found in commercial concentrations during the winter. A study of seasonal fur seal diet is underway to identify prey species.

In general, New Zealand fur seals forage more at night, particularly during the summer and late summer. However, this is not a hard and fast rule, as shown by the individual variation seen in the experimental seals. Most daylight diving took place during the autumn and winter when the deepest dives were made. This suggests bottom foraging, where the seals may be preying on benthic fishes or octopus.

The sea in the immediate vicinity of the Open Bay Islands is relatively shallow, with water depths of 100 m or less within about 9 km of the islands. Dives in excess of 100 m depth must therefore be at or over the edge of the continental shelf, which is about 9 km from the island at the nearest point.

This study provides the first data on seasonal foraging in the New Zealand fur seal. They demonstrate a general seasonal trend towards deeper and longer dives during the autumn and winter. However, there was individual variation between experimental animals instrumented at the same time. These data therefore provide a base for comparison between the new Zealand fur seal and other pinnipeds, and between data collected on this species from different locations, times, and under different conditions.

LITERATURE CITED

Boyd, I.L., Lunn, N.J. and Barton, T. 1991. Time budgets and foraging characteristics of lactating Antarctic fur seals. Journal of Animal Ecology 60: 577-592.

Boyd, I.L. and Croxall, J.P. 1992. Diving behaviour of lactating Antarctic fur seals. Canadian Journal of Zoology 70: 919-928.

Boyd, I.L., Arnould, J.P.Y., Barton, T. and Croxall, J.P. 1994. Foraging behaviour of Antarctic fur seals during periods of contrasting prey abundance. Journal of Animal Ecology 63: 703-713.

Carey, P.W. 1992. Fish prey species of the New Zealand fur seal (*Arctocephalus forsteri*, Lesson). New Zealand Journal of Ecology 16: 41-46.

Costa, D.P. 1991. Reproductive and foraging energetics of pinnipeds: Implications for life history patterns. pp 300-344 *in:* Renouf, D. (ed). The behaviour of pinnipeds. Chapman and Hall, London.

Crawley, M.C. and G.J. Wilson. 1976. The natural history and behaviour of the New Zealand fur seal (*Arctocephalus forsteri*). Tuatara 22: 1-29.

DeLong, R.L. and Stewart, B.S. 1991. Diving patterns of northern elephant seal bulls. Marine Mammal Science 7: 369-384.

Fieldkamp, S.D., DeLong, R.L. and Antonellis, G.A. 1989. Foraging behavior of California sea lions, *Zalophus californianus*. Canadian Journal of Zoology 67: 872-883.

Gentry, R.L. and Holt, J.R. 1982. Equipment and techniques for handling northern fur seals. NOAA Technical Report NMFS SSRF-758. 15 p.

Gentry, R.L. and Kooyman, G.L. (eds). 1986. Fur seals: Maternal strategies on land and at sea. Princeton University Press, Princeton. 291 p.

Gentry, R.L., Costa, D.P., Croxall, J.P, David, J.H.M., Davis, R.W., Kooyman, G.L., Majluf, P., McCann, T.S., and Trillmich, F. 1986. Synthesis and conclusions. pp 220-264 *In:* Gentry, R.L. and Kooyman, G.L. (eds). Fur seals: Maternal strategies on land and at sea. Princeton University Press, Princeton. 291 p.

Hindell, M.A., Slip, D.J. and Burton, H.R. 1991. The diving behaviour of adult male and female southern elephant seals, *Mirounga leonina* (Pinnipedia: Phocidae). Australian Journal of Zoology 39: 593-619.

Kooyman, G.L. 1981. Weddell seal: Consummate diver. Cambridge University Press, Cambridge. 135 p.

Kooyman, G.L. 1989. Diverse divers: Physiology and behavior. Springer Verlag, Berlin & London. 200 p.

Kooyman, G.L., Gentry, R.L. and Urquhart, D.L. 1976. Northern fur seal diving behavior: A new approach to its study. Science 193: 411-412.

LeBoeuf, B.J., Costa, D.P., Huntley, A.C., Kooyman, G.L., and Davis, R.W. 1986. Pattern and depth of dives in northern elephant seals, *Mirounga angustirostris*. Journal of Zoology (Lond.) 208: 1-7.

Lydersen, C. and Hammill, M.O. 1993. Diving in ringed seal (*Phoca hispida*) pups during the nursing period. Canadian Journal of Zoology 71: 991-996.

Lydersen, C and Kovacs, K.M. 1993. Diving behaviour of lactating harp seal, *Phoca groenlandica*, females from the Gulf of St. Lawrence. Animal Behaviour 46: 1213-1221.

McConnell, B.J., Chambers, C. and Fedak, M.A. 1992. Foraging ecology of southern elephant seals in relation to the bathymetry and productivity of the Southern Ocean. Antarctic Science 4: 393-398.

Mattlin, R.H. 1978. Pup mortality of the New Zealand fur seal (*Arctocephalus forsteri* Lesson). New Zealand Journal of Ecology 1: 138-144.

Mattlin, R.H. 1981. Pup growth of the New Zealand fur seal *Arctocephalus forsteri* on the Open Bay Islands, New Zealand. Journal of Zoology (Lond). 193: 305-314.

Mattlin, R.H. 1987. New Zealand fur seal, *Arctocephalus forsteri*, within the New Zealand region. *in:* Croxall, J.P. and Gentry, R.L. (eds). Status, biology, and ecology of fur seals; Proceedings of an international symposium and workshop. Cambridge, England, 23-27 April 1984. NOAA Technical Report NMFS 51: 49-51.

Mattlin, R.H., Scheibling, R.E. and Förch, E.C. 1985. Distribution, abundance and size structure of arrow squid (*Nototodarus* sp.) off New Zealand. Northwest Atlantic Fisheries Organization Scientific Council Studies No. 9: 39-45.

Miller, E.H. 1975. Annual cycle of fur seals, *Arctocephalus forsteri* (Lesson), on the Open Bay Islands, New Zealand. Pacific Science 29: 139-152.

Riedman, M. 1990. The pinnipeds: seals, sea lions and walruses. University of California Press, Berkeley. 439p.

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NOTE: Papers are in preparation arising from this research program. Copies of all published papers will be forwarded to the Office of Naval Research.

Table 1. Dive summary for all dives
Minimum dive depth recorded for OBI01-OBI10 = 2 m
Minimum dive depth recorded for OBI11-OBI24 = 4 m
OBI02 and OBI08 dove to depths => maximum recording capability of the TDR (237+/-1m)

