Factors that may have influenced the capture of New Zealand fur seals (*Arctocephalus forsteri*) in the west coast South Island hoki fishery, 1991–98

S. J. Baird
E. Bradford

NIWA Technical Report 92
ISSN 1174-2631
2000

Factors that may have influenced the capture of New Zealand fur seals (*Arctocephalus forsteri*) in the west coast South Island hoki fishery, 1991–98

S. J. Baird
E. Bradford

NIWA Technical Report 92
2000

Published by NIWA
Wellington
2000

Edited and produced by
Science Communication, NIWA,
PO Box 14-901, Wellington, New Zealand

ISSN 1174-2631
ISBN 0-478-23219-5

Citation:
Baird, S.J. & Bradford, E. 2000: Factors that may have influenced the capture of New Zealand fur seals (*Arctocephalus forsteri*) in the west coast South Island hoki fishery, 1991–98. *NIWA Technical Report 92.* 35 p.

Cover photograph by Neil Bagley

The National Institute of Water and Atmospheric Research
is New Zealand's leading provider
of atmospheric, marine,
and freshwater science

Visit NIWA's website at http://www.niwa.cri.nz

Contents

Abstract

Baird, S. J. & Bradford, E. 2000: Factors that may have influenced the capture of New Zealand fur seals (*Arctocephalus forsteri*) in the west coast South Island hoki fishery, 1991–98.
***NIWA Technical Report 92.* 35 p.**

The objective of this report was to investigate factors that may have influenced the levels of nonfish bycatch of associated or dependent species or protected species during fishing operations in the west coast South Island hoki fishery. Ministry of Fisheries scientific observers have reported the bycatch of New Zealand fur seals (*Arctocephalus forsteri*) in this fishery since 1989. The most complete data available for this investigation are from 1991 through to 1998.

New Zealand fur seals were observed caught in 3% of hoki tows in this area. Most captures were of one animal. The largest catch was of 23 animals. There were inconsistencies in the observer coverage from one year to another for some variables, especially nation of the observed vessel. Mean annual fur seal bycatch rates were highest in the most recent seasons, 1996–98. Exploratory data analysis suggested that year, nation, area, time of day, and gear type used were all possible explanatory variables for the bycatch of fur seals in this fishery. The analysis included no variables relating to the abundance of fur seals at sea because observers do not report on this.

Significant differences between possible explanatory variables were investigated by use of binomial and Poisson models. Because an interaction term between year and nation and perhaps other interaction terms were expected to be important, two subsets of the data were used where such terms could be included. The two subsets were: (a) vessels from the Commonwealth of Independent States (including Russian and Ukrainian vessels) and Japan covering all years and involving nearly 70% of the data; and (b) data from 1996 to 1998. The latter subset was chosen to investigate the observed increase in fur seal bycatch in these years. Significant predictor variables in all models were nation, year, day/night, area, and 10-day period. Gear type used was significant in some models. For subset (a), year:nation and year:day/night interaction terms were significant. In subset (b), the year:nation interaction term was significant. However, the validity of the models is questionable because of poor fit to the data.

Introduction

Distribution of New Zealand fur seals

New Zealand fur seals (*Arctocephalus forsteri*) are distributed around the New Zealand coastline, on offshore islands, and on sub-Antarctic islands. The species was heavily exploited during the 18th and 19th centuries and protection was given to it in 1894, but restricted licences were still issued for seal harvest in certain locations. In 1978, New Zealand fur seals were given total protection under the New Zealand Marine Mammal Act.

In New Zealand waters, fur seal population estimates are available only for a few discrete populations. Data are not often comparable because counts were made by different methods and at different times of the year. Wilson (1981) summarised population surveys undertaken in the 1970s and estimated population size within the New Zealand region at between 30 000 and 50 000 animals.

Data collection continues to be localised. Recent estimates have shown increases in populations at the Bounty Islands (Taylor 1996), Nelson-Marlborough region (Taylor *et al.* 1995), Otago (Lalas & Harcourt 1995, Lalas & Murphy 1998), and Cook Strait (B. Dix, pers. comm.). Evidence suggests that the numbers of haulouts and rookeries are increasing (Dix 1993, Taylor *et al.* 1995). Carey (1998) suggested that the New Zealand fur seal population at the Snares Islands has stabilised after a period of growth in the 1950s and 1960s.

There are few published data for the rookeries on the west coast of the South Island (WCSI). Estimates made in 1995–96 for some populations suggest either a stable population, as seen at Open Bay Islands where pup production has remained relatively constant since 1974–75, or an increase as measured at Cape Foulwind (H. Best, pers. comm. *in* Baird 1997).

Interaction of New Zealand fur seals and the WCSI hoki fishery

The introduction of the New Zealand 200 n. mile Exclusive Economic Zone (EEZ) in 1978 led to an expansion of commercial fishing effort for middle depth and deepwater species, and this was paralleled with an increase in the bycatch of fur seals. Ministry of Fisheries scientific observers reported a large increase in the fur seal bycatch observed caught in this fishery in 1989, which suggested that the problem was greater than previously thought (Anon. 1990).

A code of practice was developed by the fishing industry in 1990 (and updated in 1993) for vessels that operated in deepsea trawl fisheries (*see* appendix 4, Baird 1994). The WCSI hoki fishery is concentrated during mid July to late August, targeting spawning aggregations in depths of 300–700 m around the Hokitika Canyon and north of Westport. The main fur seal breeding colonies are at Open Bay Islands and Cascade Point (about 165 km from the hoki spawning grounds) and at Cape Foulwind (about 100 km north of the hoki spawning grounds). Males arrive to breed in October or November and females arrive to pup in mid November and early December (Mattlin 1987). Females suckle their pups for about 300 days and during this time are actively foraging. There is a seasonal influx of males to west coast rookeries and haulouts during the hoki season (Wilson 1992).

The origin of fur seals caught incidentally by trawlers is not known, and little is known about their foraging habits. Female fur seals from Open Bay Islands off Westland can forage off the west coast of the South Island to a maximum of 750 km from the rookery (Mattlin 1995). This suggests the potential for interaction with the hoki fleet if the fur seals are on long foraging trips. Mean distances covered in the main hoki season at the WCSI spawning grounds ranged between 130 km in July and 341 km in September. Satellite telemetry has confirmed some of these findings: in April and May fur seals foraged about 200 km offshore and in July and August fur seals travelled as far north as Greymouth and Westport (R. H. Mattlin, pers. comm. *in* Baird 1997). Harcourt *et al.* (1995) showed that most dives by lactating females from an Otago rookery in the summer months were made at night, and the deepest dives were made near dawn and dusk. Bouts of dives at night were longer than those during the day and often continued throughout the night. Average dive duration increased with dive depth for lactating females from Open Bay Islands (Mattlin *et al.* 1998): 35% of winter dives (June-August) were 100 m or deeper and 27% were to less than 20 m. These fur seals spent about 47% of their time at sea diving to depths of 6 m or more. In winter, about 30% of dives were under 3.5 min in duration.

Methods

Data sources and treatment

Data used in this study are from the Ministry of Fisheries Scientific Observer Programme (*obs* database) and are for the calendar years 1991–98. The Ministry of Fisheries also provided vessel specification data for the trawlers observed during this period, including nationality, length, breadth, width, draught, tonnage, power, and year built. The nonfish bycatch data are from the NIWA-administered *obs_lfs* database.

Data were extracted for those tows that targeted hoki off the west coast of the South Island, between 40° and 46° S, for calendar years 1991–98. Initially all available variables were extracted to determine which had consistent records and were appropriate to the investigation. Some data that relate to the fishing operation were recorded on the nonfish bycatch forms, but not on the observer forms which provide the basis for the Ministry of Fisheries *obs* database. Therefore, certain data are available only for fishing operations that resulted in incidental captures of New Zealand fur seals; for example, whether or not offal is discharged during shooting or hauling of the net is recorded only on the bycatch forms.

Inconsistent recording of whether the vessels fished on marks and lack of recorded data for sea surface temperature and headline temperature resulted in these variables being dropped from the investigation. About 36% of observed tows had no records for sea surface temperatures, and these tows accounted for 57% of the fur seal captures. The equivalent data for headline temperature records are 39% and 30% respectively.

The following observed data were included: latitude and longitude at the start of the fishing operation, date, start and end times of each tow, depth of fishing gear, gear type, headline height, towing speed, tow path, vessel type, size, and nationality, year vessel was built, numbers of fur seals observed caught. These data were error checked and erroneous data were amended where possible; for example, where position data of some tows were identified as obvious outliers or as tows made on land, the latitudes and longitudes were amended with reference to tows before and after the incorrect tow data.

Other variables were extrapolated from the observer data: these included tow duration and time of day or night of the start of each tow.

Factors chosen for testing

The factors chosen for testing were considered to be potential explanatory variables in the interaction between fur seals and the WCSI hoki fishery and for which there were consistent records in each year. These factors included:

- year — this fishery operates during winter months and therefore calendar year is used. This variable effectively equates to the season of the fishery.
- month — data were collated by month to see if there was any variation in time.
- nation — in this analysis, vessel characteristics were considered to be similar for those of the same nationality. Data from the Ministry of Fisheries showed that some vessels from Commonwealth of Independent States (CIS) countries were registered as from Russia and Ukraine, depending on the year they fished in the WCSI hoki fishery. Vessels from these two states were then grouped together into the CIS group. All vessels under charter to New Zealand companies were classified according to their nation of origin.
- gear type and headline height — tows were recorded by observers as "bottom" or "midwater".
- depth of the groundrope of the net at the start of a tow.
- towpath — the type and path of each tow and the number of turns per tow were recorded by observers in a three-digit code. There were more than 130 different combinations recorded, so the data were divided into the following groups:
  - type of tow, which actually was a record of where in the water column the net fished;
  - configuration of the path of the tow (straight, "U" bends), which included options such as pinnacle fishing or following a constant depth contour;
  - the number of turns per tow.
- tow position — position data were used to investigate any subareas within the WCSI hoki fishery.
- day/night category — an algorithm (A. Dunn, NIWA, pers comm.) which supplied the sunrise and sunset times for a given position, date, and time of the start of a tow was used to establish whether the start time of each tow was during the day or night. Day tows were defined as those that started between 1 hour before sunrise and 1 hour after sunset.
- duration of the tow — this was determined from the observed records for the start and end of a tow, with the start time representing the time the net began to fish.

Description of data

Mean bycatch rates were calculated for different strata (such as year, month, or nation) as

$$\bar{x} = \frac{\sum x}{\sum N}$$

where x is the number of New Zealand fur seals observed caught in a tow and N is the number of observed tows. The standard error of the mean ($s.e.$) is given by

$$s.e. = \sqrt{\frac{N\sum x - (\sum x)^2}{N^2(N-1)}}$$

Where the mean catch rates of New Zealand fur seals varied by more than ± 2 $s.e.$, the mean catch rates were interpreted as "substantially" different.

Results

Distribution of data

A total of 8432 tows were observed on vessels targeting hoki in the WCSI hoki fishery during 1991–98. A total of 461 New Zealand fur seals were observed caught in these fishing operations. The distribution of the observed effort and fur seals bycatch is shown in Figure 1.

Frequency of tows with fur seal bycatch

About 3% of the observed tows caught fur seals, and about 70% of these 276 tows with bycatch caught one fur seal per tow (Table 1). In most years, there were few captures of more than three fur seals per tow. The number of observed tows with multiple captures in one tow has increased in recent years.

***Table 1*: Observed frequency distribution of fur seal capture data for observed vessels in the WCSI hoki fishery, 1991–98**

No.									No. observed tows
fur seals	1991	1992	1993	1994	1995	1996	1997	1998	Total
0	1 263	776	1 267	1 568	793	972	659	858	8 156
1	12	9	19	21	16	63	17	36	193
2	2	2	4	7	3	19	10	9	56
3		1		2		2	2	3	10
4						1		1	2
5						2		2	4
6					1	1		4	6
7								1	1
10						1	1		2
12								1	1
23			1						1
Total tows	1 277	788	1 291	1 598	813	1 061	689	915	8 432
Total fur seals	16	16	50	41	28	137	53	120	461

Factors chosen

Fishing year

Figure 1 shows the annual observed effort in this fishery, with most observed tows made between 40° 30' and 43° S. This distribution differed in some years. Tows were observed further north in 1993 than in the previous two years, and in subsequent years this effort generally moved further south. This effect was especially obvious in 1996, when most observed tows were between 41° 20' and 42° 50' S. In the following years the observed effort was distributed slightly further north to about 41° S.

