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YELLOW-EYED PENGUIN FORAGING STUDY, SOUTH-EASTERN NEW ZEALAND, 1991-1993

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CONTENTS

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by
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ABSTRACT

Foraging ranges of Yellow-eyed Penguins (*Megadyptes antipodes*) were estimated using radio telemetry during the 1991-92 and 1992-93 breeding seasons off Otago Peninsula, and late in the chick rearing period at the Catlins. Birds at Otago Peninsula foraged over the continental shelf, on average 16 km (up to 57 km) from the breeding area. Individuals retained their inshore or offshore foraging patterns at different times of the breeding season and in different years. Most foraging trips were for less than 24 hours, but were longer during incubation, especially in 1991-92. Dive depth recorders combined with radio tags showed that the penguins dived to the sea floor; up to 66 m deep off the Otago Peninsula and 128 m off the Catlins. The main zones used were the wide flat expanses of continental shelf 40-80 m deep off Otago Peninsula and 80-120 m off the Catlins.

Thirty-seven types of prey made up the diet, with nine fish and one squid species constituting 95% of the estimated biomass and 67% of prey items. Opalfish, a bottom dwelling species, was the most important component of the diet in terms of the total biomass, numbers and frequency at which it was eaten. Other important biomass components were Blue Cod, Arrow Squid and Silverside. Penguins mainly ate bottom dwelling species but also pelagic prey.

The 1991-92 breeding season was more successful on the Otago Peninsula than at Catlins, Codfish or Campbell Islands, but the 1992-93 season was successful in all the areas. Since the population crash in January 1990, the three subsequent breeding seasons were increasingly productive. Nest numbers doubled after 1990-91 and further increased slightly in 1992-93.

1. INTRODUCTION

The Hoiho, Yellow-eyed Penguin (*Megadyptes antipodes*), population on the South Island of New Zealand has undergone several declines in recent years, particularly in early 1990, when about 150 adults died mysteriously around Otago Peninsula (Gill and Darby 1993). In response, the Science & Research Division and the Otago Conservancy of the Department of Conservation (DOC) embarked on a research programme. The aim was to investigate how Yellow-eyed Penguins use the marine environment, whether this changes between "good" and "bad" seasons (in terms of breeding success and adult survival), and thus identify some of the causes of declines. The Pilot Study has been reported, and gives a full introduction and details of methods used (Moore *et al.* 1991). The use of electronic devices to study foraging activity of penguins is the first of its kind in New Zealand. This report covers preliminary results of the first two full field seasons (1991-92, 1992-93) at the Otago Peninsula and Catlins study sites. Breeding data has also been collected from Yellow-eyed Penguin breeding areas by DOC staff on Codfish and Campbell Islands for comparative purposes. A third intensive field season will be conducted if it appears that Yellow-eyed Penguins are again going to have a "bad season".

2. AIMS

The aims of the study during the 1991-92 and 1992-93 breeding seasons at Otago Peninsula and Catlins were to:

- define the foraging ranges of penguins at different stages of the breeding season;
- study diving behaviour;
- describe their diet;
- measure breeding success and chick weights.

3. METHODS

3.1 Foraging Activity

Radio transmitter packages (Sirtrack Electronics, Landcare Research, Havelock North) measured 70 mm X 35 mm X 10 mm and weighed c.42 g. Each unit contained a one milliwatt transmitter and three 750 MA/hr lithium batteries in series, which gave power for about six weeks. The 280 mm long aerial was a thinner gauge than used in 1990-91. They were glued to the lower back of penguins using a contact adhesive, *Loctite 401*. These radio tags were put on 14 Otago Peninsula penguins from eight nests, 11 from Boulder Beach A1 Section, (including six that were radio tagged in February 1991) and three from adjacent Highcliff nests. Two partners from the eight nest sample were also radio tagged for part of the October 1991 period but were not subsequently tagged. This was because one bird headed around the coast to the north-east and could not be radio-tracked and the other radio tag was transferred to a bird that had been tagged the previous season.

Study periods were defined as when adults were: incubating eggs (9-31 October 1991, 1992); brooding chicks at the "guard" stage (26 November-15 December 1991; 24 November-10 December 1992); and rearing older chicks at the "post-guard" stage of the breeding season (13-31 January 1992; 11-27 January 1993). Thirteen birds were radio tagged at Long Point, on the Catlins coastline, from 1-15 February 1992 and 10 birds (including six from the previous season) from 2-12 February 1993. Radio tags were applied at the beginning and removed by peeling away from the feathers at the end of each study period at each site.

In 1992-93 a number of radio tags leaked and stopped transmitting, so that new ones had to be applied during the tracking period. Occasionally, radio tags fell off, e.g. at the Catlins in February 1992, four out of 13 tags were lost at sea, mainly because of very wet conditions during application. Gluing was improved the following summer by sanding the tag bottoms and cleaning with alcohol before application. There were no radio tag losses during the 1992-93 season.

An automatic data-logging station recorded the presence or absence of transmitter signals every 10 minutes in each tracking period at the study areas. The station had a fixed single array of five-element Yagi antenna on a 2.5 m mast. A box at the base of the mast contained a *Control-03* data-logger (M. Wilson, Wellington Polytechnic), a *Telonics TDP-2* data processor, a DOC-17 controller (Murray Douglas, S&R Division, DOC, Wellington) and a battery.

To track bird movements at sea, receiving stations were set up approximately 15 km apart on the Otago Peninsula coastline, near Sandymount trig (319 m a.s.l.) and Cargills Castle (100 m) (Fig. 1a). At each station a dual array of five-element Yagi antennae was mounted on a 3.25 m rotatable mast, similar to Hallberg *et al.* (1974). The antenna arrays were vertically polarised and wired 180° out of phase using 1/4 wavelength baluns. An adjustable protractor rose, marked in degrees, was clamped over a graticule in the base housing. *Wildlife Materials Falcon V* and *Telonics TR-4* biotelemetry receivers were used. Hourly radio-directions of each radio-tagged penguin were determined by locating the null between the two main peaks of signal amplitude simultaneously from each station. This was generally done for periods of about 7 hours a day (up to 16 hours for two days) during the tracking period. Bearings were relative to radio-directions of three land or island-based test transmitters from each station. Penguin positions at sea were later estimated by computer plotting the intersection of the radio bearings (program by Ross Pickard, S&R Division, DOC, Wellington).