ID	Body Wt. (kg)	Dates of Deployment	Season	No Dives	Mean Depth (m) +/- s.e.	Max Depth (m)	Median Depth (m)	Mean Duration (min) +/- s.e.	Max Duration (min)	Median Duration (min)	Mean Bottom Time (min) +/- s.e.	Max Bottom Time (min)	Median Bottom Time (min)
OBI01		24-28 May 91	Autumn	648	6.1 +/- 0.6	128	2	0.54 +/- 0.04	6	0.17	0.17 +/- 0.02	3.5	0
OBI02		13-23 Jul 91	Winter	1005	58.8 +/-2.5	237+	17	2.54+/-0.09	11.2	1.5	1.20 +/- 0.05	7.33	0.33
OBI03		14-27 Jul 91	Winter	1934	74.3 +/- 1.3	229	86	2.30 +/- 0.03	9.8	2.67	0.79 +/- 0.02	3.5	0.67
OBI04		12-19 Mar 93	Late Summer	2037	24.7 +/- 0.7	199	12	1.31 +/- 0.02	5.3	1.33	0.50 +/- 0.01	3.33	0.33
OBI05		12-20 Mar 93	Late Summer	1796	24.9 +/- 0.5	129	25	1.19 +/- 0.02	5.7	1.17	0.31 +/- 0.12	4.67	0.17
OBI07		11-25 Mar 93	Late Summer	3170	23.9 +/- 0.4	120	18	1.06 +/- 0.01	4.5	1	0.28 +/- 0.01	2.33	0.17
OBI08		30 Jun-9 Jul 93	Winter	1219	58.4 +/- 2.4	237+	15	2.34 +/- 0.08	9.17	0.83	1.12 +/- 0.04	5.5	0.17
OBI09		30 Jun-12 Jul 93	Winter	4971	13.4 +/- 0.3	165	4	1.02 +/- 0.02	6.17	0.33	0.44 +/- 0.01	4.33	0
OBI10		1-15 Jul 93	Winter	2492	40.7 +/- 1.1	226	3	1.77 +/- 0.04	6.67	0.67	0.73 +/- 0.02	4.17	0.17
OBI11	35.5	5 Feb-12 Aug 94	Summer	2498	16.4 +/- 0.3	150	12	0.95 +/- 0.01	4.42	0.83	0.35 +/- 0.01	2.25	0.17
OBI13	38	6-18 Feb 94	Summer	1690	24.9 +/- 1.0	186	6	1.01 +/- 0.03	5.58	0.33	0.39 +/- 0.01	2.92	0.08
OBI18	39	21-26 May 94	Autumn	380	63.0 +/- 2.6	248	50	2.68 +/- 0.07	6.33	2.67	1.21 +/- 0.04	5	1.08
OBI19	40.5	21-31 May 94	Autumn	299	49.3 +/- 3.0	224	26	2.36 +/- 0.10	5.67	2.25	1.00 +/- 0.05	3.5	0.83
OBI20	38	22-31 May 94	Autumn	205	89.1 +/- 3.6	150	118	3.21 +/- 0.10	5.33	3.67	1.55 +/- 0.06	3.08	1.75
OBI21	46	22 May-16 Aug 94	Autumn	3785	68.7 +/- 0.9	274	66	2.55 +/- 0.02	7.17	2.75	1.12 +/- 0.01	4.75	1
OBI22	38.5	12-20 Aug 94	Winter	966	73.2 +/- 1.8	238	68	2.48 +/- 0.05	5.67	2.75	0.94 +/- 0.02	4.25	0.83
OBI23	36.5	12-25 Aug 94	Winter	1632	73.5 +/- 1.4	212	60	2.43 +/- 0.03	6.08	2.75	0.88 +/- 0.02	3.42	0.75
OBI24	31	13-25 Aug 94	Winter	4228	28.9 +/- 0.5	236	16	1.29 +/- 0.02	5	1.08	0.53 +/- 0.01	3.08	0.25

Table 2. Dive summary for all dives >=6m

\+ some dives equalled or exceeded the maximum recording capability of the TDR (237+/-1m)

ID	Dates of Deployment	Season	No Dives	Mean Depth (m) +/- s.e.	Max Depth (m)	Median Depth (m)	Mean Duration (min) +/- s.e.	Max Duration (min)	Median Duration (min)	Mean Bottom Time (min) +/- s.e.	Max Bottom Time (min)	Median Bottom Time (min)
OBI01	24-28 May 91	Autumn	100	26.7 +/- 3.0	128	15	2.22 +/- 0.14	6	2	0.94 +/- 0.08	3.5	0.75
OBI02	13 - 23 Jul 91	Winter	576	100.8 +/- 3.5	237+	70.5	4.21 +/- 0.11	11.2	3.5	2.05 +/- 0.08	7.33	1.5
OBI03	14 - 27 Jul 91	Winter	1480	96.3 +/- 1.3	229	115	2.91 +/- 0.03	9.8	3	1.01 +/- 0.02	3.5	1
OBI04	12 - 19 Mar 93	Late Summer	1361	35.6 +/- 0.90	199	23	1.80 +/- 0.02	5.3	1.67	0.69 +/- 0.02	3.33	0.67
OBI05	12 - 20 Mar 93	Late Summer	1336	32.7 +/- 0.5	129	31	1.50 +/- 0.02	5.67	1.33	0.39 +/- 0.02	4.67	0.17
OBI07	11 - 25 Mar 93	Late Summer	2000	36.5 +/- 0.5	120	32	1.52 +/- 0.01	4.5	1.5	0.40 +/- 0.01	2.17	0.33
OBI08	30 Jun - 9 Jul 93	Winter	760	92.4 +/- 3.2	237+	42	3.61 +/- 0.10	9.17	2.58	1.75 +/- 0.06	5.5	1
OBI09	30 Jun - 12 Jul 93	Winter	1849	31.34 +/- 0.6	165	27	2.26 +/- 0.03	6.17	2.17	1.10 +/- 0.02	4.33	0.83
OBI10	1 - 15 Jul 93	Winter	1185	83.1 +/- 1.5	226	104	3.40 +/- 0.04	6.67	3.83	1.44 +/- 0.03	4.17	1.33
OBI11	5 Feb - 12 Aug 94	Summer	2298	17.4 +/- 0.3	150	12	1.02 |/- 0.01	4.42	0.92	0.38 +/- 0.01	2.25	0.25
OBI13	6 - 18 Feb 94	Summer	922	42.3 +/- 1.5	186	18	1.72 +/- 0.04	5.58	1.33	0.64 +/- 0.02	2.92	0.42
OBI18	21 - 26 May 94	Autumn	366	65.2 +/- 2.6	248	52	2.78 +/- 0.07	6.33	2.67	1.25 +/- 0.04	5	1.08
OBI19	21 - 31 May 94	Autumn	239	60.64 +/- 3.4	224	50	2.90 +/- 0.09	5.67	3.08	1.22 +/- 0.05	3.5	1.17
OBI20	22 - 31 May 94	Autumn	185	98.3 +/- 3.4	150	118	3.54 +/- 0.08	5.33	3.83	1.72 +/- 0.06	3.08	1.83
OBI21	22 May - 16 Aug 94	Autumn	3400	76.1 +/- 0.9	274	76	2.82 +/- 0.02	7.17	3	1.23 +/- 0.02	4.75	1.17
OBI22	12 -20 Aug 94	Winter	886	79.4 +/- 1.8	238	78	2.68 +/- 0.04	5.67	3	1.01 +/- 0.02	4.25	0.83
OBI23	12 - 25 Aug 94	Winter	1529	78.2 +/- 1.5	212	66	2.58 +/- 0.03	6.08	2.83	0.94 +/- 0.02	3.42	0.75
OBI24	13 - 25 Aug 94	Winter	3847	31.3 +/- 0.5	236	18	1.40 +/- 0.02	5	1.17	0.56 +/- 0.01	3.08	0.33

Table 3. Data summary by trip.
* = one or more dives at or exceeded maximum of TDR

Date	Dive Number	sample size	mean depth	+/-s.e.	max depth	median depth	mean duration	+/-s.e.	max duration	median duration	mean bottom time	+/-s.e.	max bottom time	median bottom time
May '91	OBI01	648	6.08	0.58	128	2	0.54	0.04	6	0.17	0.17	0.02	3.5	0
July '92	OBI02, 03	2939	69.00	1.23	237*	53	2.38	0.04	11.17	2.5	0.93	0.02	7.33	0.67
March '93	OBI04, 05, 07	7003	24.40	0.31	199	18	1.16	0.01	5.67	1.17	0.35	0.01	4.67	0.17
July '93	OBI08, 09, 10	8682	27.55	0.52	237*	4	1.42	0.02	9.17	0.33	0.62	0.01	5.5	0
February '94	OBI11, 13	4188	19.82	0.31	186	4	0.98	0.01	5.58	0.08	0.37	0.01	2.92	0
May '94	OBI18, 19, 20, 21	4669	67.91	0.81	274	62	2.58	0.02	7.17	2.75	1.14	0.01	5	1.08
August '94	OBI22, 23, 24	6826	45.81	0.59	238	20	1.73	0.02	6.08	1.5	0.67	0.01	4.25	0.5