The number of fur seal captures reported each year varied (*see* Table 1), as did the distribution of observed captures. Although captures extend throughout the range of the observed tows, in most years the observed tows with bycatch were made south of 41° 30' S and were just off the 200 m contour. During 1996–98, fur seal captures were concentrated around 42° 30' S; in 1996 and 1998, the observed effort appeared to be closer in to the shelf than in other years.

Mean bycatch rates for fur seals and the number of observed tows by year are shown in Figure 2. The number of tows observed each year ranged from about 700 in 1997 to about 1600 in 1994. In the earlier years of observer coverage mean bycatch rates were similar, but in 1996 the mean bycatch rate of 0.129 fur seals per tow (*s.e.* = 0.017) was substantially higher than that in previous years (for example, 0.034 fur seals per tow, *s.e.* = 0.009, in 1995). There was a slight drop in the mean for 1997, but the mean bycatch rate for 1998 was very similar to that in 1996.

Month

This fishery operates over the winter months of June to September during the hoki spawning season, the main fishing activity taking place during July and August (Figure 3). About 90% of the observed effort during 1991–98 was in these months and this accounted for 75% of the observed fur seals captures. There was no difference in the mean bycatch rates for these months, about 0.045 fur seals per tow. However, in September, when less than 10% of the observed tows were made and 23% of the fur seals were observed caught, the mean bycatch rate was substantially higher at 0.145 fur seals per tow (*s.e.* = 0.017).

Nation

Observers were placed on 70 vessels operating in the WCSI hoki fishery during 1991–98 and these represented eight nations: China (1 vessel), Japan (20), Korea (11), Norway (4), New Zealand (11), Poland (3), Russia, and Ukraine. Vessels from the last two states were combined into the Commonwealth of Independent States (CIS) group (20 vessels).

The distribution of the observed tows, including those that caught fur seals, by year and nationality is shown in Figures 4–10. The one vessel from China was observed in 1993–95 and generally was observed when fishing throughout the fishery, though in the last two years, the observed tows were above 42° 30' S (Figure 4). There was no apparent pattern in the distribution of fur seal captures from one year to the next.

The vessels from CIS and Japan had similar distributions of observed fishing effort, and in years that observed Japanese tows had fur seal bycatch (all years other than 1992 and 1993), the distribution of the tows with bycatch is similar (Figures 5 and 6). Observed effort on Korean vessels was sparse in the earlier years, with most effort north of 42° S (Figure 7). The distribution extended south in 1996 and north in 1997 and 1998. Fur seals were observed caught only in 1996.

Vessels from Norway were observed only in 1991, 1993, and 1994 and tows were observed throughout the fishery, though in 1993 and 1994 observed tows appeared to be in deeper waters further from the 200 m contour than those observed on vessels from other nations. Fur seals were captured in 1991 and 1993 (Figure 8).

Observers were placed on New Zealand vessels in all years except 1991 and 1995. However, in some years, there was little observed effort on these vessels (Figure 9) except in 1996 and 1998 — the only years in which observed New Zealand tows caught fur seals. Polish vessels were observed only since 1996. In that year, observed Polish tows caught fur seals wherever they fished, but in the following years, the tows with bycatch were concentrated around 42° 30' S (Figure 10).

The number of tows with observed fur seal captures by nation group is given in Table 2. Vessels from CIS and Poland accounted for most of the observed tows with multiple captures. About 70% of the observed tows from these seven nation groups were on CIS and Japanese vessels, and these tows accounted for 72% of the fur seals observed caught. However, of these fur seals (n = 334), 298 were caught on observed CIS tows. After CIS, Polish vessels accounted for the next highest number of fur seals caught (75). Vessels from Poland had the least amount of observed effort, at less than 400 tows, but accounted for the highest mean bycatch rate of 0.208 fur seals per tow (*s.e.* = 0.046) (Figure 11). The next highest was for the CIS observed tows, at 0.097 fur seals per tow (*s.e.* = 0.012); this mean bycatch rate was just within ± 2 *s.e.* of that for the Polish tows and the New Zealand tows. All other mean bycatch rates by nation were substantially lower, with the most noticeable difference being between CIS and Japan, which were the nation groups with the most observed effort.

***Table 2*: Observed frequency distribution of fur seal capture data for observed vessels in the WCSI hoki fishery for 1991–98, by nation**

No.							No. observed tows	
fur seals	China	CIS	Japan	Korea	Norway	NZ	Poland	Total
0	578	2 892	2 689	641	519	517	320	8 156
1	7	111	31	3	7	7	27	193
2	1	41	1		2	2	9	56
3		7	1				2	10
4		2						2
5		3				1		4
6	1	3					2	6
7						1		1
10		2						2
12							1	1
23		1						1
Total tows	587	3 062	2 722	644	528	528	361	8 432
Total fur seals	15	298	36	3	11	23	75	461

Area and depth of fishing

The distribution of tows that caught fur seals shown in Figure 1 suggests that fur seals are more often caught in tows south of about 41° 30' S. The data were stratified into two areas, north and south of this latitude. About 62% of observed tows were made south of 41° 30' S, and these accounted for 90% of the fur seal captures and a substantially higher mean bycatch rate (0.08 fur seals per tow, *s.e.* = 0.008, compared with 0.013, *s.e.* = 0.003, in the northern area).

Further stratification of the data for the vessels with the most fur seal captures, those from CIS, showed that the observer coverage was at least 60% in the southern area in 1991 and 1992. However, in 1993 and 1994 about 30% of tows were observed south of 41° 30' S. In 1995, observed CIS vessels were more likely to be fishing in the southern waters, and 72% of the 169 observed tows were made here. The subsequent years showed this stronger observer effort in the south, particularly in 1996 and 1998 when 86% and 91% of observed tows were south of 41° 30' S. Similarly, most of the observed Polish effort was in the southern area, as was most of the observed New Zealand effort in years of higher fur seal bycatch (1996 and 1998). There were substantial differences in the overall mean fur seal bycatch rates between the two areas for observed tows on vessels from CIS, Japan, and Poland. For example, on Japanese vessels in the northern area a mean bycatch rate 0.002 fur seals per tow (*s.e.* = 0.002) was observed, compared with 0.018 (*s.e.* = 0.003) in the southern area. Observed effort on Chinese and Korean vessels was greater in waters north of 41° 30' S.

These data were further stratified into 100 m depth ranges based on the recorded data for the depth of the groundrope. In both northern and southern areas most of the observed effort was in waters at least 300–500 m deep. Northern area tows had substantially higher mean fur seal bycatch rates when the groundrope was recorded at 200–300 m than at 300–500 m (Figure 12). There was no real difference between mean bycatch rates for the 100 m categories in the southern area, though mean bycatch rates followed the general pattern of the number of observed tows, with a slight peak at groundrope depths of 300–500 m.

Time of day

Tows were observed throughout the 24-hour period. Fur seals were observed caught in tows throughout this time. Observed tows in the "night" category represented 42% of the total observed tows and 56% of the observed fur seal captures. The mean fur seal bycatch rate for these night tows was substantially higher at 0.073 fur seals per tow (*s.e.* = 0.007) than that for the day tows at 0.041 fur seals per tow (*s.e.* = 0.006) (Figure 13).

All nation groups had more observed tows in the "day" category and mean fur seal bycatch rates for night and day tows were similar for each nation, though mean bycatch rates for the night tows appeared to be higher. Small sample sizes restrict the ability to show any substantial differences with the nation group data.

Gear type and headline height

About 88% of the observed tows were made using midwater nets with headline heights of 13–110 m (median = 60 m). These 7445 midwater tows accounted for 436 of the fur seals observed caught. The remaining 987 observed tows used bottom nets and accounted for 25 fur seals. Bottom tows used headline heights that ranged from 2.0 to 8.5 m (median = 3 m). The mean fur seal bycatch rate for midwater tows was substantially higher at 0.058 fur seals per tow (*s.e.* = 0.005) than that for bottom tows at 0.025 fur seals per tow (*s.e.* = 0.007).

There were differences in the headline heights used by vessels from different nations. Greater headline heights were used on bottom tows by vessels from Japan (median = 7 m) and Korea and New Zealand (median = 4 m) compared with those used on CIS and Norwegian vessels (median = 2.5 m). Poland used the greatest headline heights when fishing with midwater nets (median = 70 m), compared with China (64 m), CIS and Japan (60 m), and Norway, Korea, and New Zealand (50, 48, and 45, respectively).

Fur seals were caught throughout the range of headline heights. Headline heights were grouped into five strata and catches of two or more fur seals occurred in observed tows in each stratum (Figure 14). The mean fur seal bycatch rate observed in the bottom tows of 2–10 m headline height was no different from that observed in the main midwater tow categories. No fur seals were reported from the midwater trawls with small headline heights of 10–20 m. For larger midwater trawls, mean fur seal bycatch rates increased with greater headline heights. When these data were stratified by nation, no substantial differences in the mean bycatch rates for these categories were observed, though bycatch rates appeared to be higher with greater headline heights for all nations, except Norway for which the higher bycatch rates appeared to be in the 2–10 m trawls.

Tow path

Generally bottom trawls were towed on the bottom, whereas the midwater trawls were towed either on the bottom, in midwater depths, and a mixture of the bottom and midwater depths. The highest mean fur seal bycatch rate was observed for midwater trawls towed in midwater depths; at 0.085 fur seals per tow, this was substantially higher than for midwater trawls towed near the bottom (0.033 fur seals per tow) (Figure 15). The bycatch rate for midwater tows made in a range of depths in the water column was between these bycatch rates.

About 60% of observed tows were made in a straight line and 30% in a "U" bend. Mean fur seal bycatch rates were substantially higher for straight-line tows than "U" bend tows (Figure 16). This result was confirmed when the data were stratified by the number of turns made during fishing (Figure 17), with a decreasing trend in mean bycatch rates as the number of turns increased.

Tow duration

Observed tows in the WCSI hoki fishery varied in length from several minutes to about 20 hours, with most tows taking between 1 and 5 hours. Data were grouped by tow duration into 1 hour groups and mean fur seal bycatch rates were highest in tows of 1–2 or 2–3 hours duration (Figure 18), and generally decreased for longer tows.

Vessel

The observer data represent effort on few vessels from a nation in a year (Table 3). Of the 20 CIS vessels, 15 were observed in one year, 4 were observed in two years, and 1 was observed in three years. The number of Japanese vessels observed each year has dropped in recent years, and of the 20 Japanese vessels that were observed, 3 were observed in one year, 1 in three years, 3 in four years, and 1 in five years. In recent years there has been an increase in the number of vessels from Korea and New Zealand that have had observers placed on them.

Vessel characteristics

Data provided by the Ministry of Fisheries on the characteristics of observed vessels operating in the WCSI hoki fishery during 1991–98 showed some large differences in age, size, and power (Table 4). Average speed by vessels when towing the net was similar for all nations at about 4.4 kn. The vessels from CIS had the largest age range in the fishery; the oldest vessel was built in 1968 and the newest one in 1997.

In all years there was a wide range of age of vessel observed in the fishery. About 60% of the observed tows were from vessels aged between 1 and 10 years old at the time of observation. The year a vessel was built seemed to have no effect on the bycatch of fur seals.

***Table 3*: Numbers of vessels, tows (in parentheses), and trips observed in the WCSI hoki fishery, 1991–98, by nation**

	No. observed vessels (and no. observed tows)							
Year	China	CIS	Japan	Korea	Norway	NZ	Poland	Total
1991		3 (384)	7 (699)	3 (107)	1 (87)			14 (1 277)
1992		2 (206)	6 (437)	1 (33)		1 (29)		9 (788)
1993	1 (206)*	5 (525)*	5 (244)*	1 (32)	3 (284)*			15 (1 291)
1994	1 (196)	4 (686)†	6 (421)*	1 (50)	1 (157)	2 (88)		15 (1 598)
1995	1 (185)*	1 (169)	6 (405)	1 (54)				9 (813)
1996		5 (489)	3 (207)	2 (128)		4 (135)	1 (102)	15 (1 061)
1997		3 (177)*	4 (164)	3 (115)		1 (38)	1 (195)	12 (689)
1998		4 (343)	2 (145)	3 (125)		6 (238)	1 (64)	16 (915)
Total vessels	1	20	20	11	4	11	3	70
Total tows	587	3 062	2 722	644	528	528	361	8 432
Total trips	5	32	41	15	6	14	3	116

* Two trips were observed on one vessel.
† Two trips were observed on three vessels.