Offshore bathymetry at the Catlins (Fig. lb), differs from that of the Otago Peninsula. Although the edge of the continental shelf is a similar distance offshore (about 35 km), the 50-70 m contours at the Catlins are only 1-2 km offshore, and there is a wide area of shelf 80-130 m deep. A two-station system, similar to that used in Otago, was set up in the Catlins at Hinahina Cove (140 m a.s.l.) and Florence Hill (160 m), either side of Long Point, 110 km south-west of Otago Peninsula (Fig. lb). This area was chosen for radio-tracking because penguin breeding and diet was being studied there and access was good. Problems in February 1992 included difficulties with gluing radio tags to birds in persistent wet conditions; faulty antenna cabling affecting signal quality from

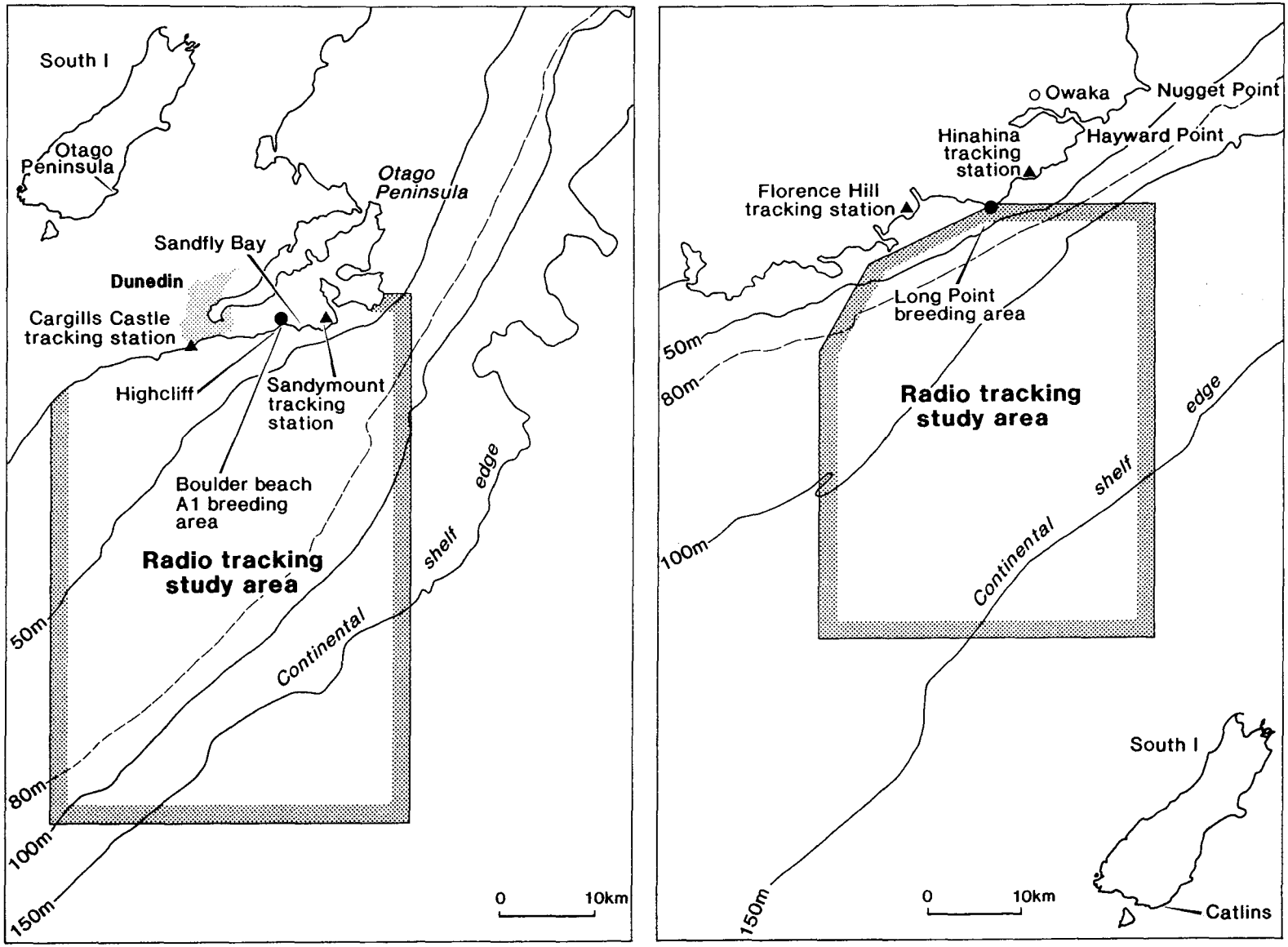

Figure 1 (a) Otago Peninsula and (b) Catlins Yellow-eyed Penguin radio-tracking study areas.

Florence Hill; coastline shape causing shadowing of radio signals; unreliable radio contact between stations; and poor signal quality at the automatic datalogger location at Long Point. All problems were remedied or were less apparent in February 1993.

Despite the errors inherent in the system (Moore *et al.* 1991, after Lloyd 1988) most tracking plots of birds at sea were regular, with few outliers. Accuracy of the radio-tracking system was tested in October 1992 by towing a dummy duck with a radio tag behind the Otago University research vessel *Munida* 6-40 km away from the tracking stations. The vessel made GPS satellite fixes of its position simultaneously with the radio-tracking team on land. Accuracy was higher than expected, with standard deviation of angular error of about 0.7^{o} at each station. The mean distance between true location and that estimated from triangulation of radio bearings was 269 $\pm$ 155 m at 5-15 km (n = 12), 422 $\pm$ 228 m at 15-30 km (n = 10), and 1471 $\pm$ 455 m at 30-40 km (n = 8).

It was possible to track most birds when they were at sea using the two receiving stations. However, fixes were not accurate when radio-tagged penguins were close to the coast, or when projections of the coast obscured the signals from one of the stations. This sometimes resulted in the program plotting locations on land. These points were deleted from the dataset. Occasional gross errors (i.e. impossible movements between hourly fixes) were also deleted. One bird in October spent all its time along the coast and to the north-east of the baseline (so was not tracked at all). This bird was not subsequently radio tagged. One of our regular 14 birds also travelled north-east of the baseline.

Only the radio-tracking data of birds assumed to be foraging were used for subsequent analyses. Long dives (>c.100 seconds) which were usually associated with long surface times (c.45 s.) were assumed to be foraging dives. Observers estimated these dive/surface times while taking radio bearings on birds, and every hour, individual birds were timed to determine dive:surface time ratios. Not considered for analysis were locations of birds that were obviously travelling (making short dive and surface times), diving for less than about 100 seconds, giving constant signals while sitting on the surface and records where observers did not note the dive type.

3.2 Dive Depths

Three time-depth recorders manufactured by Platypus Engineering, Hobart, Australia, were used to determine dive depths. Nose-cones of epoxy resin were added to improve streamlining. Total dimensions were 100 X 40 X 18 mm and they weighed 110 g (c.39 g in seawater). Recorders were used on eight Otago Peninsula birds during the 1992-93 breeding season (October, November-December and January) and three at the Catlins in February 1993. They were glued to the penguins' lower backs, and removed by peeling off after 3-16 days. After October, small radio-tags (22 X 37 X 16 mm; 20 g) were glued behind the dive recorders. Data was downloaded to a laptop computer.

3.3 Diet

Stomach contents were collected from as many radio-tagged birds as possible at the end of each tracking session at Otago Peninsula, and further samples from Catlins birds at

corresponding times. Non-radio-tagged birds were sampled where necessary to obtain at least 10 stomach contents/site/period. Pre-season sampling was conducted July-August. At Otago Peninsula 77% of birds were breeding at the time they were sampled for diet and at the Catlins, 51% were known to be breeding.

Prey remains were obtained from penguin stomachs by a water flushing technique (Wilson 1984), previously used on Yellow-eyed Penguins by van Heezik (1988, 1990). Using a catheter and hand pump, penguin stomachs were filled to overflowing with water to stimulate regurgitation. This was repeated two to three times until no further prey remains were flushed out. Afterwards, birds were fed fish fillets as a replacement meal. The stomach contents were then strained through muslin and frozen.