Table 4. Data summary by trip.
* = one or more dives at or exceeded maximum of TDR
Dives >=6m depth

Date	Dive Number	sample size	mean depth	+/-s.e.	max depth	median depth	mean duration	+/-s.e.	max duration	median duration	mean bottom time (min)	+/-s.e.	max bottom time (min)	median bottom time (min)
May '91	OBI01	100	26.67	3.04	128	15	2.22	0.14	6	2	0.94	0.08	3.5	0.75
July '92	OBI02, 03	2056	97.57	1.34	237*	113	3.27	0.04	11.17	3.17	1.3	0.03	7.33	1
March '93	OBI04, 05, 07	4697	35.15	0.37	199	30	1.6	0.01	5.67	1.5	0.48	0.01	4.67	0.33
July '93	OBI08, 09, 10	3794	59.74	0.96	237*	38	2.88	0.03	9.17	2.67	1.34	0.02	5.5	1.17
February '94	OBI11, 13	3220	24.58	0.53	186	14	1.22	0.02	5.58	1	0.45	0.01	2.92	0.25
May '94	OBI18, 19, 20, 21	4190	75.21	0.83	274	74	2.85	0.02	7.17	3	1.25	0.01	5	1.25
August '94	OBI22, 23, 24	6262	49.57	0.62	238	24	1.87	0.02	6.08	1.67	0.72	0.01	4.25	0.58

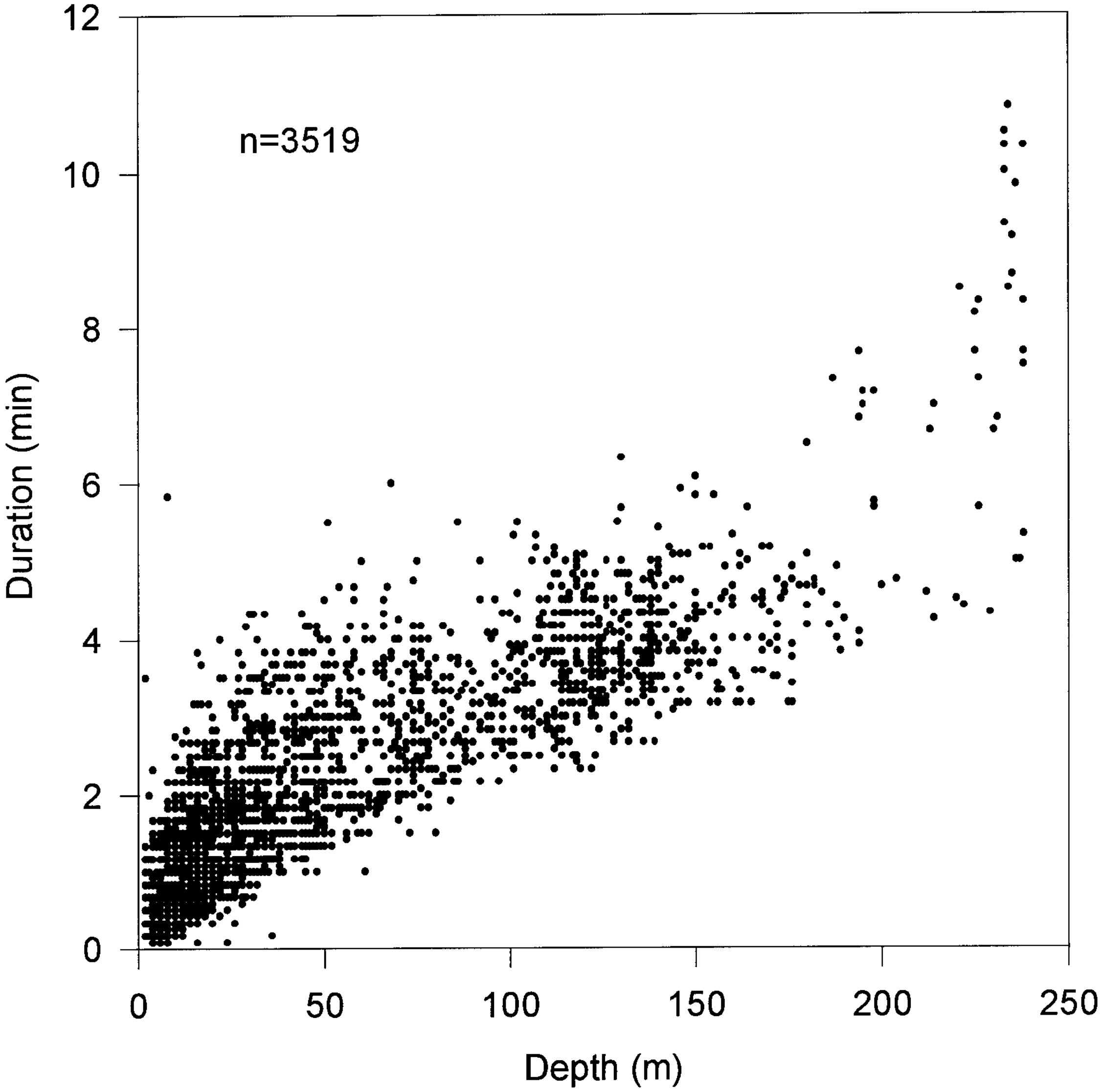


Figure 1. Random sample of about 10% of all dives showing duration (minutes) by maximum depth (meters).