***Table 4*: Characteristics of observed vessels in the WCSI hoki fishery, 1991–98, by nation**

	Nation						
Characteristics	China	CIS	Japan	Korea	Norway	NZ	Poland
Length range (m)	83.5	62.2–104.5	56.5–104.8	46.2–77.0	57.0–69.2	42.0–67.0	88.9–102.6
Weight range (t)	2 305	1 898–4 407	253–4 991	279–1 878	1 597–2 882	335–2 926	2 930–4 410
Power range (kW)	2 207	855–5 250	379–5 669	311–2 834	2 425–3 042	1 080–3 600	2 647–3 827
Breadth range (m)	13.5	13.6–16.0	9.3–17.8	8.0–12.8	13.4–14.0	9.0–15.5	15.0–17.0
Draught range (m)	5.5	5.1–10.2	4.0–9.8	3.5–7.0	5.5–7.6	4.0–8.3	5.2–6.0
Year built	1989	1968–1997	1967–1990	1966–1984	1987–1988	1972–1992	1977–1986
No. vessels	1	20	20	11	4	11	3
No. tows	587	3 062	2 722	644	528	528	361
No. fur seals	15	298	36	3	11	23	75

Fitting regression models to the data

The observer data covering the fur seal bycatch in the target hoki fishery off the west coast of the South Island of New Zealand is, in many ways, better balanced than that for the sea bird bycatch of the tuna longline fishery around New Zealand (*see* Baird & Bradford 2000). However, the data set still has problems for use in regression modelling to determine the factors influencing the bycatch of fur seals.

- Little is known about the fur seal population in the area, nor how their behaviour has changed in response to the fishing effort.

- The percentage of tows that catch fur seals is low (about 3%), and of these tows, about 70% caught one seal. Thus the model is essentially binomial (either catch or no catch) with a very high probability of not catching fur seals. Binomial models for data with a very low (or very high) success probability may require a very large data set to give adequate fits. The data contain too few multiple catches to give information that could explain them.

- The exploratory data analysis suggested that nation of origin of the fishing vessel was an important factor in determining the probability of catching fur seals. Most of the observed tows were on CIS and Japanese vessels (the major fishing nations in the fishery (Annala *et al.* 1999)). Other nations were involved in the fishery only in some of the years for which we have observer data: generally these nations did less fishing than the CIS and Japanese vessels, and had fewer observed tows (*see* Table 3). Any interaction effect between nation and year cannot be included in models using the full data set.

- The fur seal bycatch rate appears to change during the hoki spawning season. The timing of peak spawning varies from year to year (Annala *et al.* 1999) and so do the timing of the fishery and timing of the observer programme. The lack of balance in the data, particularly at the beginning and end of the hoki fishing season in any one year, prevents the inclusion of this interaction in the models.

Factors chosen as predictor variables in the models

The data used in modelling were grouped into categories taking into account the exploratory data analysis results. To keep the data set as large as possible, missing values were imputed and assigned to categories as described in Table 5. The amount of missing data is small and these assignments should not influence the results significantly. The variables to use were chosen on the basis of the exploratory analysis described earlier.

To capture a possible seasonal effect, the observed tows were assigned to 10-day periods from 1 June of the year of fishing (Table 6). To avoid problems arising from small numbers in the periods at the beginning and end of the season, these counts were moved forwards or backwards in time to give the pattern shown in the second part of Table 6. The low numbers of observed tows in most of time period 3, and zeros and low numbers in time periods 9 and 10, mean that the data are still inadequate to support a *year:week* interaction which almost certainly exists.

***Table 5*: Definitions of explanatory variables used in regression modelling**

Variable	Description
Year	As given; categorical, up to 8; called *year*
Nation	As given; categorical, up to 7; called *nation*
Area	North and south of 41°30' S; categorical; called *area*
Day/night	Tow started during daylight (including 1 h twilight), or at night; categorical; called *DN*
Time period	10 day periods from 1 June of each year. Modified slightly (*see* below); categorical; called *week*
Tow duration	In hours, missing values replaced by mean; log(towdur) treated as an "offset", that is, is included in the model but no multiplier determined; called *towdur*
Net type	Categorical 4. All bottom trawls; midwater net on bottom; midwater net in mid-water; midwater net in variable position (includes missing data); called *nettype*
Direction	Straight; U-bend; other (including missing values); called *direct*
Headline	3 categories; < 40 m; 40 to < 60 m (including missing values); 60+ m; called *hline*
Number of turns	4 categories; none; 1 or 2; 3 to 6; other (including missing values); called *noturns*

The tow durations were first divided into categories with roughly equal numbers and best fitting models selected. However, treating the logarithm of tow duration as an offset in the regressions appears to give better fitting models. Thus, we are effectively modelling bycatch per hour rather than per tow.

Table 6: **Definition of 10-day periods from 1 June of each year**

10 day period	Year 1991	1992	1993	1994	1995	1996	1997	1998
Numbers of occurrences in data								
0	0	0	0	0	0	3	0	3
1	1	0	0	0	0	6	1	0
2	32	3	4	0	9	0	7	0
3	177	41	77	21	50	28	51	30
4	232	201	195	205	113	99	66	105
5	237	192	262	284	173	134	42	274
6	231	151	254	281	162	127	145	183
7	210	146	263	263	131	165	177	111
8	149	51	112	303	70	143	130	124
9	8	3	60	198	43	193	70	84
10	0	0	44	43	60	142	0	1
11	0	0	20	0	2	21	0	0
Modified numbers of occurrences								
3	210	44	81	21	59	37	59	33
4	232	201	195	205	113	99	66	105
5	237	192	262	284	173	134	42	274
6	231	151	254	281	162	127	145	183
7	210	146	263	263	131	165	177	111
8	157	54	112	303	70	143	130	124
9	0	0	60	198	43	193	70	85
10	0	0	64	43	62	163	0	0

Fitting regression models

The primary models assume a binomial distribution (with logit link). Secondary models assume a Poisson distribution (with log link) and fit a distribution of fur seal bycatch modified so that all tows where more than two fur seals were caught are counted as two (that is, a zero, one, many distribution). The modelling strategy was first to fit a model using all the explanatory variables from Table 5 and then use a stepwise procedure to eliminate non-significant explanatory variables. The suggested model was checked in detail to ensure that significance levels were adequate, and whether marginally significant explanatory variables took the dispersion closer to its nominal value of 1 for binomial and Poisson models as a further test for goodness of fit.

Lack of balance in the complete data set means it is unsuitable for examining the significance of most of the possible interaction terms. Two subsets of the data were examined. The first used data from the CIS and Japanese vessels that cover all years and involve almost 70% of the data. The second used data from vessels fishing in 1996–98 to investigate possible reasons for the observed increase in fur seal bycatch in these years. The stepwise procedure was used to add in any of the likely (and possible) interaction terms. The significant predictor variables in all initial models were: *nation* (most important); *year*; *DN* (day/night start of set); *area*; and *week* (time period). In some models, *nettype* entered as significant (Table 7).

A *year:nation* interaction term enters all models where it can be tried. Such a term cannot be included in the "All data" model because vessels from some nations were not observed in some years (nor did they fish in all years). Some of the other predictor variables appear to be acting as surrogates for the *year:nation* interaction and become less significant after this term is added. The inclusion of the interaction terms improves the dispersion as well as increasing the percentage of deviance explained. A *DN:area* interaction was almost significant in some models but has not been included. For the CIS and Japanese vessels a *year:DN* interaction is also significant (but not a *nation:DN* interaction).

Table 7: **Models giving factors influencing the bycatch of fur seals in the west coast South Island target hoki fishery. Models labelled (1) contain no interaction terms: models (2) contain them**

Data used	Model	Deviance explained (%)	Dispersion
Binomial models			
All	*Year + nation + DN + area + week + nettype*	22	1.044
CIS, Japan	(1) *year + nation + DN + area + week*	22	1.147
	(2) *year + nation + DN + area + week + year:nation + year:DN*	24	1.001
1996–98	(1) *year + nation + DN + area + week + hline + nettype*	20	1.064
	(2) *year + nation + DN + area + week + year:nation*	22	1.014
Poisson models			
All	*Year + nation + DN + area + week + nettype*	28	1.394
CIS, Japan	(1) *year + nation + DN + area + week*	30	1.351
	(2) *year + nation + DN + area + week + year:nation + year:DN*	32	1.182
1996–98	(1) *year + nation + DN + area + week + nettype*	27	1.399
	(2) *year + nation + DN + area + week + nettype + year:nation*	30	1.278

Binomial models with a logit link function are explaining variation in the odds ratio, defined here as the probability of catching fur seals to the probability of not catching them. Figures 19 and 20 show the odds ratio and the mean fur seal bycatch (using the modified bycatch distribution) and plot the values for nation and the day/night effect against year for the CIS and Japanese vessels and all vessels in 1996–98. These figures illustrate the nature of the *year:nation* and *year:DN* interactions.

Vessels from five nations were observed in 1996–98 (Figure 20). Here the *year:nation* interaction comes primarily from the large catch rates by Polish vessels in 1998 and to some extent from the decline in bycatch rate shown by the CIS vessels. The lines for day and night start of set times are roughly parallel for these data, that is, the *year:DN* interaction is not significant as shown in the modelling. The large catch rates by the CIS vessels in 1996 and 1997 and Polish vessels in 1998 will have biased the upward trend in time seen in the raw data (*see* Figure 2), that is, the raw data inflate that part of the time trend that could be related to an increase in fur seal population.

Discussion

Anecdotal evidence suggests that the physical presence of the fishing vessels, including the sound of the trawl net activity, attract fur seals to the fishing vessels. Fur seals are thought to be caught either when the net is being shot or during hauling (Shaughnessy & Payne 1979). Shaughnessy & Davenport (1996) suggested, from video footage of fur seals interacting with a trawl net, that seals enter the net to feed and become so confused in the low light that they cannot escape. The mean dive duration for Open Bay Islands female fur seals during the hoki fishery is 2.87 ± 1.93 min, with a 1.23 ± 1.19 min bottom time (Mattlin *et al.* 1998), which suggests that fur seals are unlikely to survive the haul.

There appear to be real effects by some variables in the determination of whether a hoki target tow catches a fur seal or not in the WCSI fishery. These include year, time period during the hoki fishing season, nation, area, time of tow, and gear type.

Both Japanese and CIS vessels showed a general increase in fur seal bycatch over time, but the CIS vessels showed a more marked increase in 1996 and 1997. The appearance (in the observer data) of Polish vessels in the years 1996–98 had a marked effect on the bycatch of fur seals. Similarly, the time during the fishing season (*week*) seems to be quite important, and there are almost certainly interaction effects involving this variable, but the data imbalance prevents investigation of them.

The bycatch of fur seals at night also increased more than during the day in 1996 and 1997. This may be a result of an increase in fur seals around the fishing vessels, especially at night, when fur seals are more likely to be feeding on those fish species (such as hoki and myctophids) which undergo diel vertical migration (Harcourt *et al.* 1995). However, there are no data for the abundance of fur seals at sea.

Hoki tows closer to the main rookeries on the west coast of the South Island have higher bycatch rates of fur seals than those north of about 41° 30' S. Furthermore, the positions of the start of tows that caught fur seals (*see* Figure 1) suggest that fur seals are more likely to be caught closer to the coast than further away; that is, they appear less likely to be caught in deeper water. We have been unable to define a variable that conveniently categorises such an effect.

The models fitted to the observed WCSI hoki fishery data are almost certainly poorly determined. The standard diagnostic plots for such models are not easy to interpret. Figure 21 contains examples of the types of diagnostic plots obtained.* Plots like those in Figure 21 suggest that the models fitted here probably have little validity.