In the laboratory, intact prey items were measured and otoliths (calcareous structures used for balance) dissected from intact fish skulls and weighed as pairs to 0.00001 g. Other flesh and prey remains were broken down by high water pressure, sieved, and identifiable hard parts sorted. Unpaired otoliths from digested fish were sorted into left and right-sided and identified to species using van Heezik's (1988) reference collection, and photographs from Lalas (1983), later verified by C. Lalas (pers. comm.). Each otolith from the most abundant side (left or right) was weighed and the figure doubled to calculate pair weight. Calculation of fish biomass from otolith paired weights (Appendix 1) followed equations by Lalas (1983), which were used also by van Heezik (1988, 1990). Wear of otoliths was arbitrarily graded 1-5 (from no erosion to heavily eroded). Intact squid and octopus and unworn cephalopod beaks were included in the analysis, whereas beaks with frayed wings or greater wear were considered to be from the birds' previous day's feeding (van Heezik and Seddon 1989). Lower beak rostral length was used to calculate biomass (Clarke 1986).

Prey were categorised in groups following van Heezik (1988, 1990). Some types, such as "Other Crustacea", were assemblages. Fish otolith types probably represented one species in most cases, but a few otolith types may have included a dominant species and closely related species; e.g. Opalfish, Triplefin (Appendix 1). Nematodes were collected but not included in diet analysis.

Data were analysed as percent occurrence (% of stomachs that each diet type occurred in), percent number (% of each diet type as a proportion of total number of prey items eaten) and percent weight (% of each diet type as a proportion of the total calculated prey biomass). Calculations were based on all fish otoliths, regardless of wear.

A trial for estimating prey availability was made in October 1992. The University of Otago research vessel *Munida* made several trawls along the sea floor both in and out of Yellow-eyed Penguin foraging zones. The trial was abandoned as very few fish were captured.

3.4 Breeding

Breeding was monitored at three areas on the Otago Peninsula (Boulder Beach A1, Highcliff and Sandfly Bay; Fig. la) and three areas at Catlins (Nugget, Hayward and Long Points; Fig. lb). Nests were located in September-October, adults were banded

and measured (if this had not been done previously) and weekly visits (less frequent in the Catlins in 1991-92) were made until March. Chicks were weighed every week until they fledged. Breeding was also monitored by DOC staff on Codfish Island and Campbell Island for two seasons (Appendix 2).

4. RESULTS

4.1 Foraging Activity Pattern on the Otago Peninsula

Times at sea were estimated using presence-absence data (usually of nine individuals) from the automatic data-logger system and supplemented by dive recorder information in the 1992-93 season.

The overall pattern is for trips to sea to be of less than 24 hours, except when adults were incubating eggs (Table 1). The main difference between the years occurred during incubation, with longer times at sea (up to 7 days) in October 1991 than the following season (Table 1). Although there are only 15 foraging trips included in the October 1991 sample because of equipment malfunctions, daily radio-tracking confirmed that individuals were taking long trips to sea at that time. During the guard stage, breeding birds made day, evening or overnight trips, whereas during post-guard they usually took day trips.

Failed breeders stayed longer at sea and on land than breeders. For example, four recently failed birds made, on average, 18.5 hour trips during the guard stage in 1991 and three birds made 32.4 hour trips in 1992 (a fourth bird could not be monitored as it was radio-tracked near Tunnel Beach, 11 km from Boulder Beach, and apparently landed there each day). In the post-guard stage, failed breeders were at sea, on average, 41.8 hours in 1992 and 39.5 hours in 1993.

Table 1 Length of lime at Sea and on Land of Radio-tagged Yellow-eyed Penguins (breeders only), Otago Peninsula

Breeding Season	Stage of Season	Estimated Time (Hours)					
		At Sea			On Land		
		Mean	S.D.	No. of foraging trips (no. birds)	Mean	S.D.	No. of foraging trips (no. birds)
1990-91	Post-Guard	16.4	9.0	43(5)	12.7	6.9	43(5)
1991-92	Incubation	64.9	41.2	15(9)	76.2	49.5	12(9)
	Guard	14.3	7.0	52(7)	25.0	8.9	46(7)
	Post-Guard	15.9	5.3	28(5)	10.6	4.5	28(5)
1992-93	Incubation	27.3	23.3	46(10)	43.6	30.4	41(10)
	Guard	13.3	5.9	53(7)	23.9	9.1	49(7)
	Post-Guard	15.4	6.8	92(9)	12.1	5.3	86(9)

Key: Incubation = egg stage of breeding cycle
Guard = stage when chicks are brooded by parents
Post-Guard = stage when chicks are left unattended

4.2 Foraging range (Otago Peninsula)

4.2.1 Daily track Figure 2 shows two examples of penguin tracks at sea. The lines join the estimated points of intersection of radio-bearings at the hourly fixes for each bird. In this case, an offshore feeder was approximately 34 km from the breeding area at 0500 hours in the morning (when it had a constant signal on the surface). Most fixes were obtained when the bird was making long foraging dives, and moving up to 2km between each hourly fix. After 1600 hours it was travelling 5-7km/hour towards the breeding area. The other bird foraged closer to land, about 15 km along the coast from the breeding area.

4.2.2 Individual patterns Each radio-tagged bird showed individual differences in foraging range, although most ranges overlapped. Six examples are shown in Figs. 3-4. These are plots of presumed foraging locations (see Section 3.1: last paragraph) for all tracking periods February 1991-January 1993. Three birds were regular inshore feeders (M2 being the most extreme case), foraging <15 km from the breeding area and <10 km from the coast. The range of F16 is incomplete as it sometimes travelled out of tracking range to the northeast. Five birds (e.g. M1) were more mid-zone feeders, with overlapping ranges <35 km from the breeding area and <25 km offshore. The remaining five (particularly F2) showed more offshore activity, ranging up to 55 km from the breeding area and 35 km offshore.

These individual differences are summarised (Fig. 5) by plotting distance from the breeding area of all foraging fixes. In this case the inshore feeder travelled, on average, 9.1 $\pm$ 5.7 km (range 1-41, n = 292) from the breeding area, whereas the other bird was, on average, 21.5 $\pm$ 13.4 km away (range 1-57, n = 317), with a wide range of locations well offshore. Individuals of both sexes were inshore or offshore feeders. Table 2 and Fig. 6 show the distance data for all birds.

Table 2 Estimated Distance from Breeding Area of Foraging Radio-tagged Yellow-eyed Penguins (all hourly fixes of breeders and failed breeders making long dives), Otago Peninsula

Breeding Season	Stage of Season	Distance from Breeding Area of Foraging Location		
		Mean (km)	S.D.	N
1990-91	Post-Guard	14.4	7.2	255
1991-92	Incubation	23.3	11.2	456
	Guard	12.8	5.8	511
	Post-Guard	17.1	9.8	966
1992-93	Incubation	14.0	8.6	522
	Guard	14.6	5.8	449
	Post-Guard	13.0	6.5	699
Total	All Seasons	15.6	8.9	3858