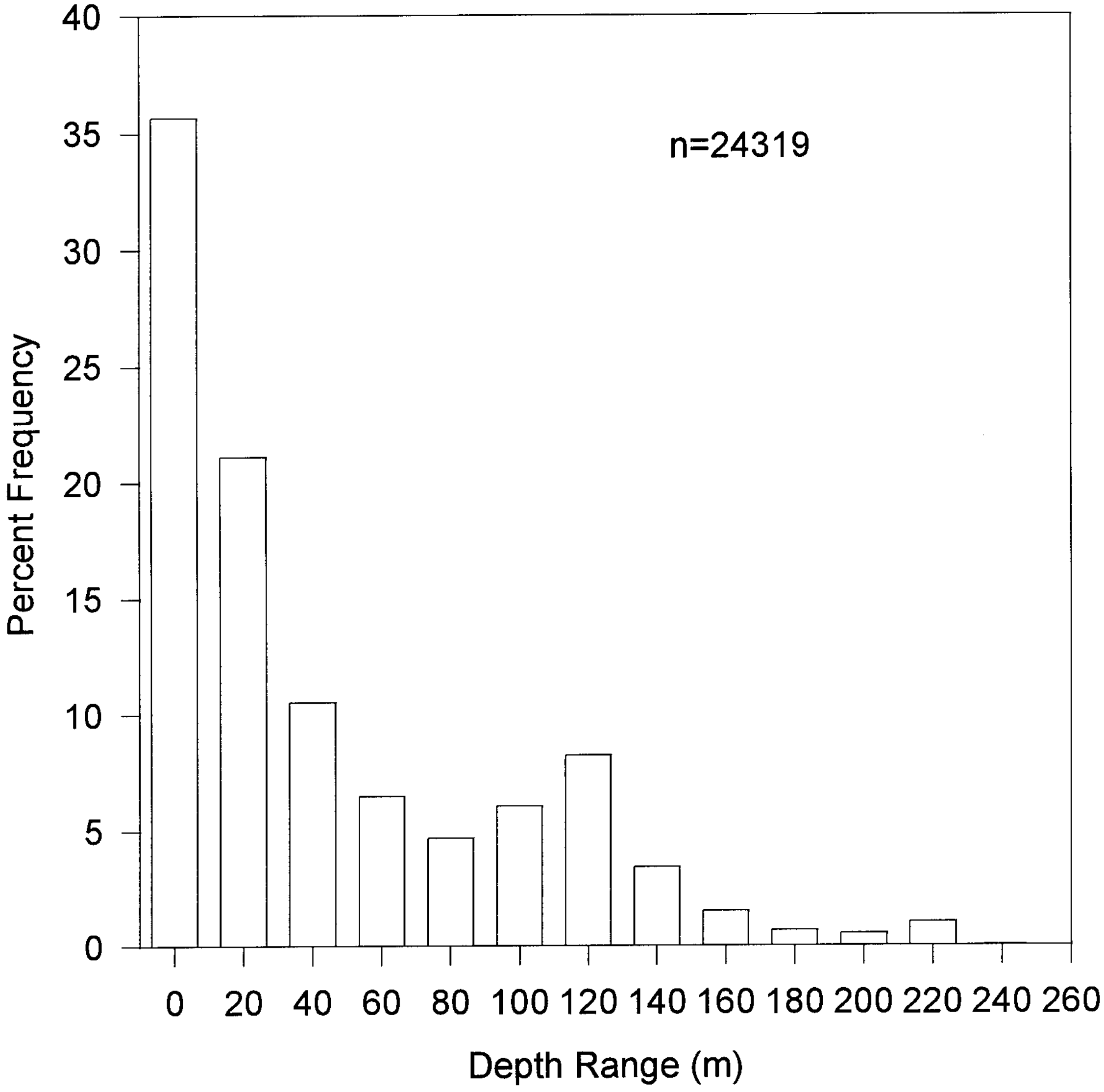


Figure 2. Percent frequency of all dives >= 6 m depth by 20 m block.

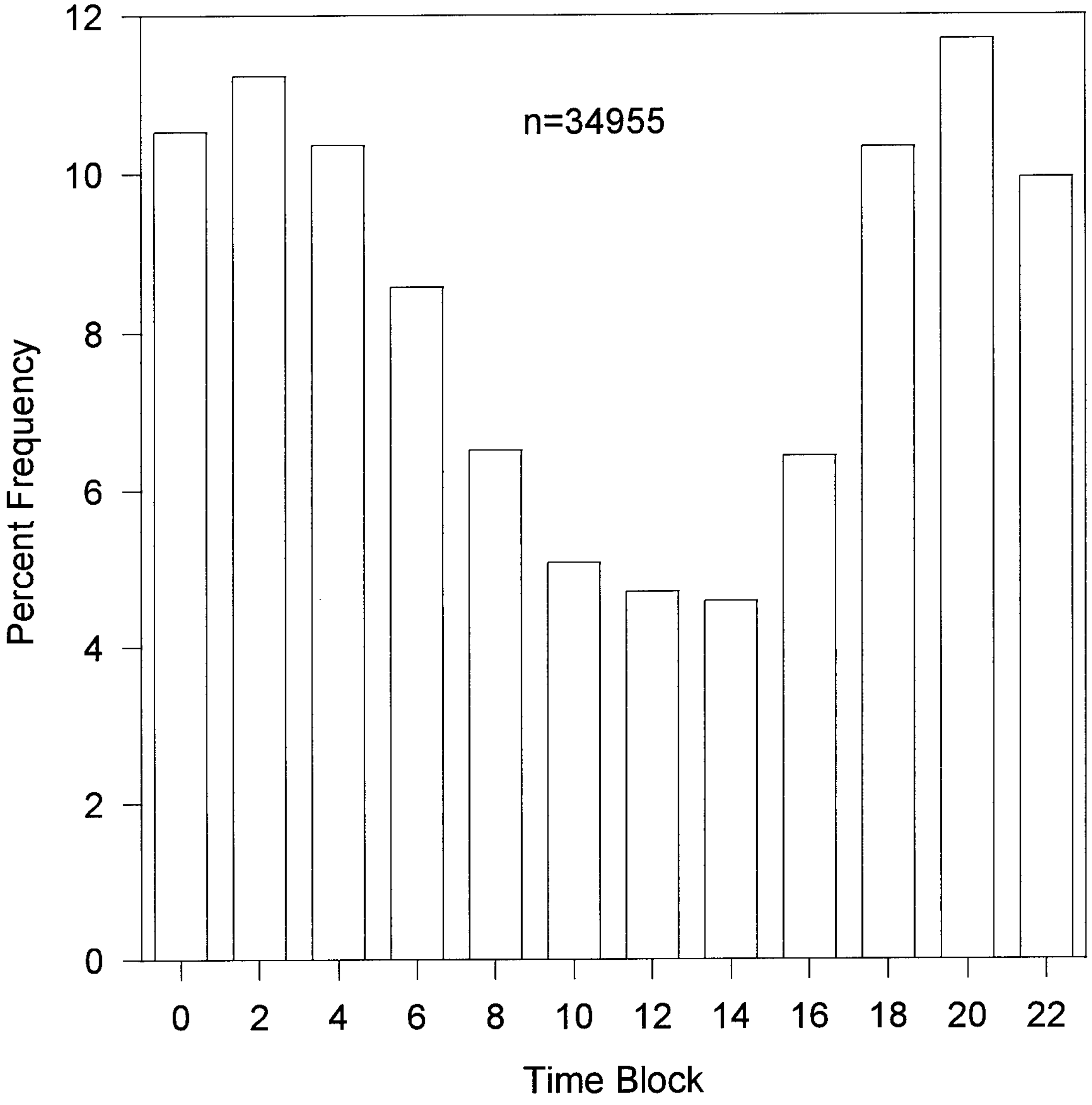


Figure 3. Percent Frequency of all dives by two hour time block.