Increasing the complexity of the regression model is unlikely to improve the model determination. Other interaction terms are likely to be important, but a more balanced data set would be required to investigate them. Some variables are necessarily unbalanced because of the nature of the fishing operation. Generalised additive models which include smoothed values of the continuous predictor variables would possibly improve the model fits somewhat, but make the inclusion of interactions more difficult. The best technique to use in investigating factors that might influence fur seal bycatch may well be the careful examination of the data, perhaps using bootstrap techniques to investigate the significance of any critical differences in mean bycatch rate or probability of catching fur seals (*see* Baird & Bradford 2000).

Acknowledgments

We thank the Ministry of Fisheries scientific observers for the collection of the data, the NIWA data entry staff, and Brian Sanders (NIWA) for the management of the data. Thanks also to Rosie Hurst for constructive comments in her review of this work. This report was prepared under contract to the Ministry of Fisheries as part of the completion of Objective 3 of ENV9801.

---

* These plots were produced in SPLUS© using routines made publicly usable by A. J. Canty and distributed with Davison & Hinkley (1997).

References

Annala, J.H., Sullivan, K.J., & O'Brien, C.J. 1999: Report from the Fishery Assessment Plenary, April 1999; stock assessments and yield estimates. 430 p. (Unpublished report held in NIWA library, Wellington.)

Anon. 1990: Report of the Fur Seal-Hoki Fishery Technical Working Group. MAF Fisheries, Wellington. 25 p. (Unpublished report held in NIWA library, Greta Point, Wellington.)

Baird, S.J. (Comp.) 1994: Nonfish Species and Fisheries Interaction Working Group Report. N.Z. Fisheries Assessment Working Group Report 94/1. 54 p. (Unpublished report held in NIWA library, Greta Point, Wellington.)

Baird, S.J. 1997: Report on the incidental capture of nonfish species during fishing operations in New Zealand waters. 15 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Baird, S.J. & Bradford, E. 2000: Factors that may have influenced seabird bycatch on tuna longlines in New Zealand waters, 1986–87 to 1997–98. *NIWA Technical Report 93.* 61 p.

Belsley, D.A., Kuh, E., & Welsch, R.E. 1980: Regression diagnostics. J. Wiley & Sons, New York.

Carey, P.W. 1998: New Zealand fur seals (*Arctocephalus forsteri*) at the Snares Islands: a stabilised population? *N.Z. Journal of Marine and Freshwater Research 32*: 113–118.

Cook, R.D. & Weisberg, S. 1982: Residuals and influence in regression. Chapman and Hall, New York.

Davison, A.C. & Hinkley, D.V. 1997: Bootstrap methods and their application. Cambridge University Press. Cambridge. 582 p.

Dix, B. 1993: Population changes and diet preferences of the New Zealand fur seal *Arctocephalus forsteri* in eastern Cook Strait. 100 p. (Unpublished MSc. thesis, Victoria University of Wellington, Wellington.)

Harcourt, R.G., Schulman, A.M., Davis, L.S., & Trillmich, F. 1995: Summer foraging by lactating female New Zealand fur seals (*Arctocephalus forsteri*) off Otago Peninsula, New Zealand. *Canadian. Journal of Zooogy 73*: 678–690.

Lalas, C. & Harcourt, R. 1995: Pup production of the New Zealand fur seal on Otago Peninsula, New Zealand. *Journal of the Royal Society of New Zealand 25 (1)*: 81–88.

Lalas, C. & Murphy, B. 1998: Increase in the abundance of New Zealand fur seals at the Catlins, South Island, New Zealand. *Journal of The Royal Society of New Zealand 28(2)*: 287–294.

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

Mattlin, R.H. 1995: Attendance patterns and foraging range of female New Zealand fur seals. WWF-NZ Final Report. 24 p. (Held by WWF-NZ, Wellington.)

Mattlin, R.H., Gales, N.J., & Costa, D.P. 1998: Seasonal dive behaviour of lactating New Zealand fur seals (*Arctocephalus forsteri*). *Canadian Journal of Zoology 76*: 350–360.

Shaughnessy, P.D. & Davenport, S.R. 1996: Underwater videographic observations and incidental mortality of fur seals around fishing equipment in south-eastern Australia. *Marine and Freshwater Research 47*: 553–536.

Shaughnessy, P.D. & Payne, A.I.L. 1979: Incidental mortality of Cape fur seals during trawl fishing activities in South African waters. *Fisheries Bulletin, South Africa 12*: 20–25.

Taylor, R.H., Barton, K.J., Wilson, P.R., Thomas, B.W., & Karl, B.J. 1995: Population status and breeding of New Zealand fur seals (*Arctocephalus forsteri*) in the Nelson-Marlborough region, 1991–94. *N.Z. Journal of Marine and Freshwater Research 29*: 223–234.

Taylor, R.H. 1996: Distribution, abundance and pup production of the New Zealand fur seal (*Arctocephalus forsteri* Lesson) at the Bounty Islands. *Science for Conservation 32.* 14 p.

Wilson, G.J. 1981: Distribution and abundance of the New Zealand fur seal, *Arctocephalus forsteri. Fisheries Research Division Occasional Publication No. 20.* 40 p.

Wilson, G.J. 1992: Fur seals and the South Island hoki fishery. (Unpublished paper presented at the Workshop on Seals and Seabirds-Fisheries Interactions, 27–30 April 1992, Wellington, New Zealand.) 12 p.

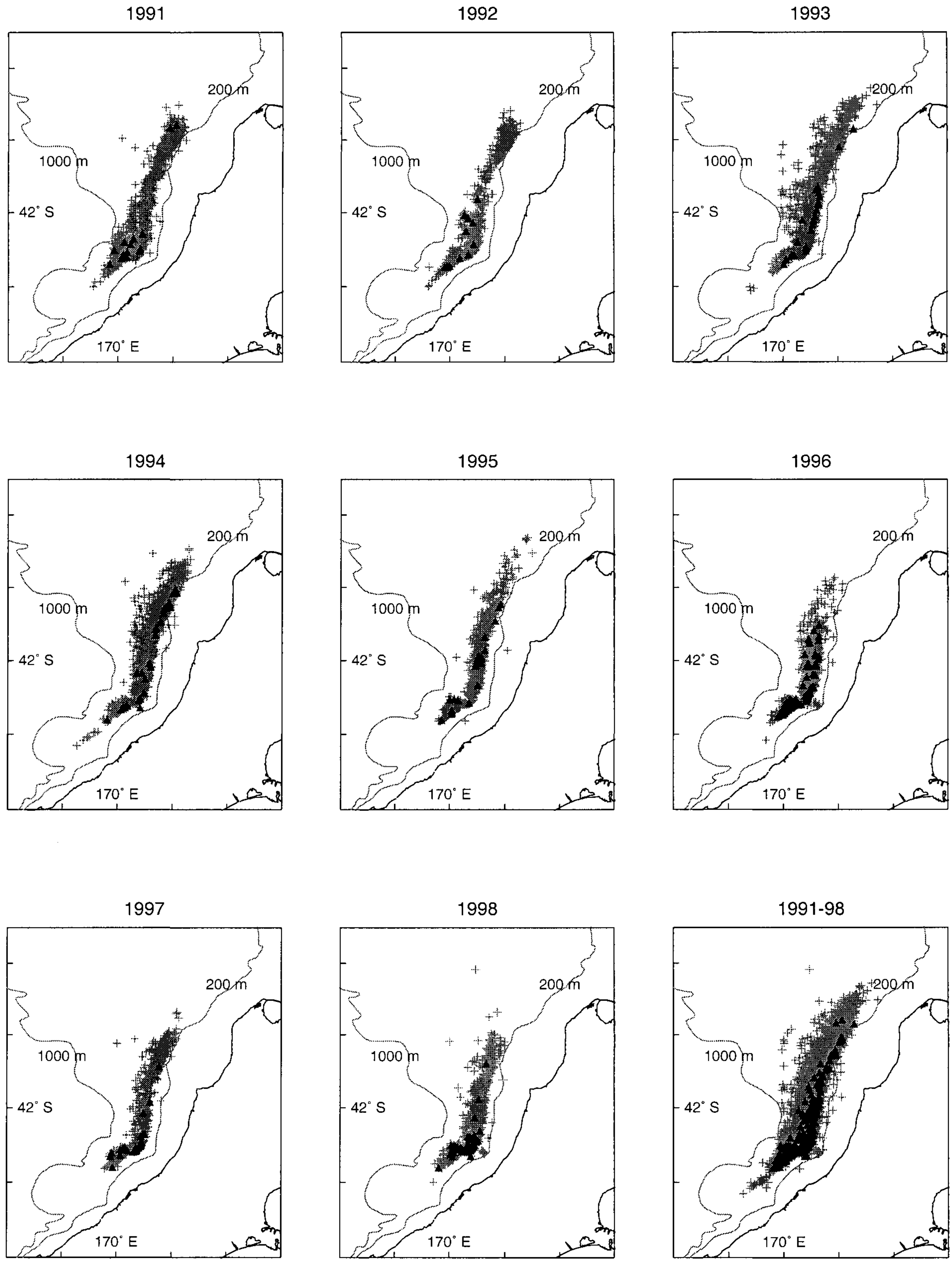

Figure 1: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), 1991–98.**

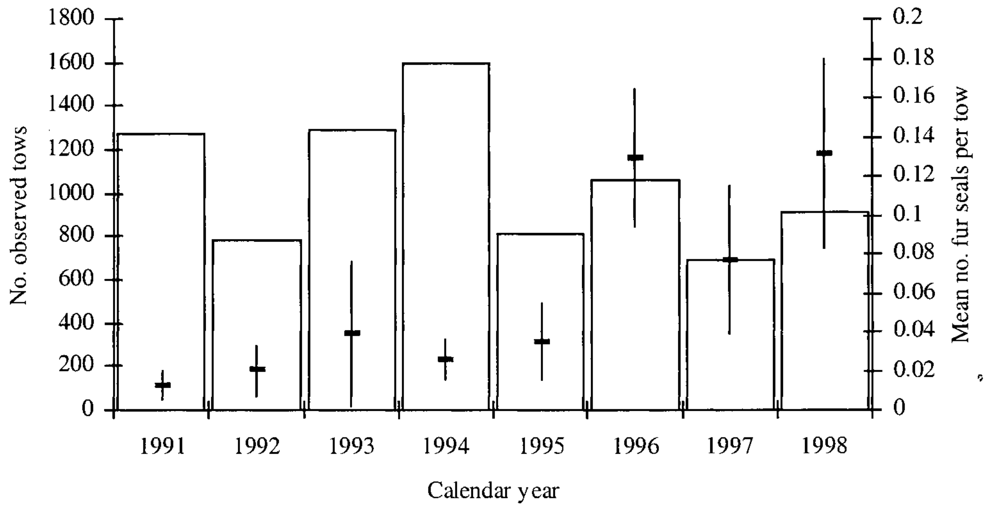

Figure 2**: Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, 1991–98.**

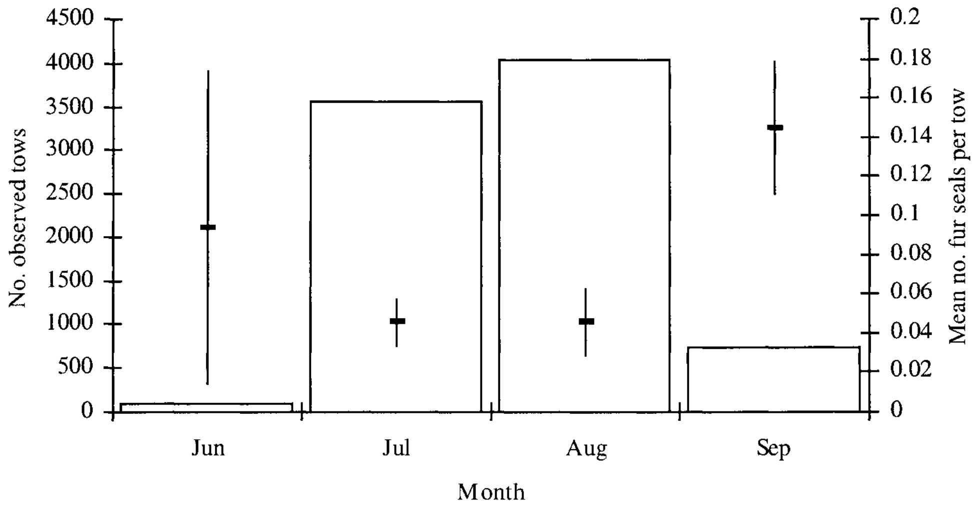

Figure 3**: Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, for years 1991–98, by month.**