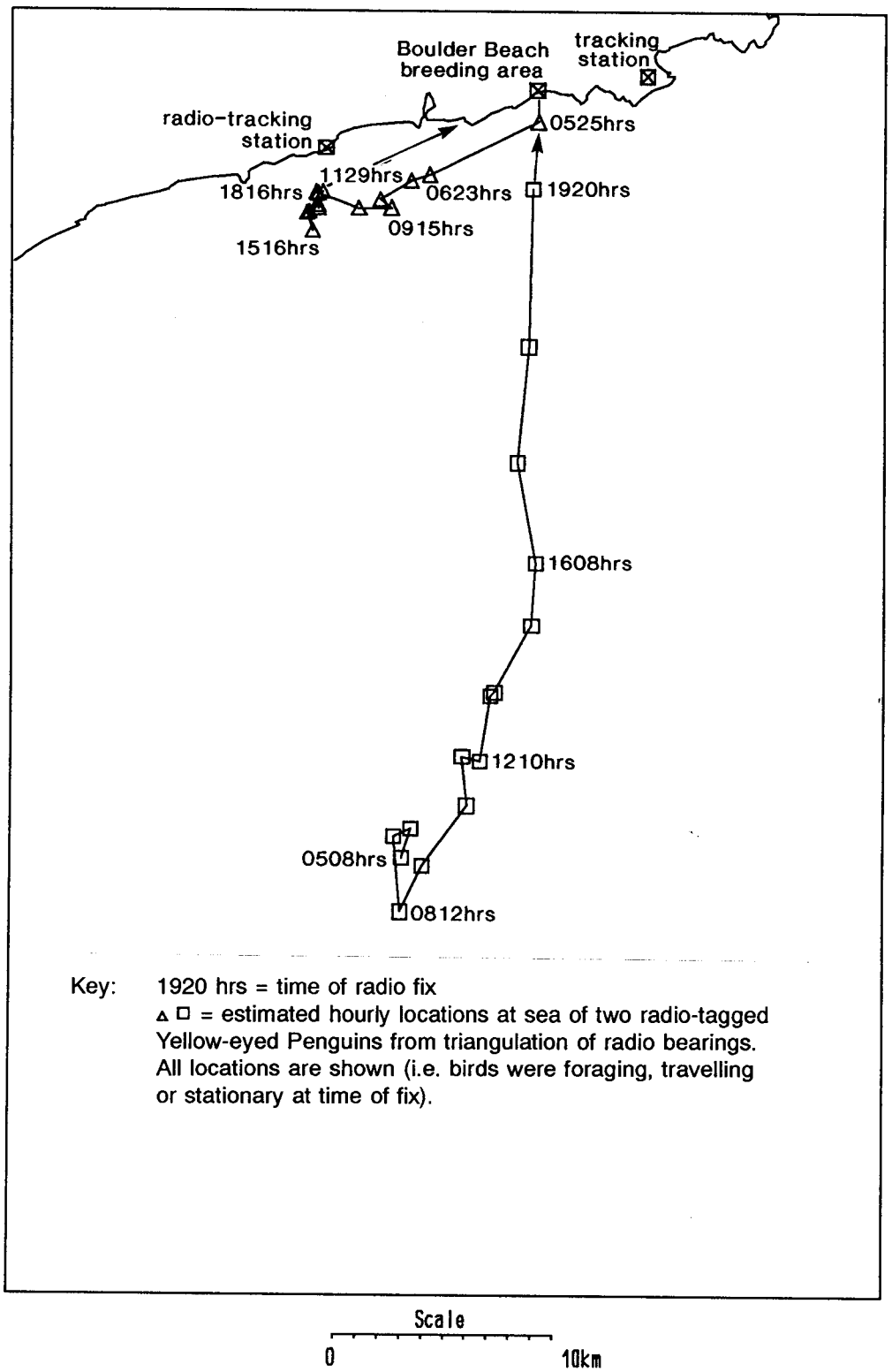

Figure 2 Movements at sea of two radio-tagged Yellow-eyed Penguins off the Otago Peninsula, 22 October 1991.

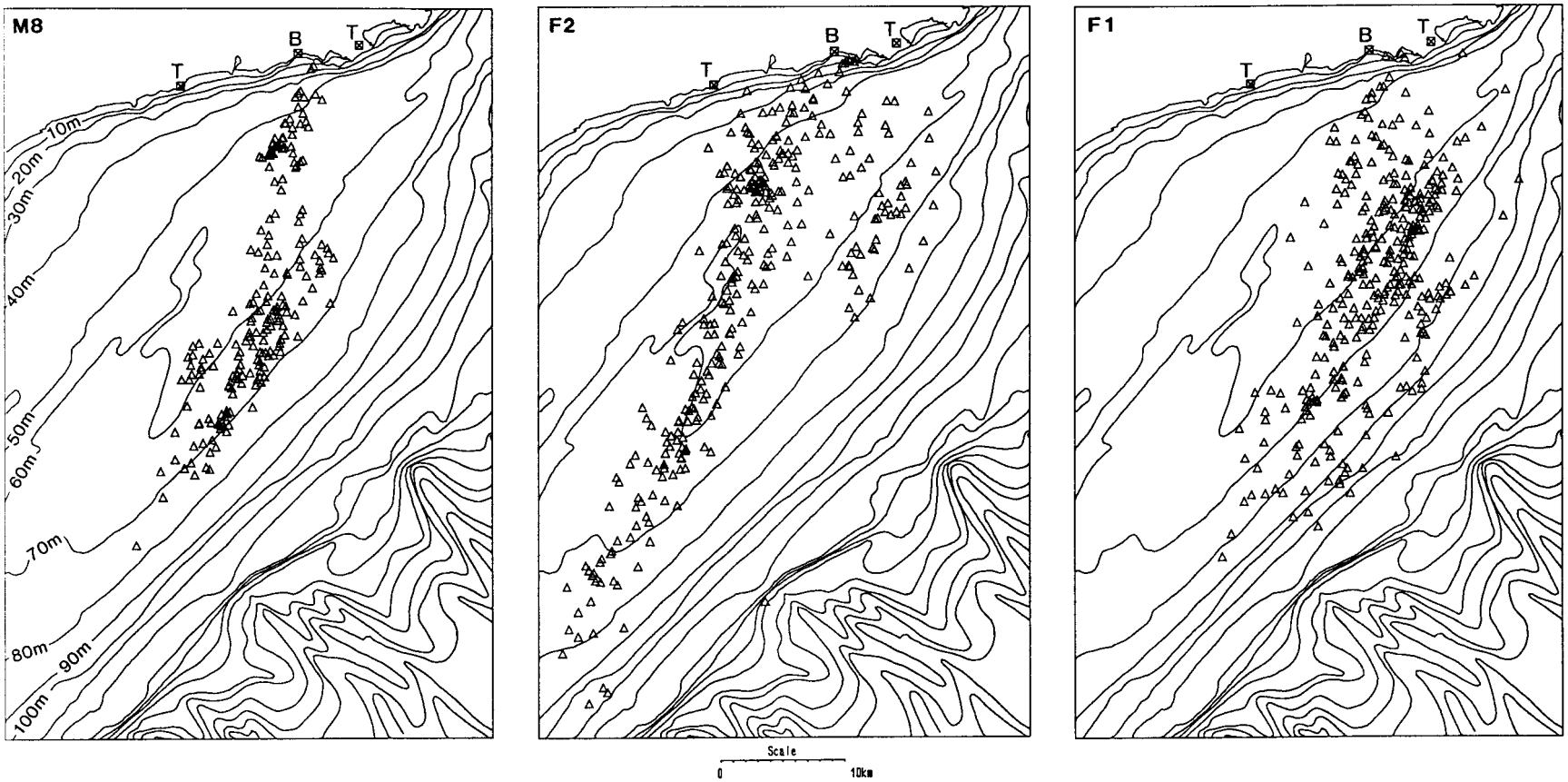

Figure 3 Foraging locations of three radio-tagged Yellow-eyed Penguins (M8, F2, Fl) during all tracking periods, 1991-1993, and bathymetry offshore of Otago Peninsula