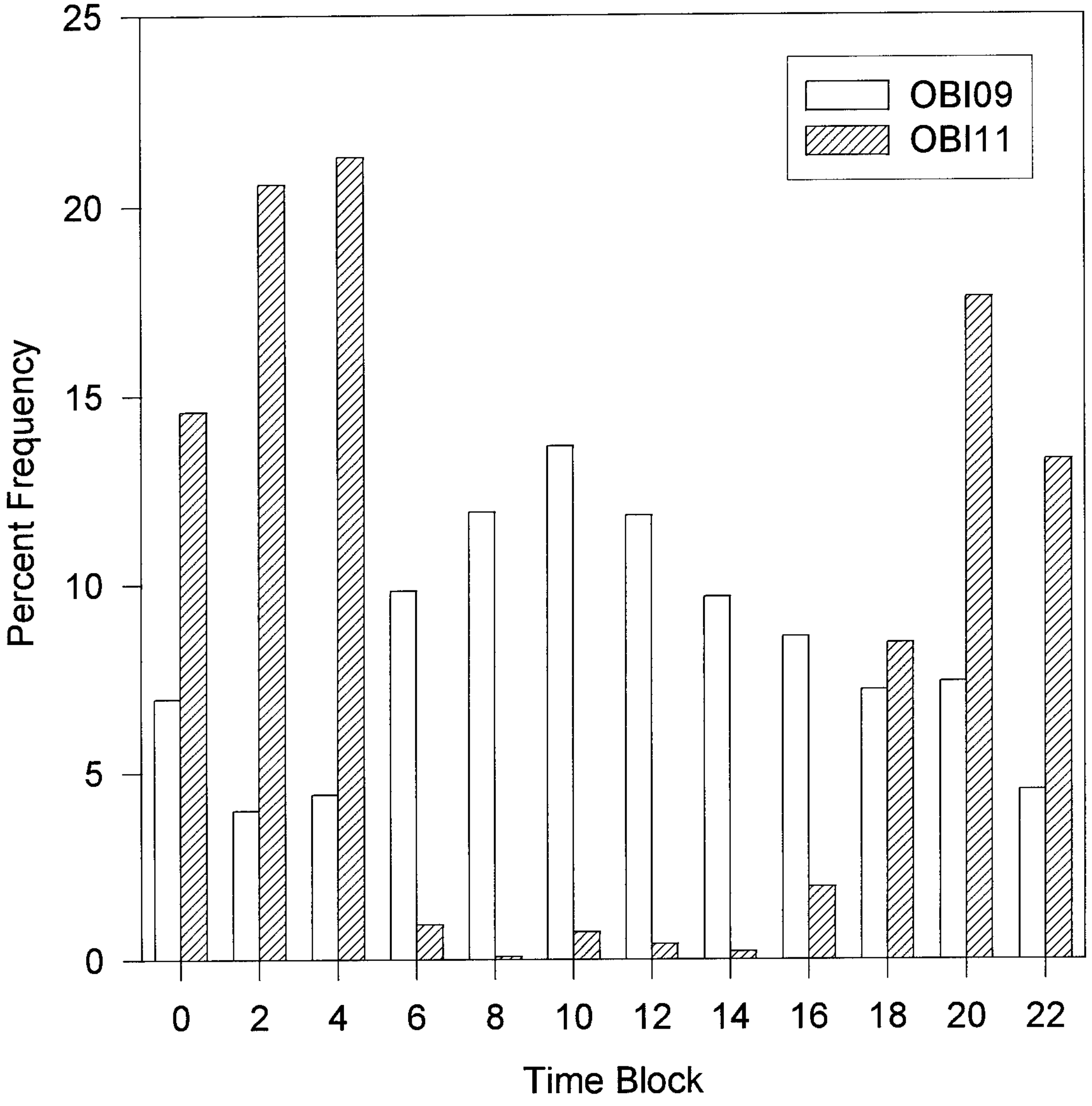


Figure 4. Percent frequency of dives for OBI09 and OBI11 by two hour time block.

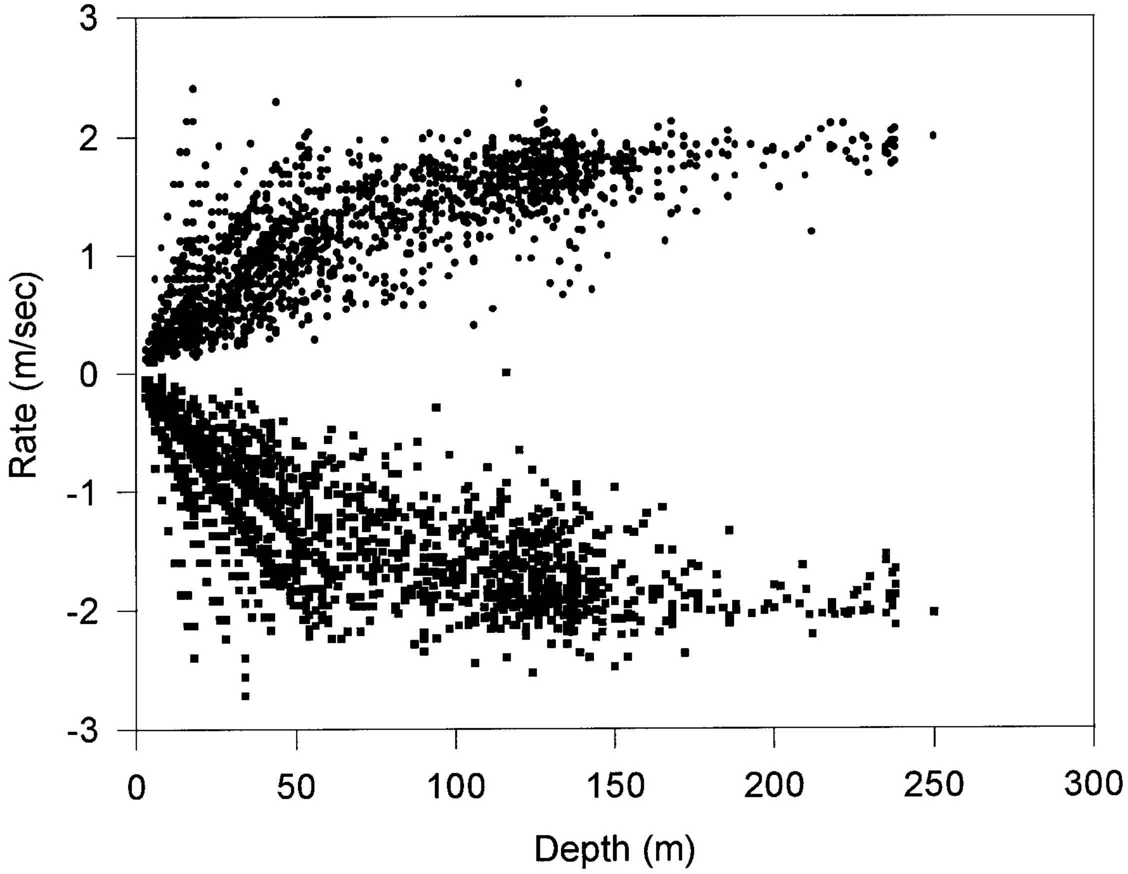


Figure 5. Average rate of descent and ascent by maximum depth of dive for a random sample of 2000 dives.

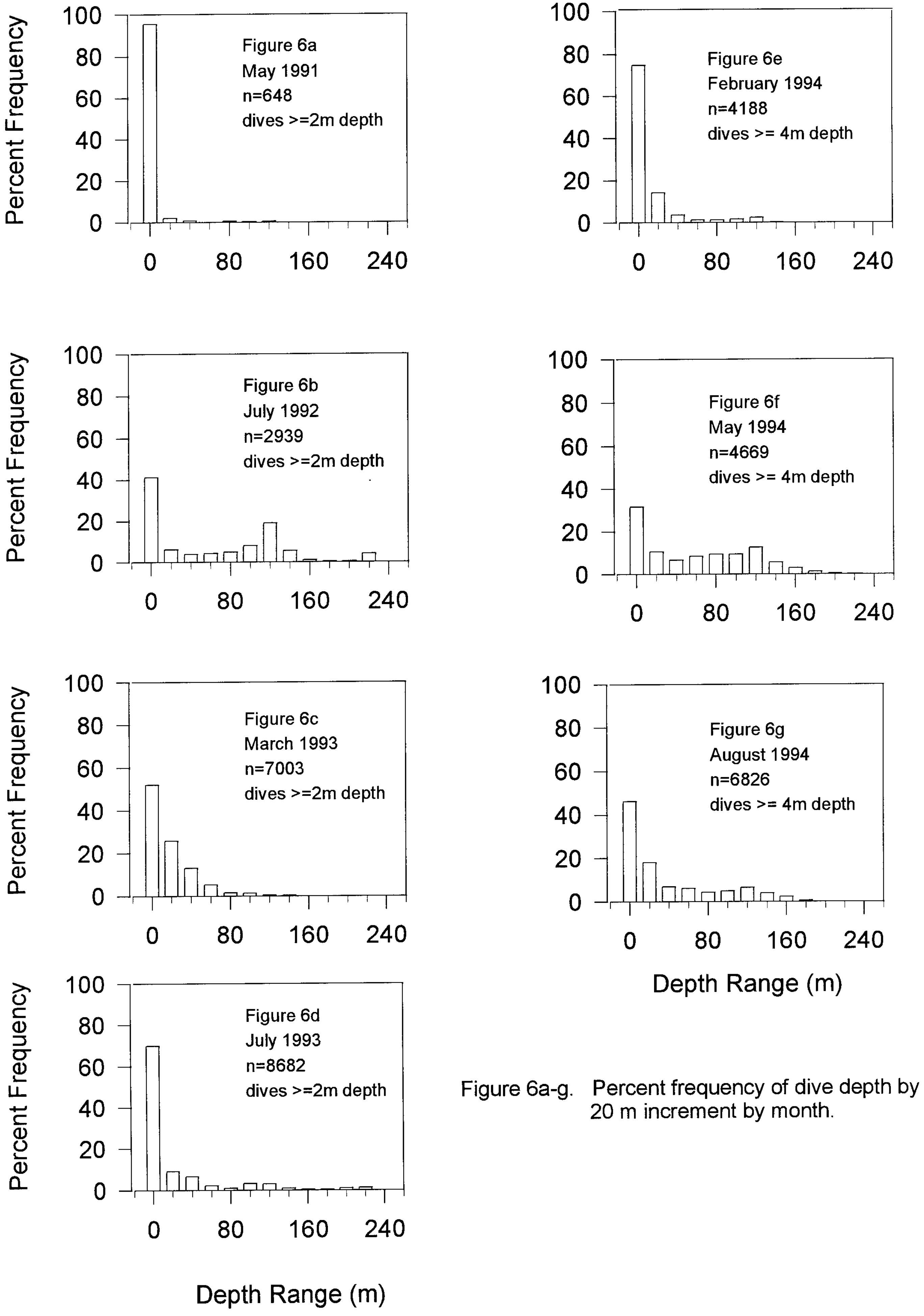
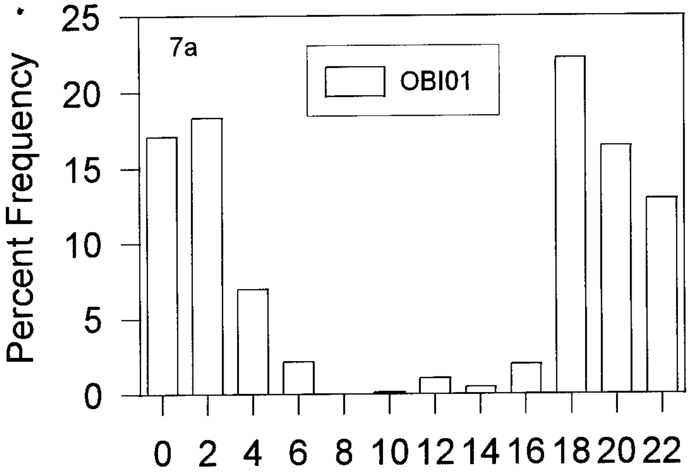