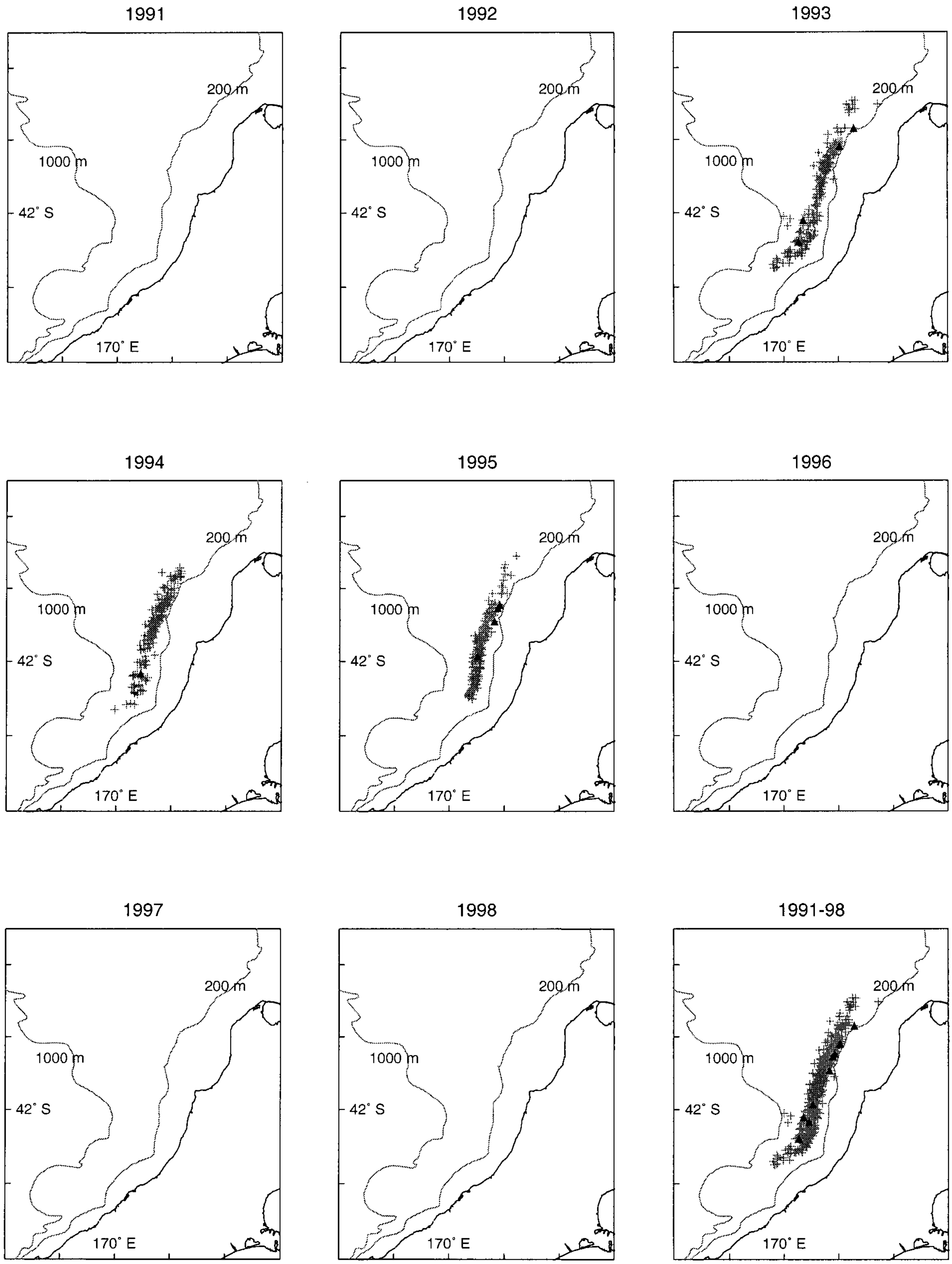

***Figure 4*: Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed Chinese vessels, 1991–98. (No tows were observed in 19991, 1992, 1996–98.)**

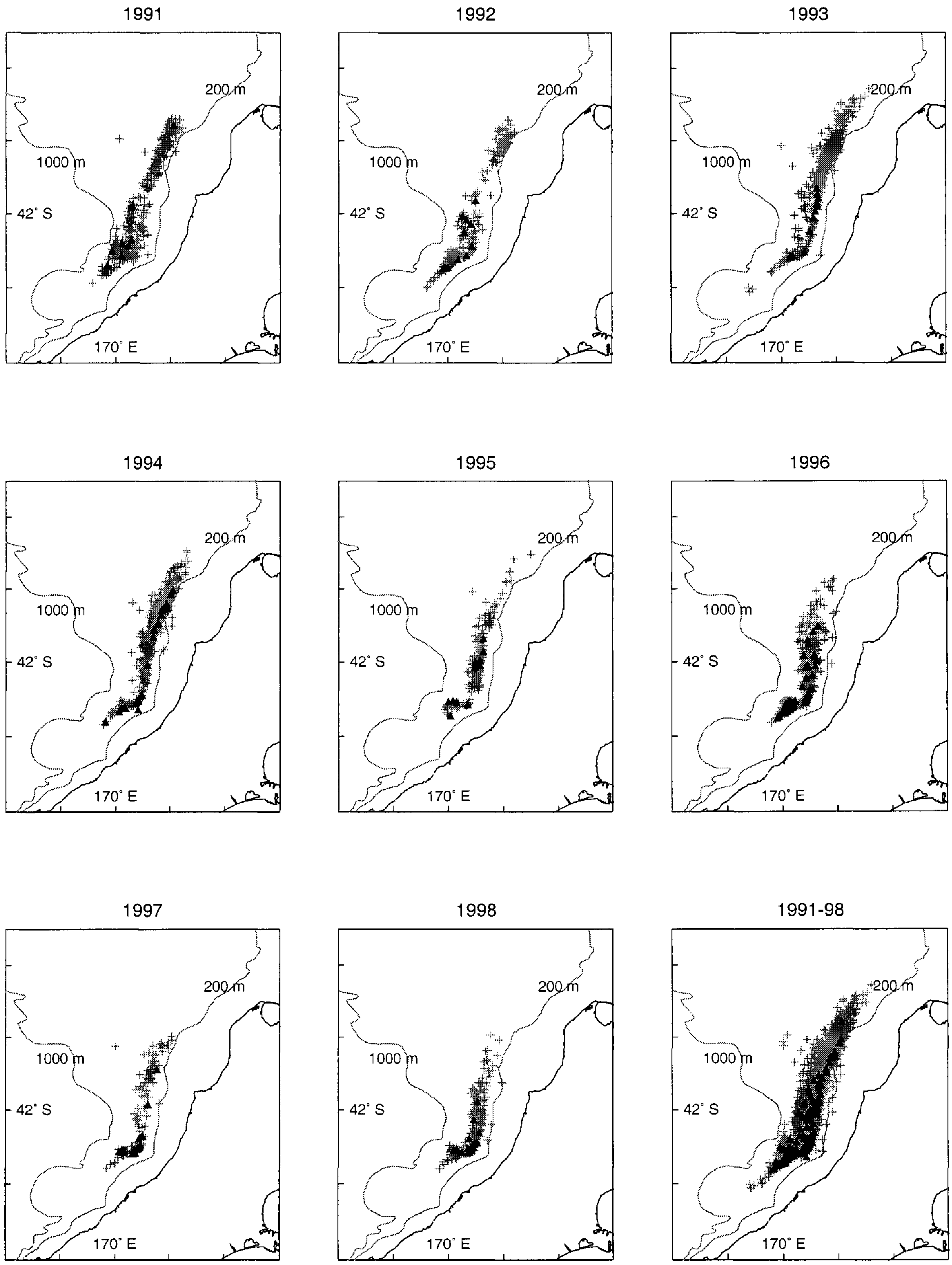

Figure 5: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed CIS vessels, 1991–98.**

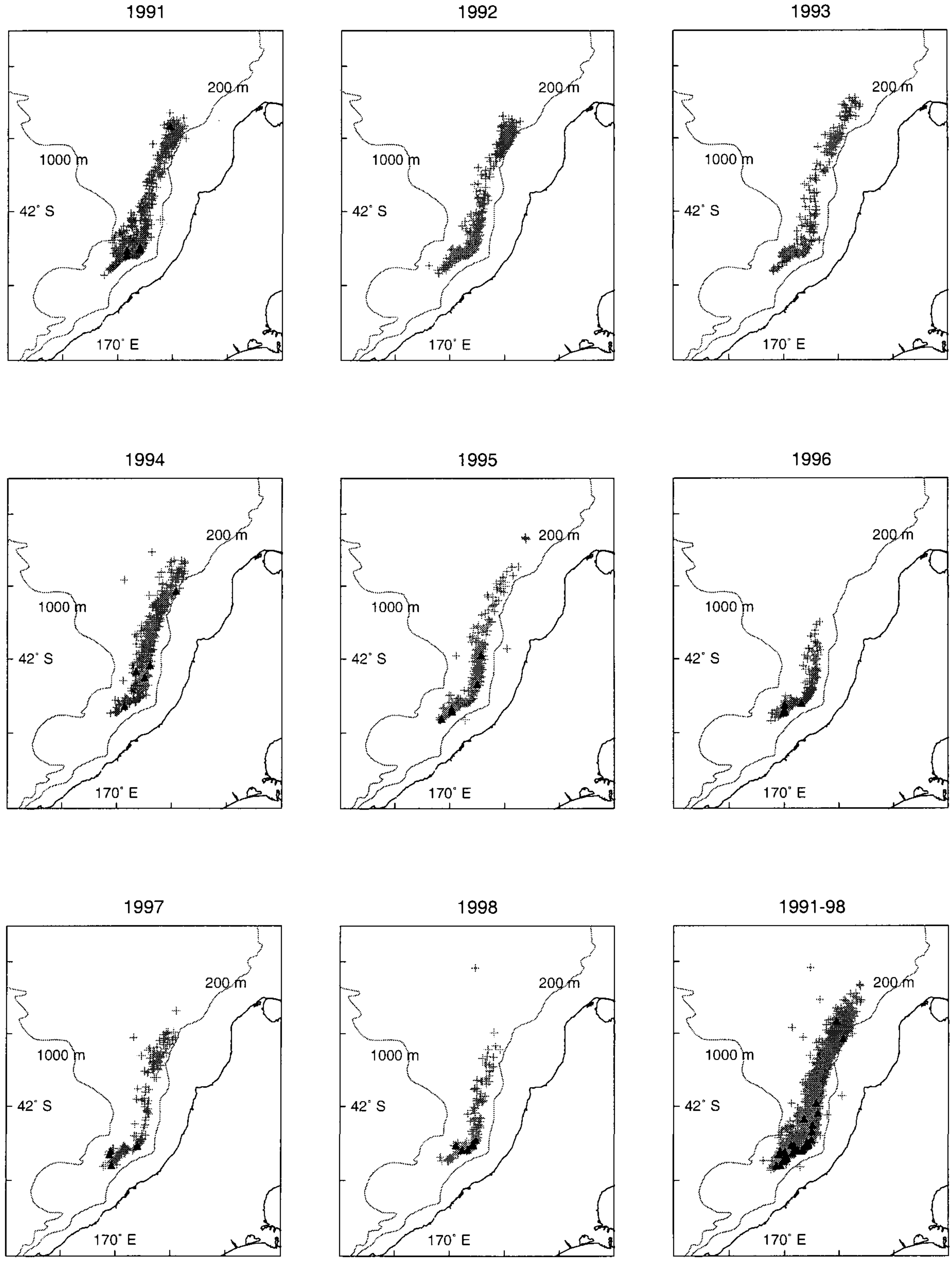

Figure 6: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed Japanese vessels, 1991–98.**