Key: T = tracking station, B = breeding area, lines are isobaths

▲ = estimated hourly fixes when radio-tagged Yellow-eyed Penguins made foraging (i.e. long) dives

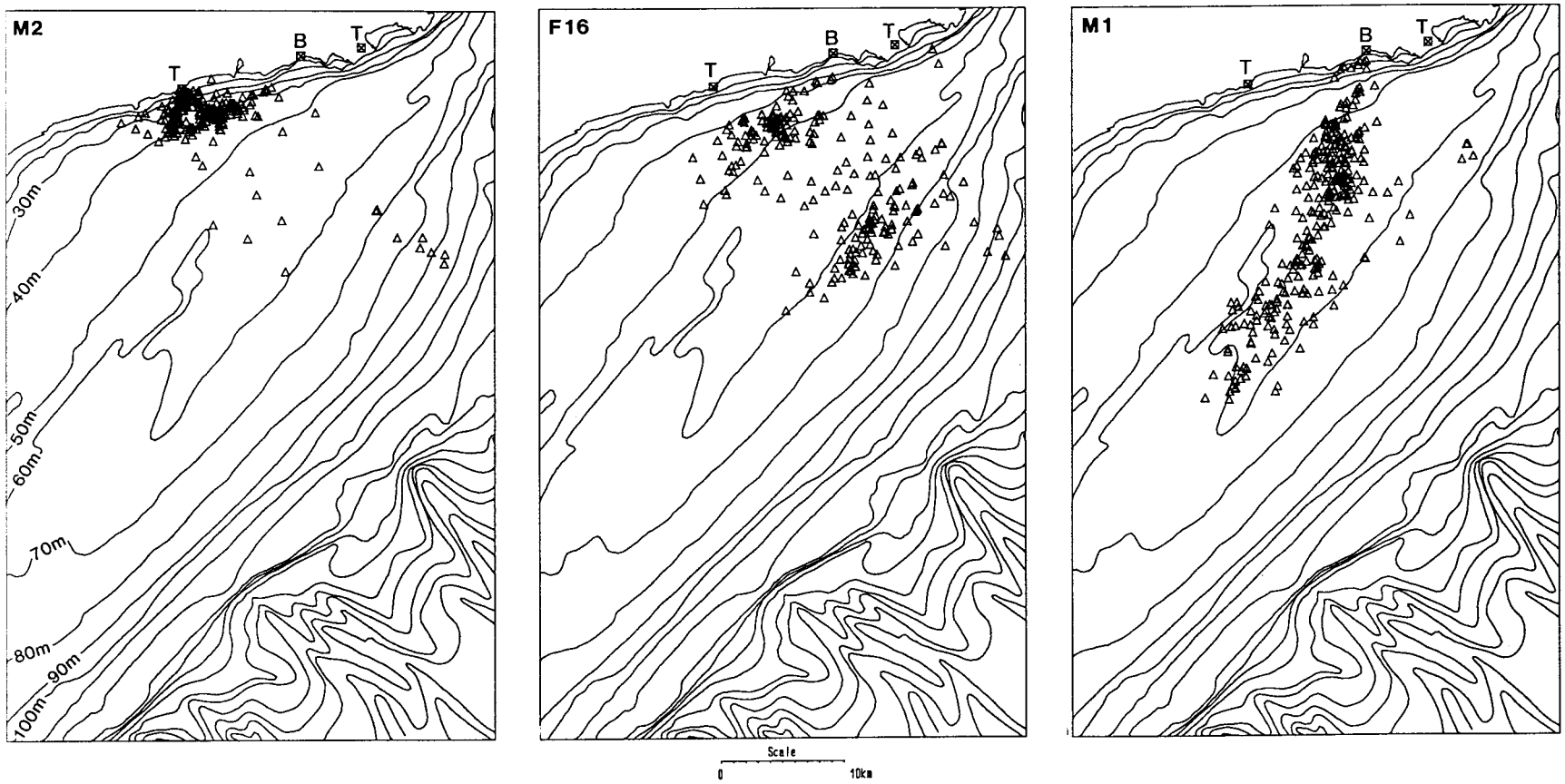

Figure 4 Foraging locations of three radio-tagged Yellow-eyed Penguins (M2, F16, Ml) during all tracking periods, 1991-1993, and bathymetry offshore of Otago Peninsula

Key: T = tracking station, B = breeding area, lines are isobaths

▲ = estimated locations at sea: all hourly fixes when radio-tagged Yellow-eyed Penguins made foraging (i.e. long) dives.