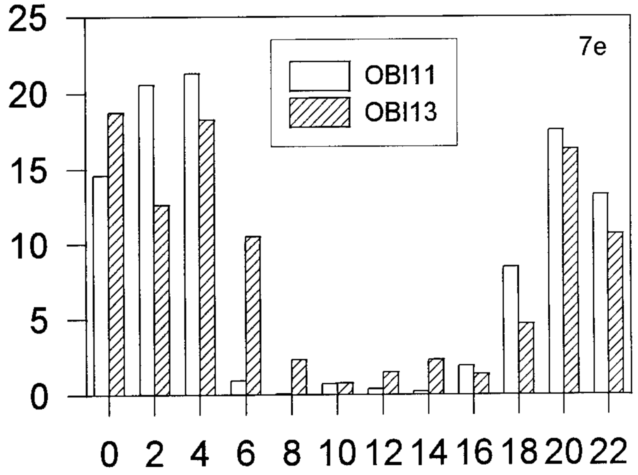
Figure 6a-g. Percent frequency of dive depth by 20 m increment by month.

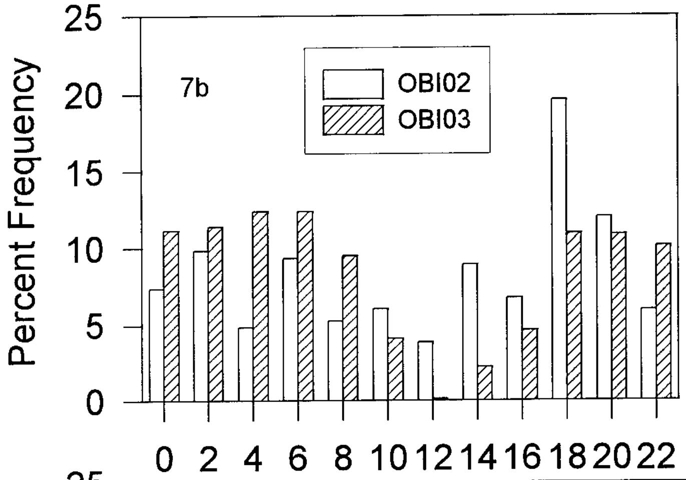
Figure 7a-g. Percent frequency of dives by two hour time block (e.g. time block 0 = 0000 - 0159 h, time block 2 = 0200 - 0359 h, etc). 7a = May 1991, 7b = July 1992, 7c = March 1993, 7d = July 1993, 7e = February 1994, 7f = May 1994, 7g = August 1994.

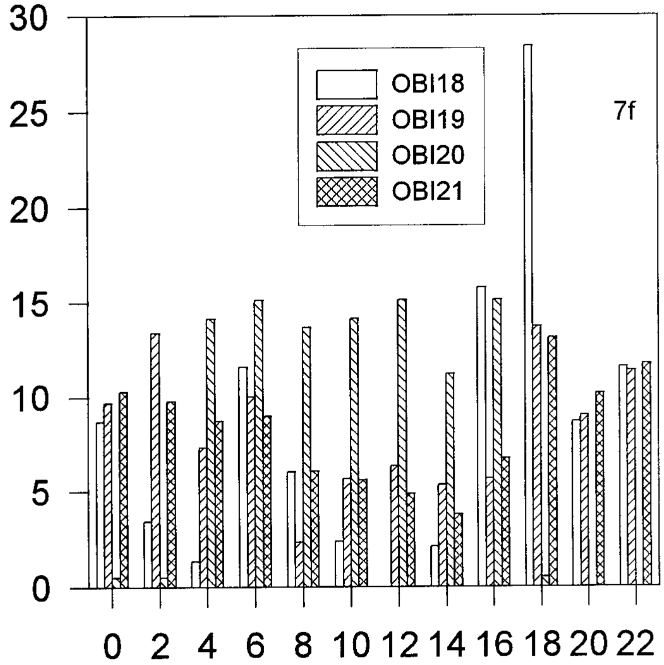
Figure 8a-g. Mean dive depth ± s.e. (meters) by time block (e.g. time block 0 = 0000 - 0159 h, time block 2 = 0200 - 0359 h, etc). 8a = May 1991, 8b = July 1992, 8c = March 1993, 8d = July 1993, 8e = February 1994, 8f = May 1994, 8g = August 1994.

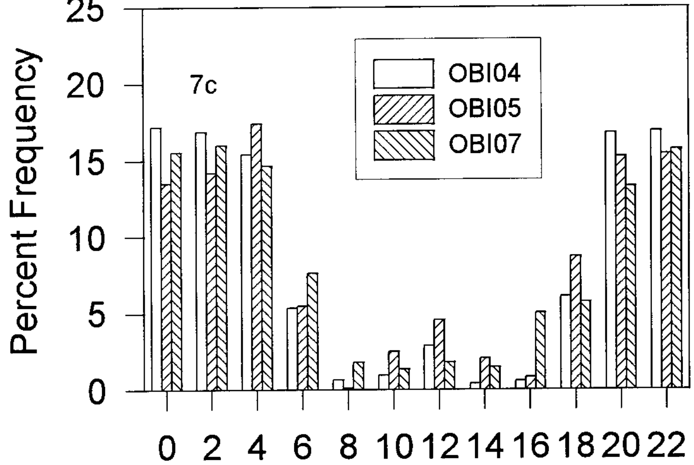
Figure9a-c. 9a. Mean dive depth ± s.d. (meters), 9b. mean dive duration ± s.d. (minutes) and 9c. mean bottom time ± s.d. (minutes) by season (Summer = OBI11, 13; Late Summer = OBI04, 05, 07: Autumn = OBI01, 18, 19, 20, 21; Winter = OBI02, 03, 08, 09, 10, 22, 23, 24).