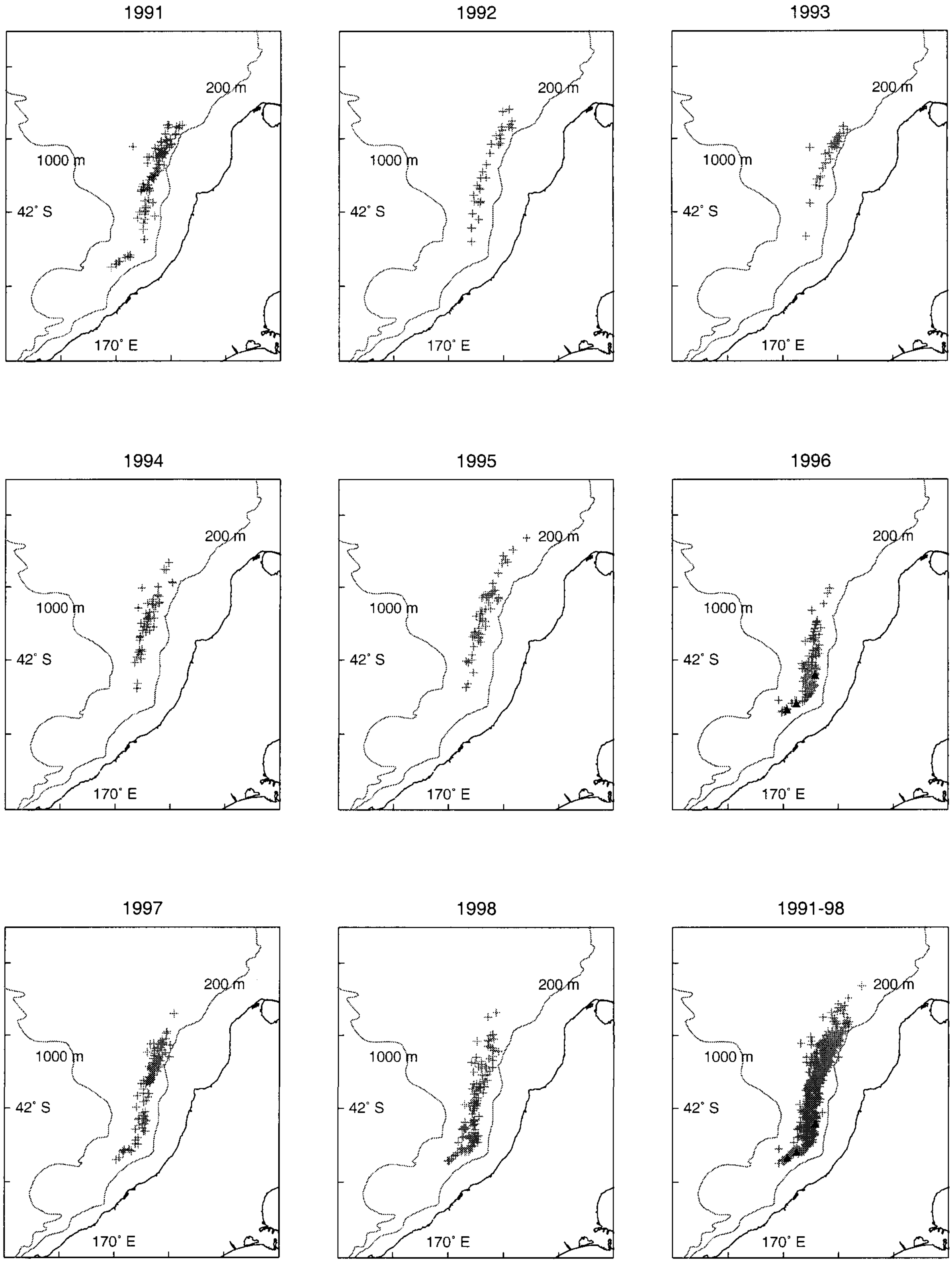

Figure 7: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed Korean vessels, 1991–98.**

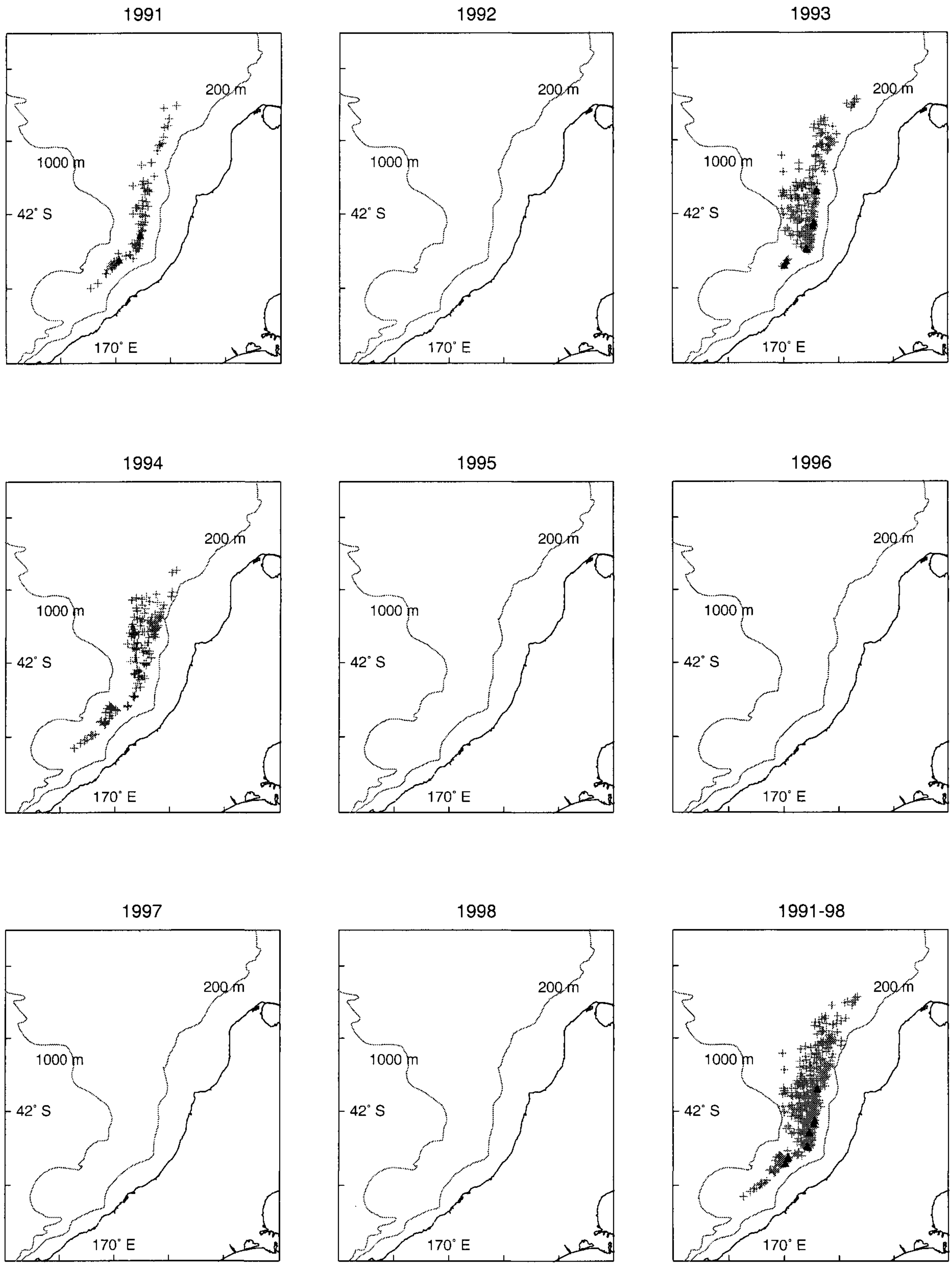

***Figure 8*: Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed Norwegian vessels, 1991–98. (No tows were observed in 1992, 1995–98.)**

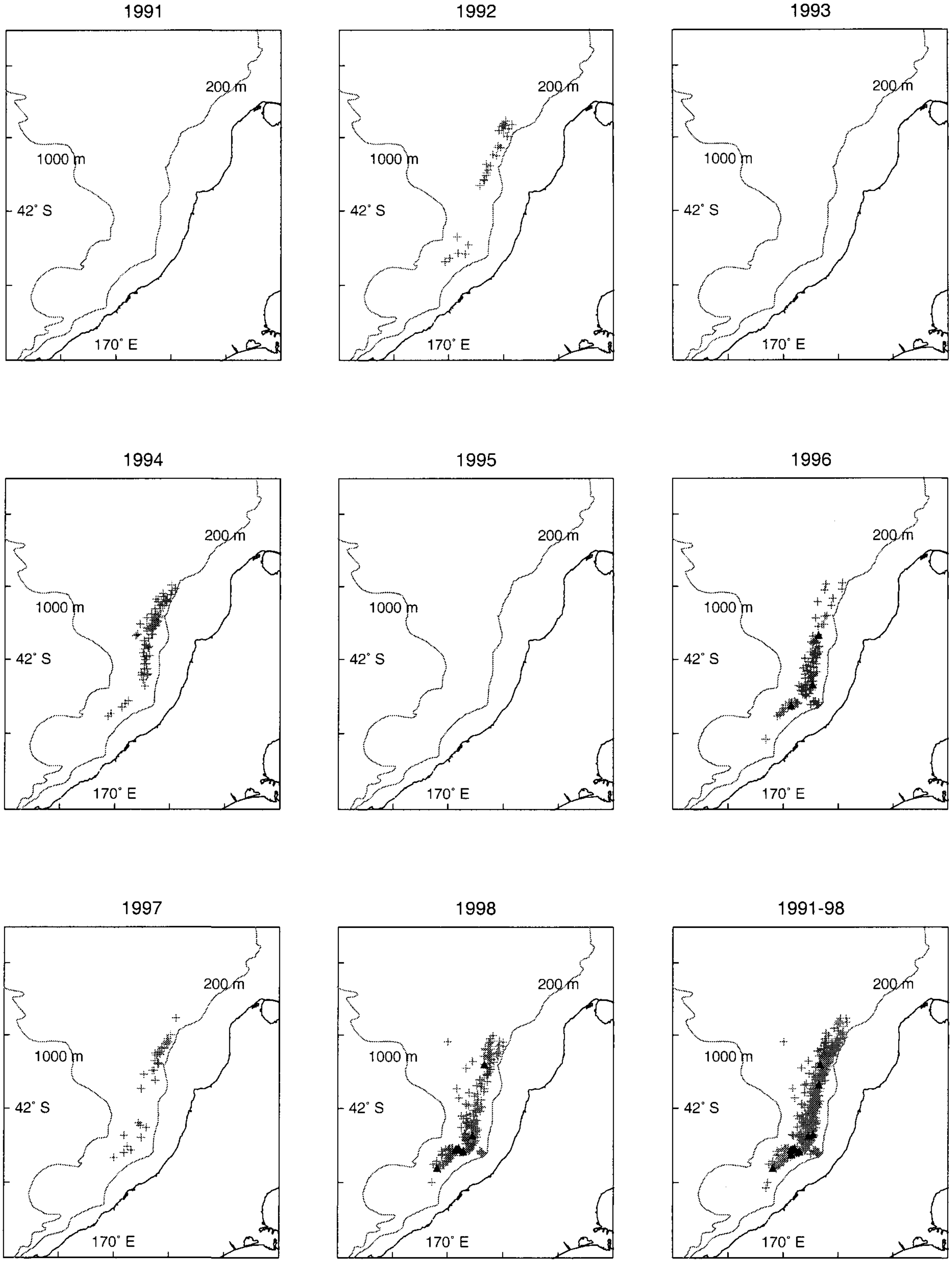

Figure 9: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed New Zealand vessels, 1991–98. (No tows were observed in 1991, 1993, 1995.)**