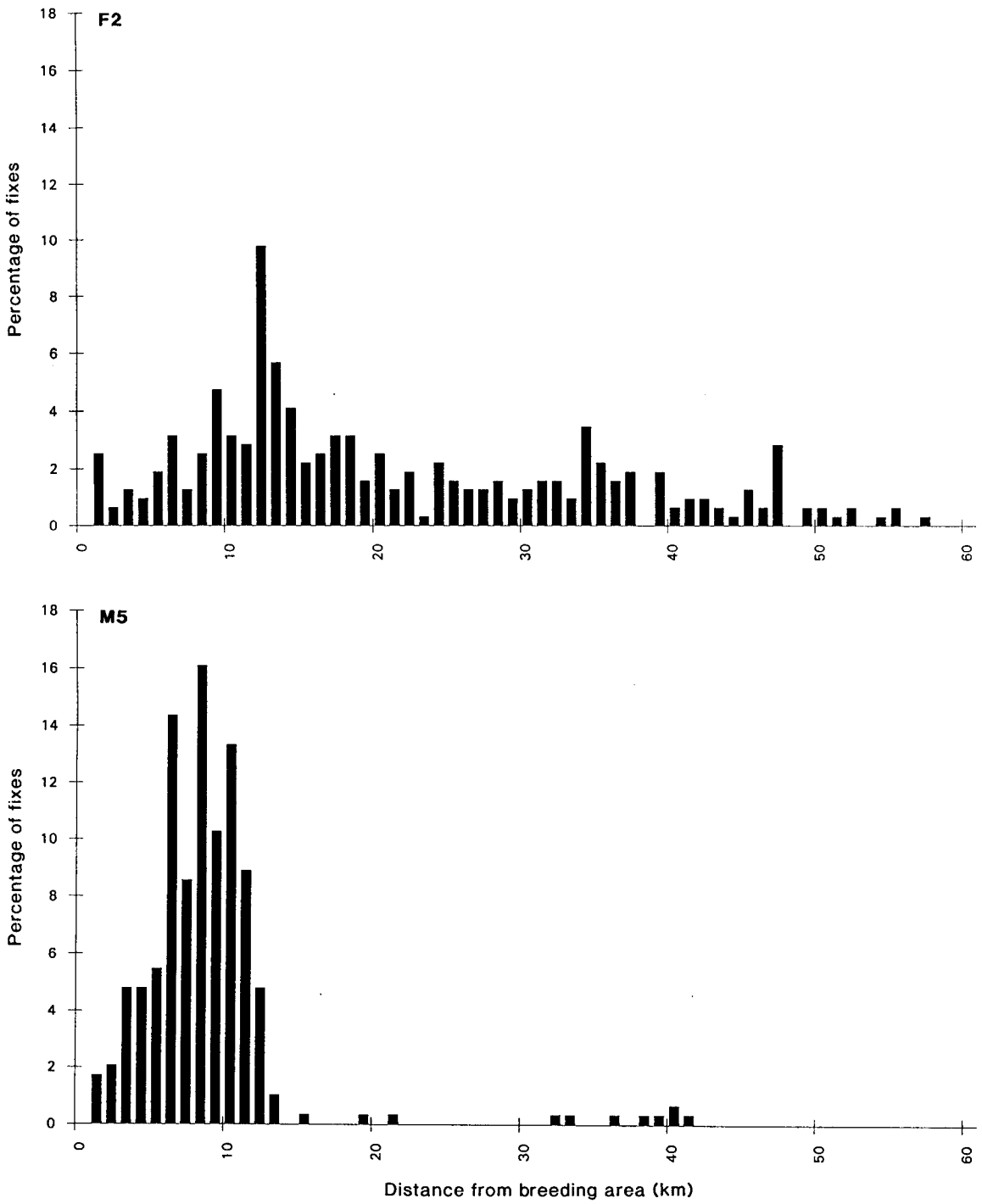

Figure 5 Distance from the breeding area of two foraging Yellow-eyed Penguins (M5, F2) during all radio-tracking periods, 1991-93.

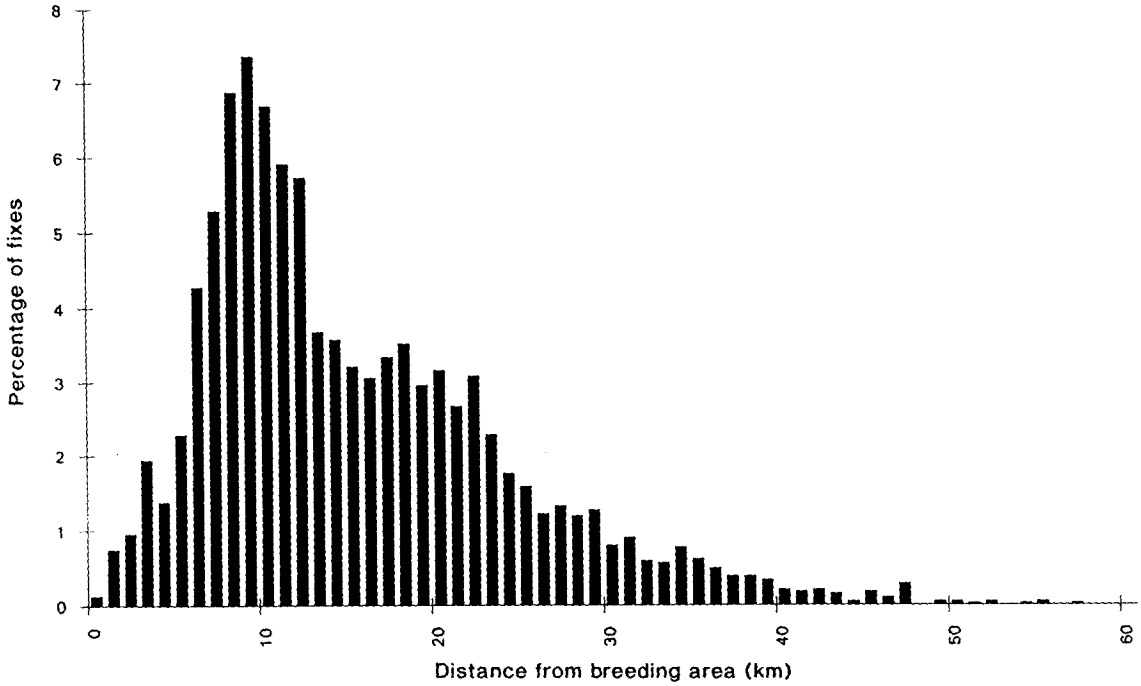

Figure 6 Distance from the breeding area of all foraging Yellow-eyed Penguins at Otago Peninsula during all radio-tracking periods, 1991-93.

4.2.3 Breeding stage patterns The pattern of foraging location during different stages of the breeding season is illustrated by scatter plots (Figs. 7-8). These show that birds foraged south to south-west of the breeding area, spreading out over the continental shelf, generally in water 50-70 m deep.

During incubation in 1991, when birds were making the longest trips to sea (section 4.1), they were usually foraging offshore, 10-45 km from the breeding area. During the guard stage, most birds foraged closer to shore, with more movement to the south-east. By the post-guard stage, there was more of a concentration near the coast, but still a wider scatter of foraging locations. Two pairs in 1991-92 showed a pattern during the season of decreasing distance offshore (e.g. Fig. 9).

In the 1992-93 breeding season (Fig. 8) there was less offshore foraging than in the previous season (Fig. 7), particularly during October and January. For a period during incubation in 1992-93, several birds foraged very close to the coastline. Three breeders and one failed breeder foraged closer to shore as the season progressed, but one breeder did the reverse.

4.3 Foraging range (Catlins)

Figure 10 shows the combined locations of hourly fixes of six birds (five males, one of which was not breeding the first season, and one female) during the February 1992 and 1993 tracking periods. Four additional birds tracked in each period (but not both) have not been illustrated. Individuals travelled to similar areas to feed each day. In 1992