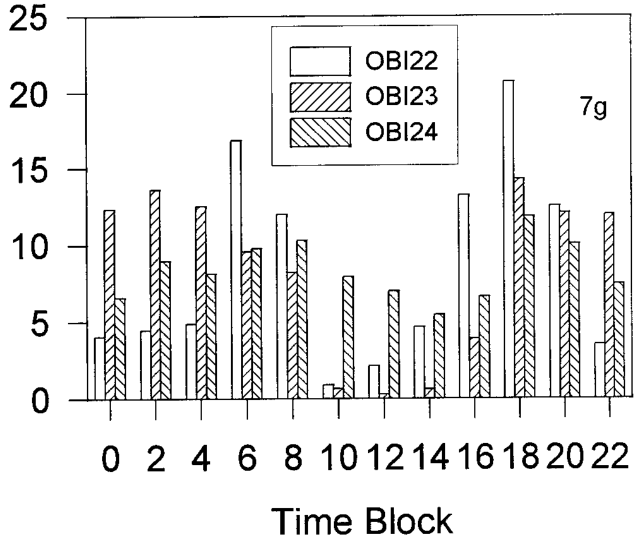

7a
OBI01
Percent Frequency
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22

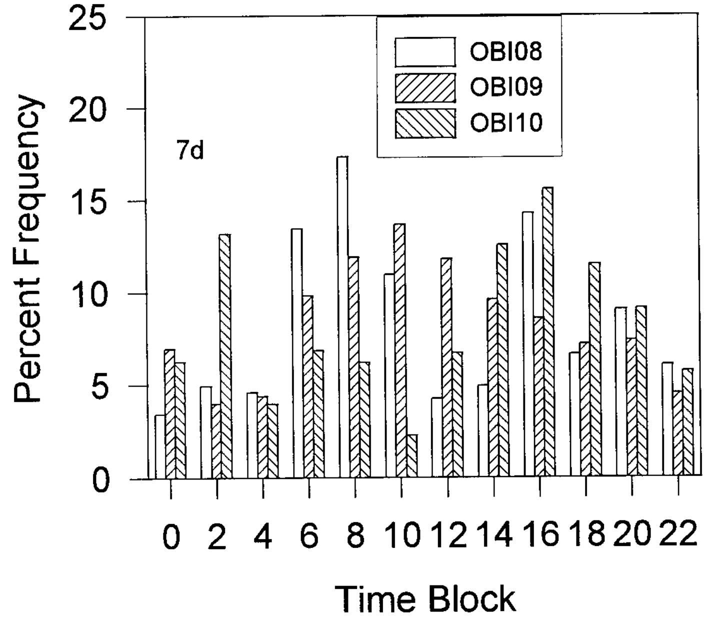

7e
OBI11
OBI13
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22

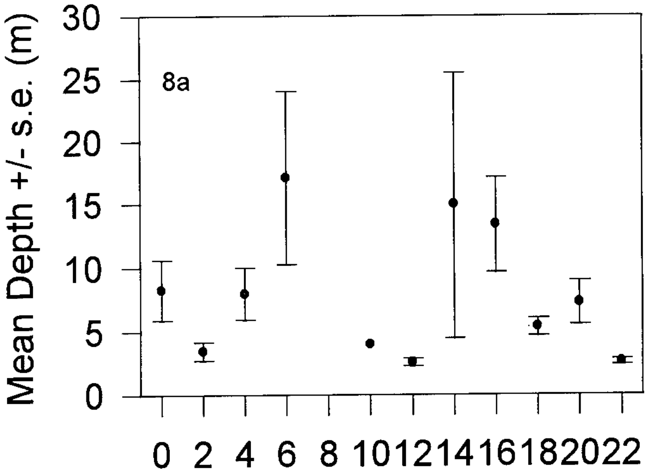

7b
OBI02
OBI03
Percent Frequency
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22

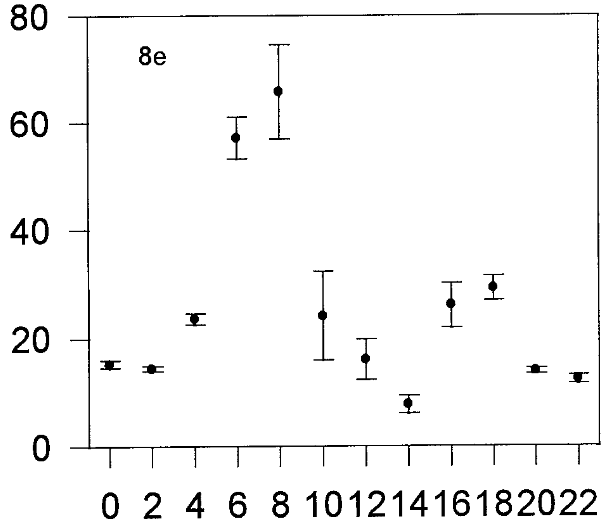

7f
OBI18
OBI19
OBI20
OBI21
0
5
10
15
20
25
30
0 2 4 6 8 10 12 14 16 18 20 22

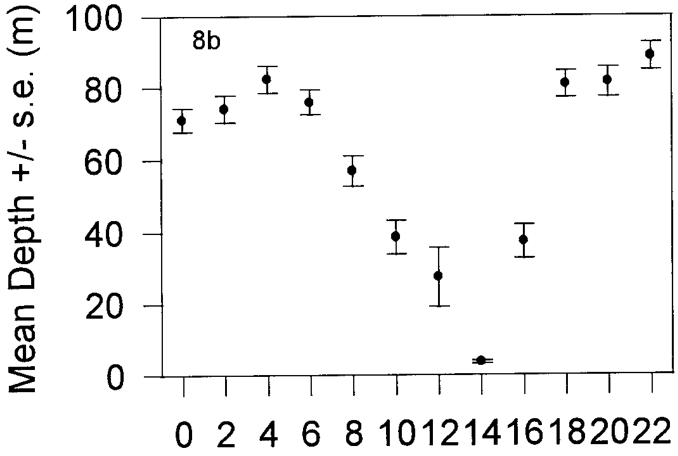

7c
OBI04
OBI05
OBI07
Percent Frequency
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22

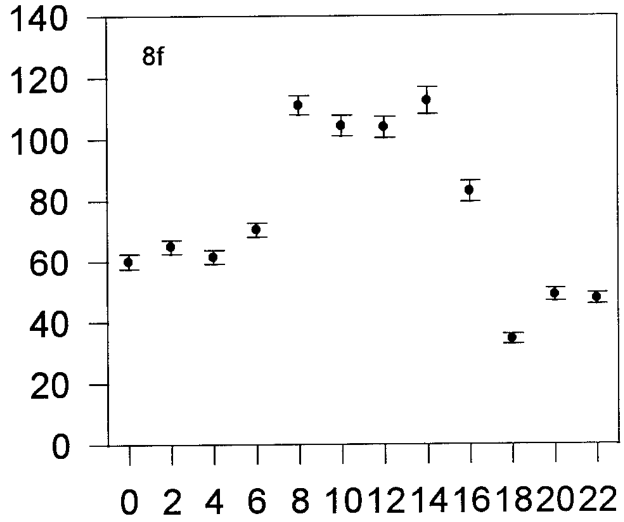

7g
OBI22
OBI23
OBI24
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22
Time Block