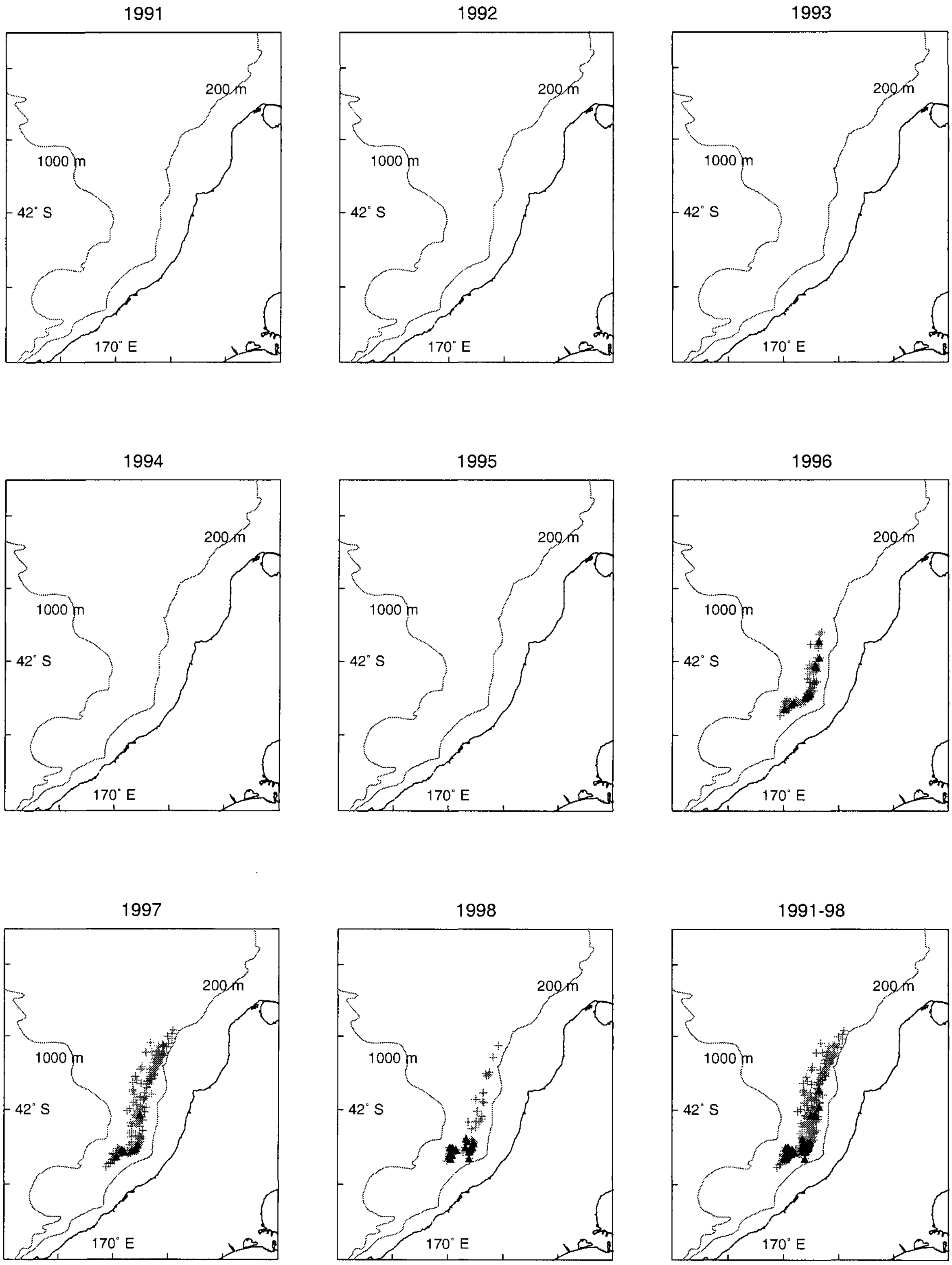

Figure 10: **Start positions of observed WCSI hoki tows (+), including those that caught fur seals (▲), for observed Polish vessels, 1991–98. (No tows were observed before 1996.)**

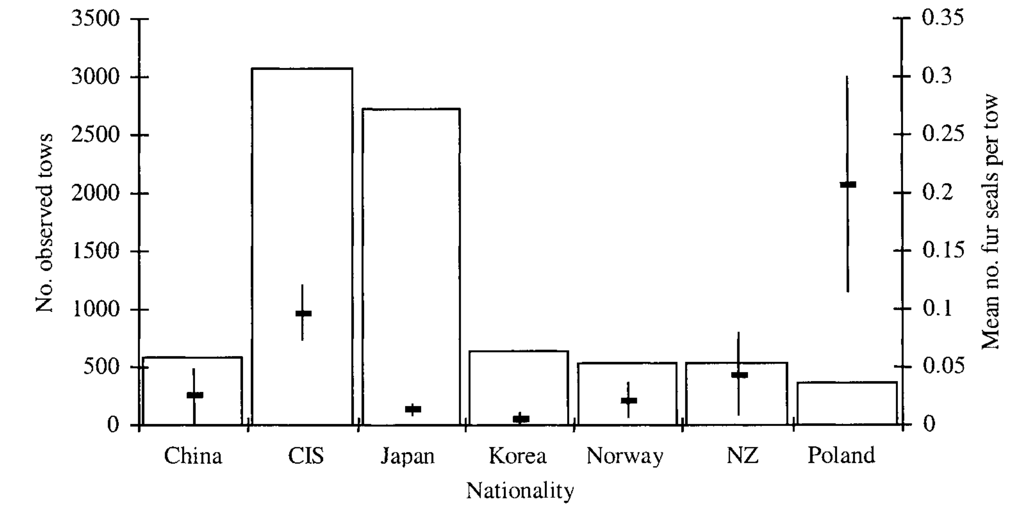

***Figure 11*: Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, 1991–98, by nation group.**

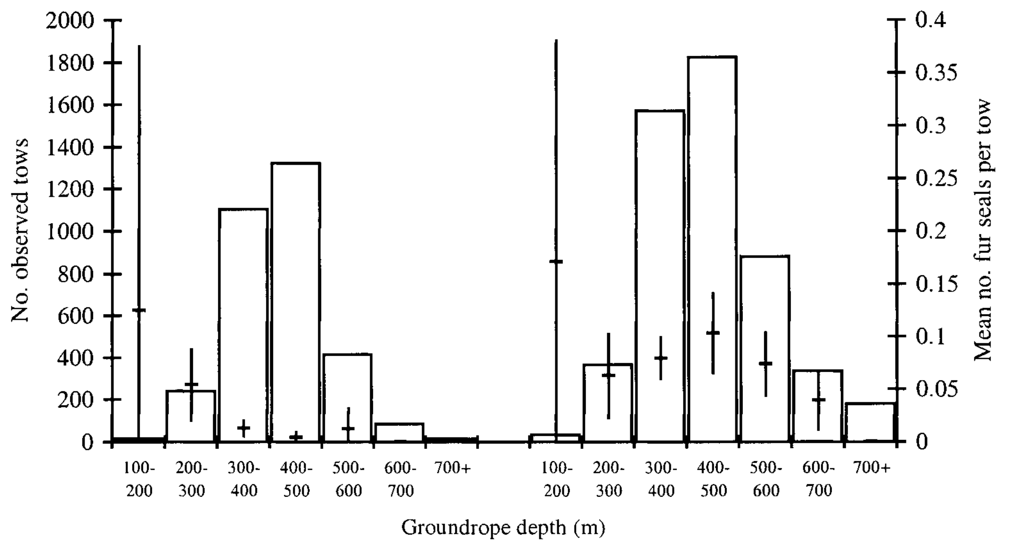

***Figure 12*: Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, for years 1991–98, for tows north (left) and south (right) of 41° 30' S, by 100 m depth categories.**

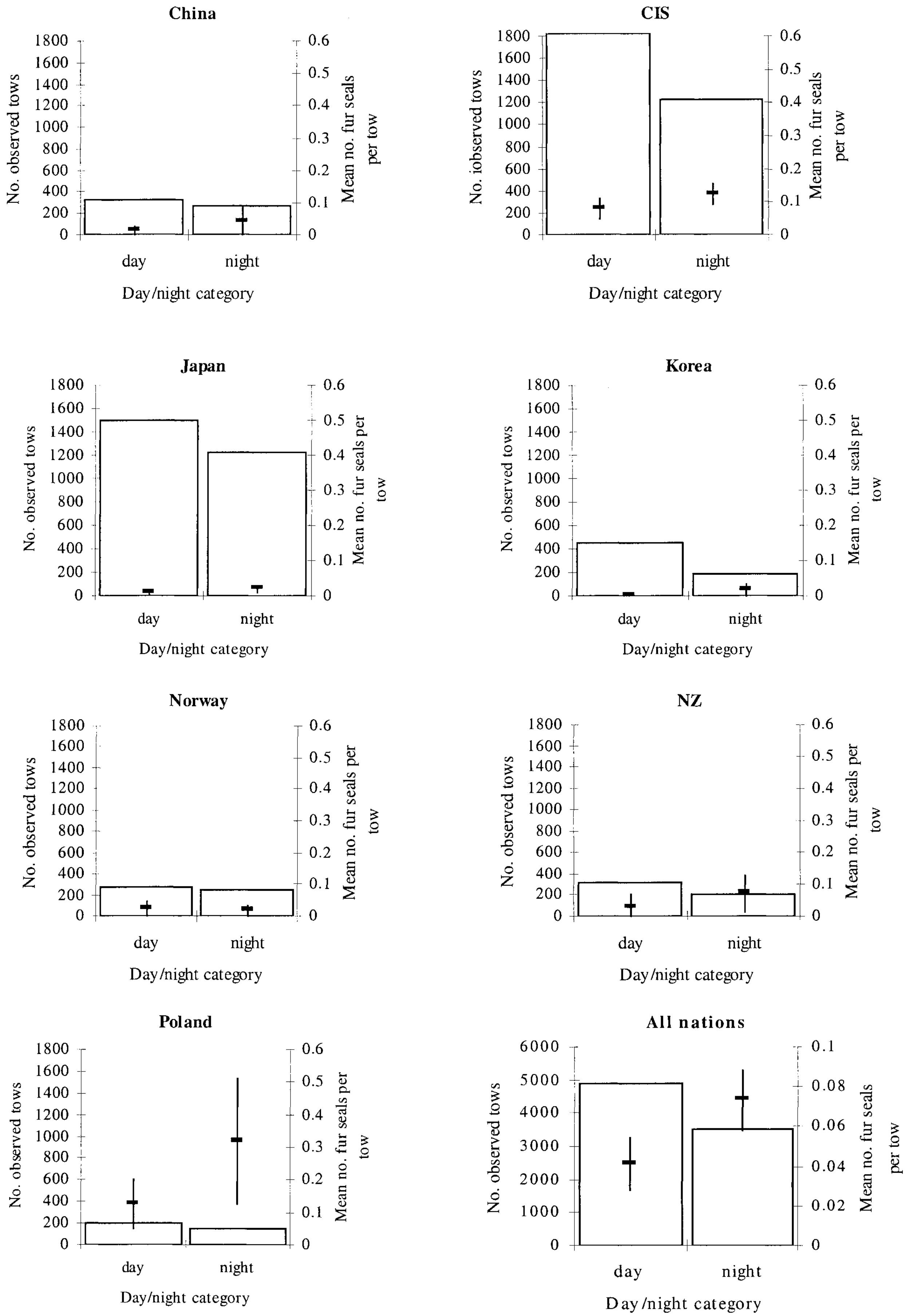

Figure 13: **Number of observed tows (histogram) and mean fur seal bycatch (± 2 *s.e.*) in the WCSI hoki fishery, by "day" and "night" categories, by nation.**

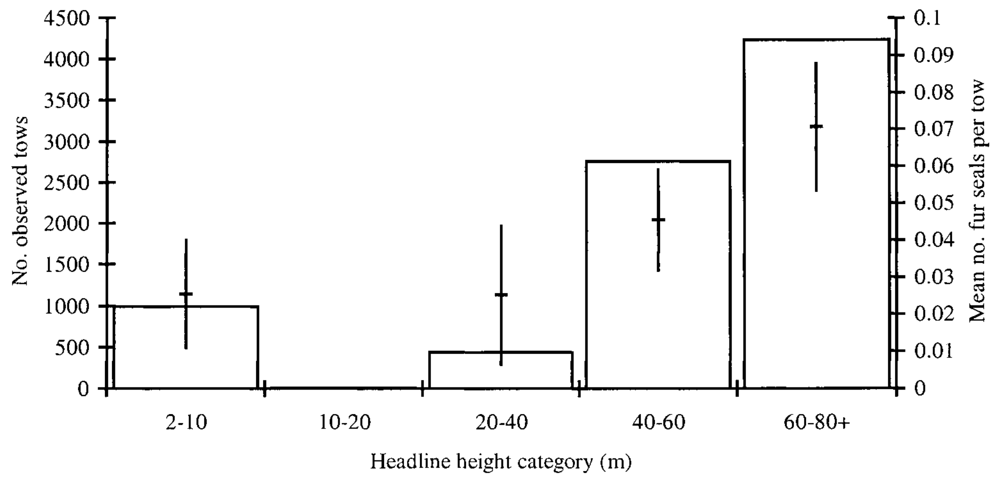

***Figure 14*: Number of observed tows (histogram) and mean number of fur seals observed caught (± 2 *s.e.*) in the WCSI hoki fishery, 1991–98, by headline height. category**