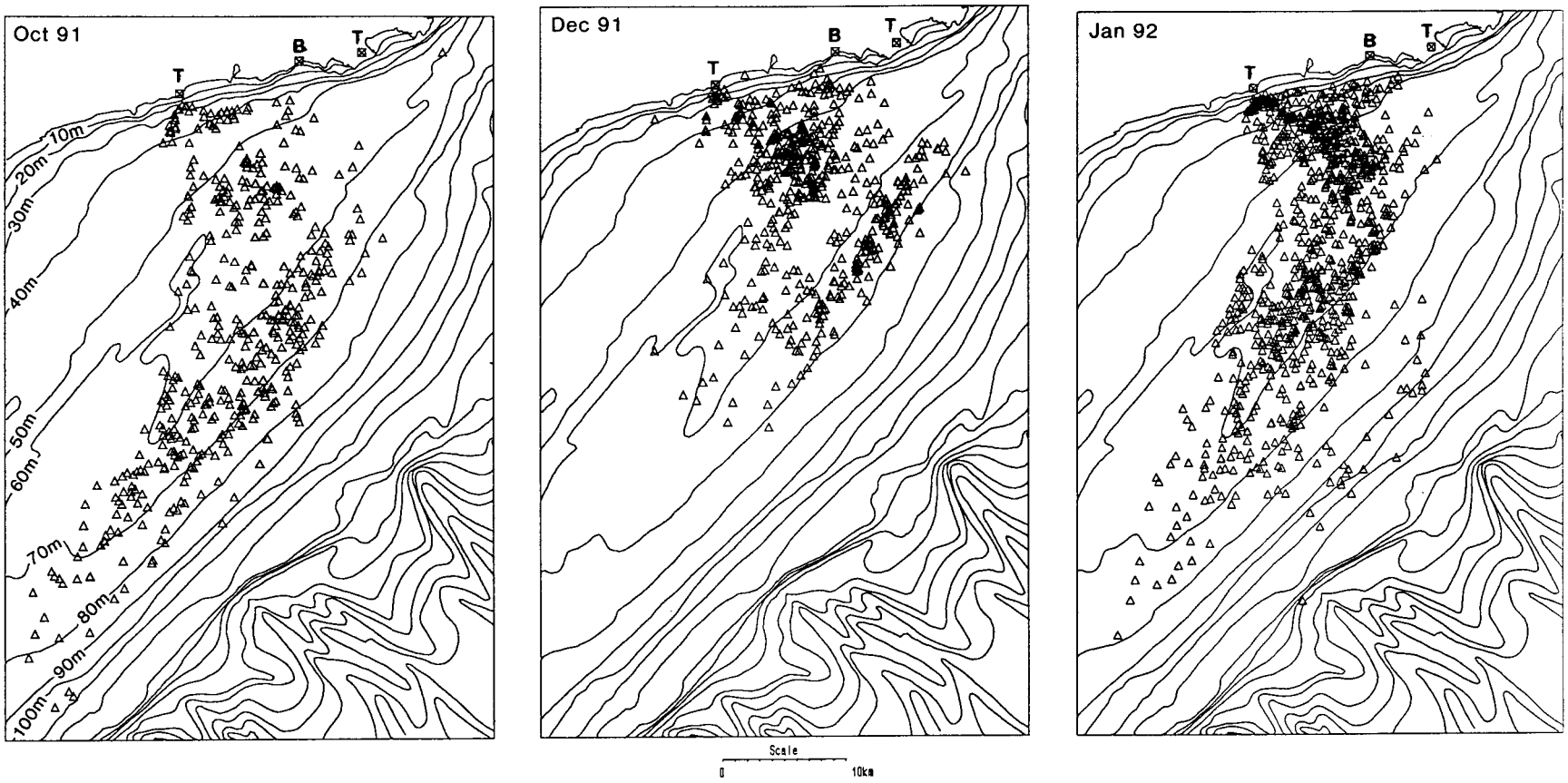

Figure 7 Foraging locations of all radio-tagged Yellow-eyed Penguins during three tracking periods of the 1991-92 breeding season, Otago Peninsula.

Key: T = tracking station, B = breeding area, lines are isobaths

▲ = estimated hourly fixes when radio-tagged Yellow-eyed Penguins made foraging (i.e. long) dives.

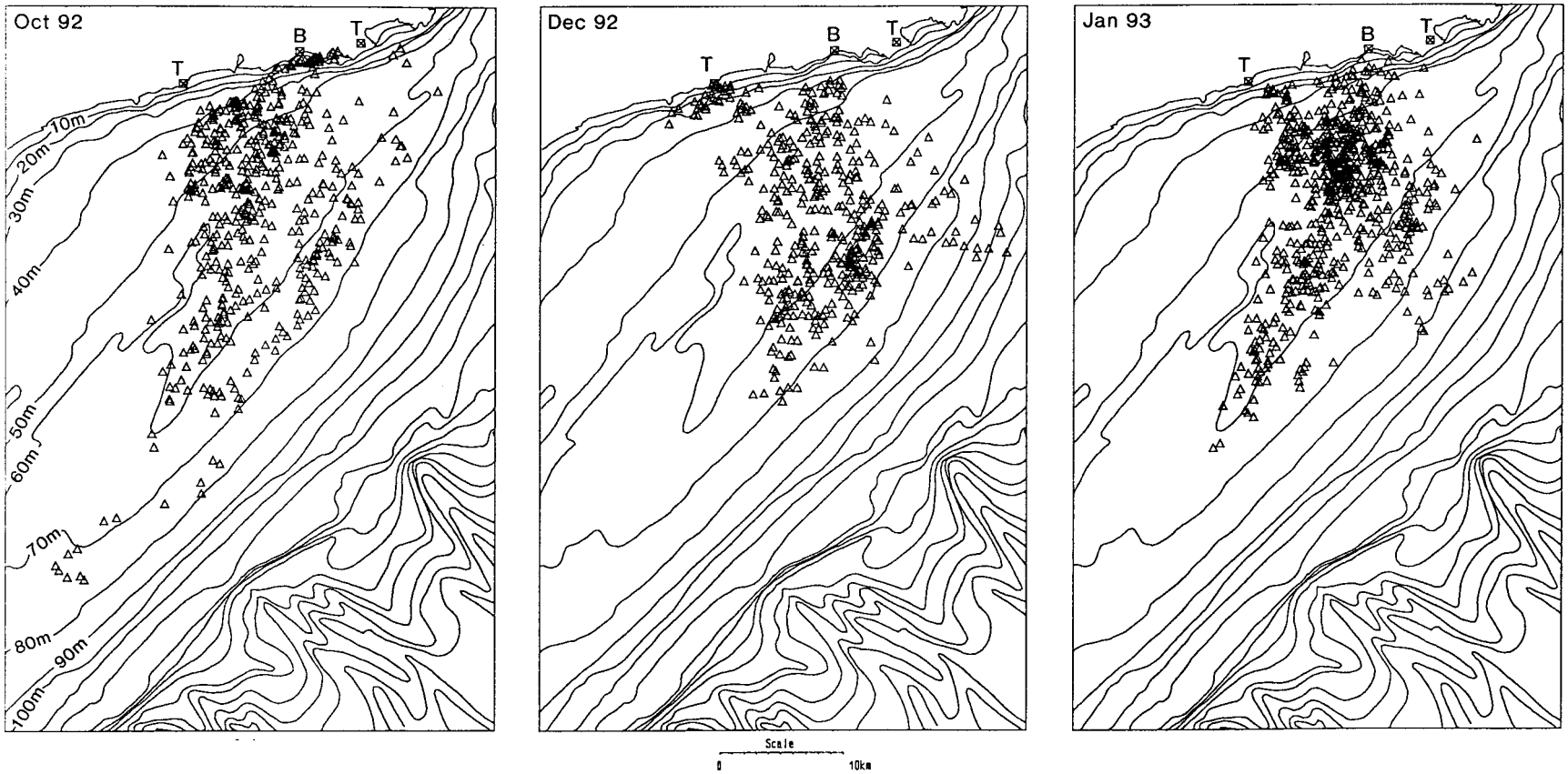

Figure 8 **Foraging locations of all radio-tagged Yellow-eyed Penguins during three tracking periods of the 1992-93 breeding season, Otago Peninsula.**

Key: T = tracking station, B = breeding area, lines are isobaths

▲ = estimated hourly fixes when radio-tagged Yellow-eyed Penguins made foraging (i.e. long) dives.