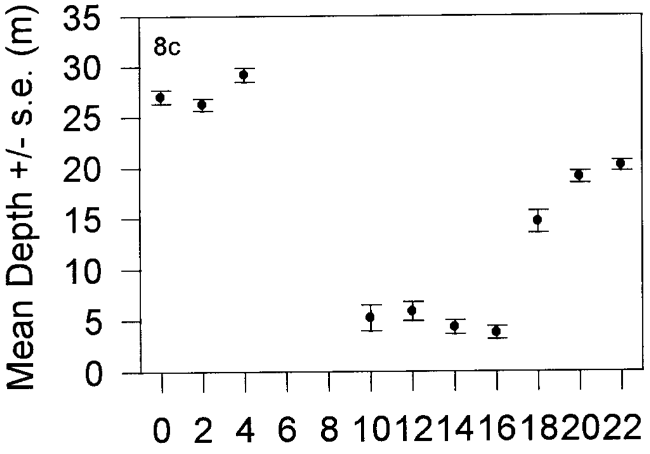

7d
OBI08
OBI09
OBI10
Percent Frequency
0
5
10
15
20
25
0 2 4 6 8 10 12 14 16 18 20 22
Time Block

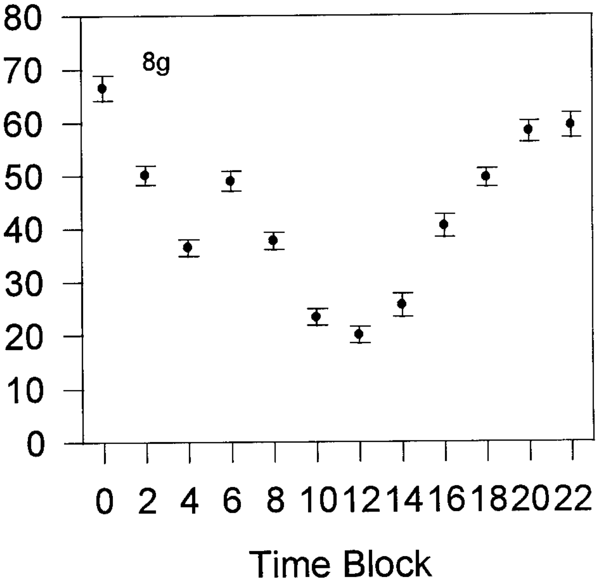

8a
Mean Depth +/- s.e. (m)
0
5
10
15
20
25
30
0 2 4 6 8 10 12 14 16 18 20 22

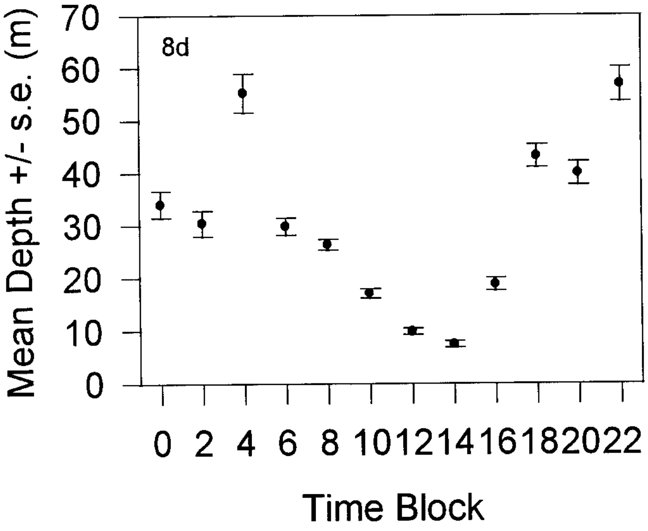

8e
0
20
40
60
80
0 2 4 6 8 10 12 14 16 18 20 22

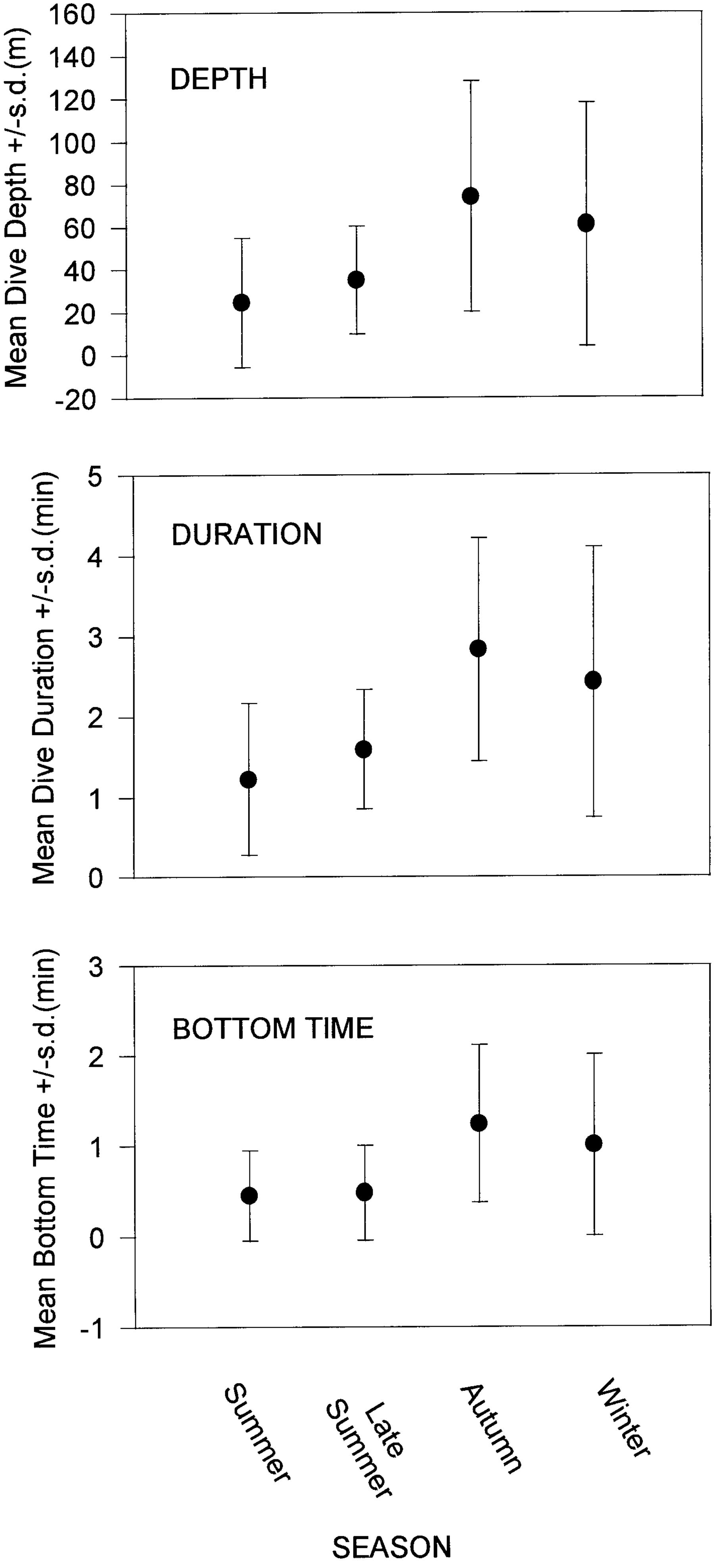

8b
Mean Depth +/- s.e. (m)
0
20
40
60
80
100
0 2 4 6 8 10 12 14 16 18 20 22


8f
0
20
40
60
80
100
120
140
0 2 4 6 8 10 12 14 16 18 20 22


8c
Mean Depth +/- s.e. (m)
0
5
10
15
20
25
30
35
0 2 4 6 8 10 12 14 16 18 20 22


8g
0
10
20
30
40
50
60
70
80
0 2 4 6 8 10 12 14 16 18 20 22
Time Block


8d
Mean Depth +/- s.e. (m)
0
10
20
30
40
50
60
70
0 2 4 6 8 10 12 14 16 18 20 22
Time Block


DEPTH
Mean Dive Depth +/-s.d.(m)
160
140
120
100
80
60
40
20
0
-20
DURATION
Mean Dive Duration +/-s.d.(min)
5
4
3
2
1
0
BOTTOM TIME
Mean Bottom Time +/-s.d.(min)
3
2
1
0
-1
Summer
Late Summer
Autumn
Winter
SEASON

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