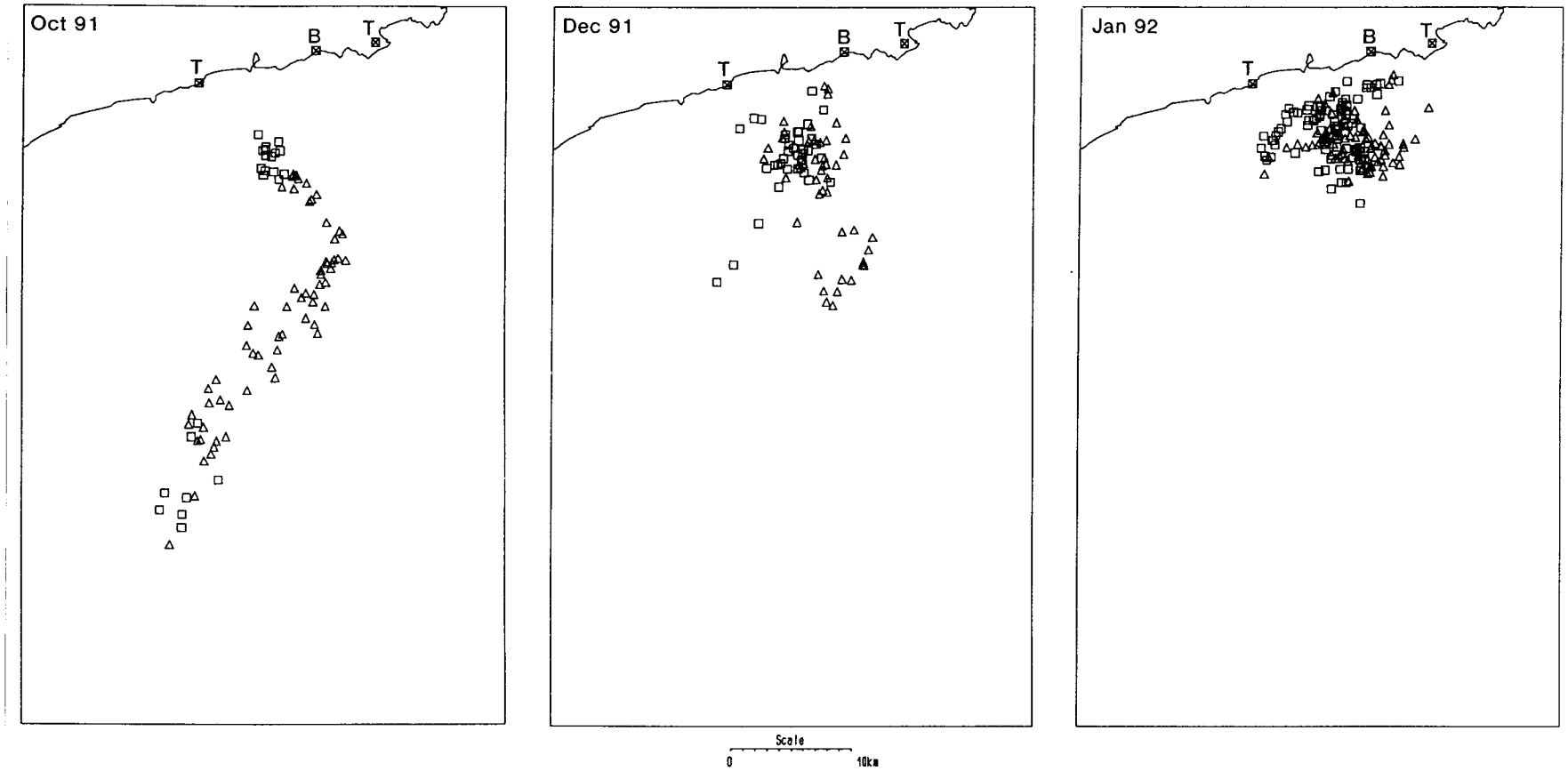

Figure 9 **Foraging locations of a Yellow-eyed Penguin breeding pair during three tracking periods of the 1991-92 breeding season, Otago Peninsula.**

Key: T = tracking station, B = breeding area

△ = ♀, □ = ♂, estimated hourly fixes of each bird of a breeding pair, when they made foraging (i.e. long) dives.

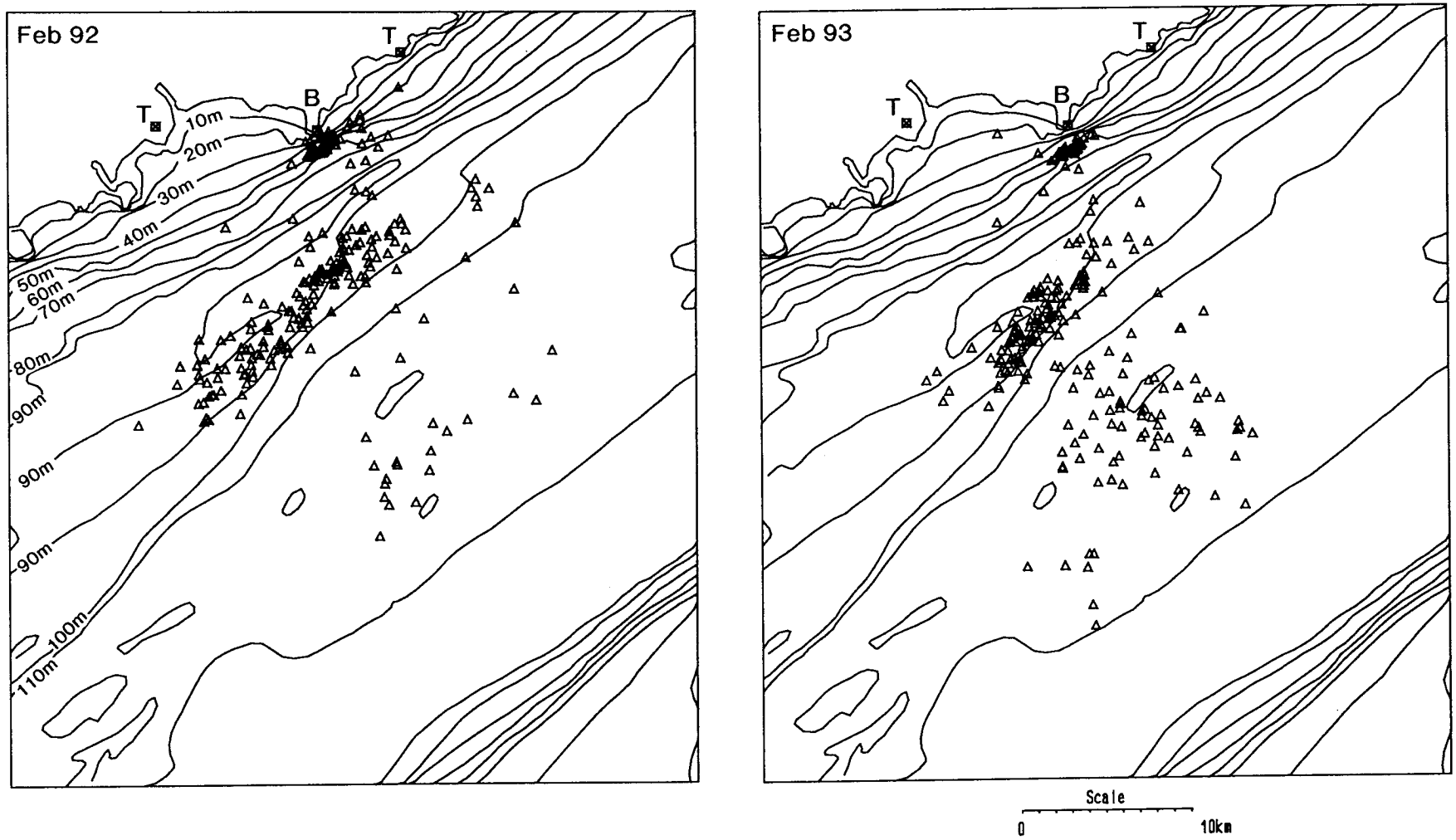

Figure 10 **Foraging locations of six radio-tagged Yellow-eyed Penguin during February 1992 and 1993 at Long Point, the Catlins.**

Key: T = tracking station, B = breeding area, lines are isobaths

▲ = estimated locations at sea: all hourly fixes when radio-tagged Yellow-eyed Penguins made foraging (i.e. long) dives

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