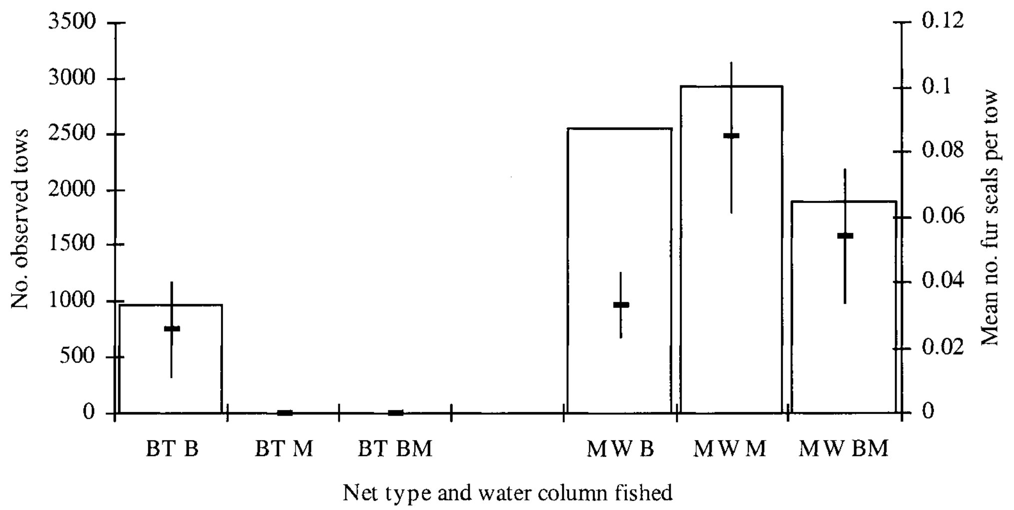

***Figure 15*: Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, 1991–98, by net type used and position of net in the water column. (BT B is bottom trawl fishing on the bottom, M is when the net fished in midwater, BM is when the net fished in a mixture of bottom and midwater depths, MW is a midwater net.)**

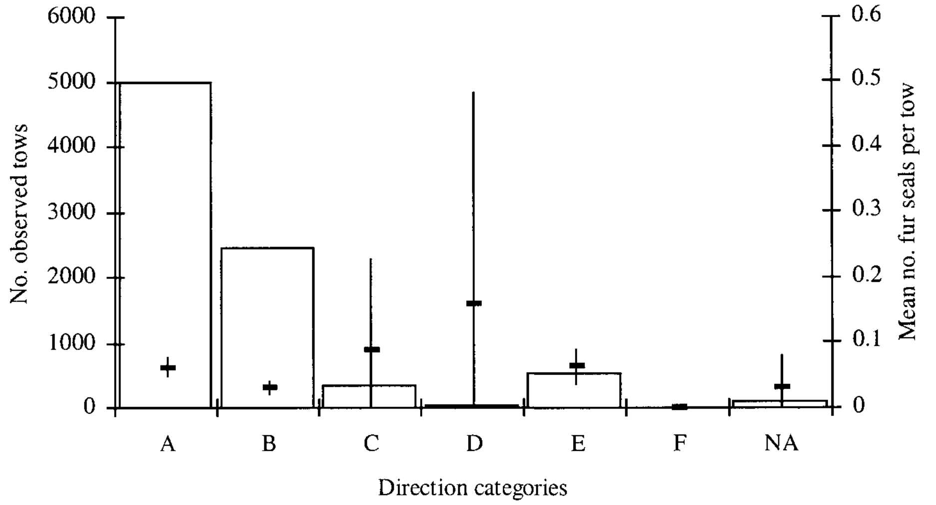

Figure 16: **Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, 1991–98, by tow direction. (A is straight line, B is U-bend, C is zigzag, D is circle or loop, E is following a constant depth contour, F is pinnacle fishing, NA is no record.)**

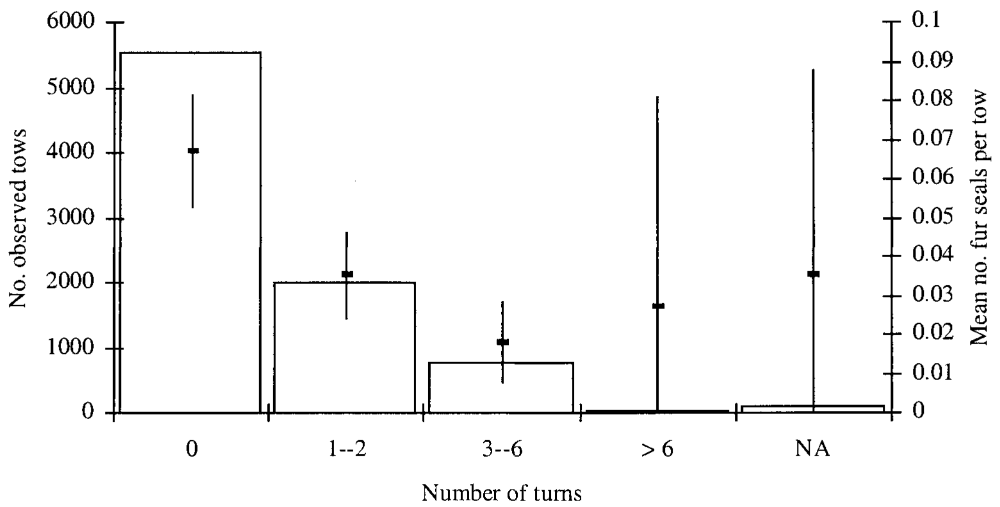

Figure 17: **Number of observed tows (histogram) and mean number of fur seals (± 2 *s.e.*) observed caught in the WCSI hoki fishery, 1991–98, by number of turns.**

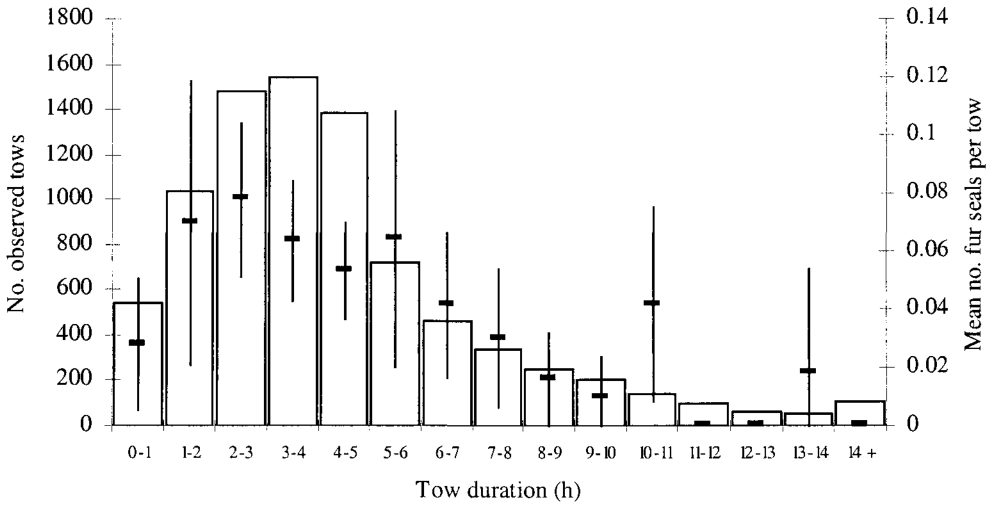

***Figure 18*: Number of observed tows (histogram) and mean number of fur seals caught per tow (± 2 *s.e.*) for the WCSI hoki fishery, 1991–98, for all nations, by tow duration.**

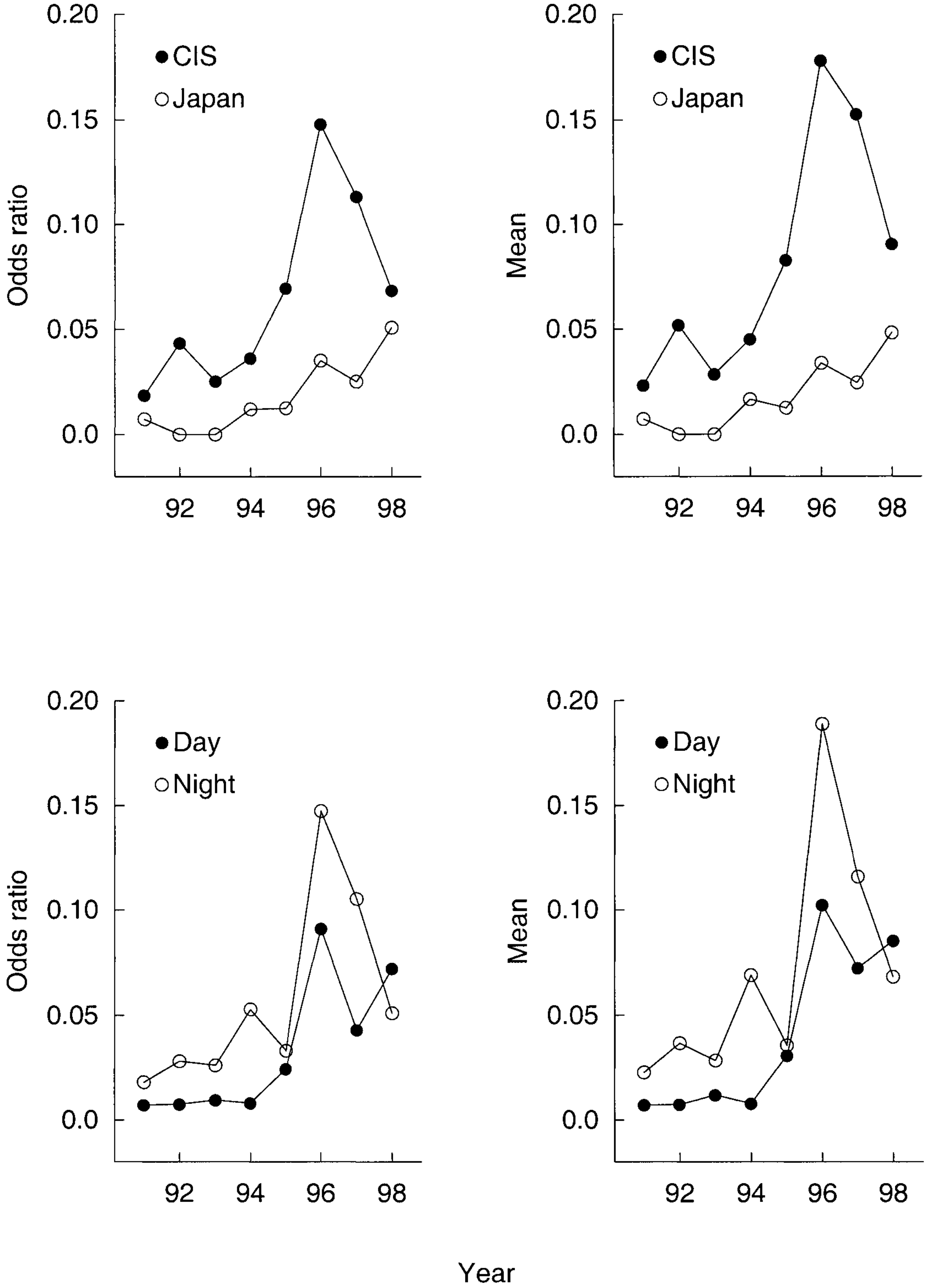

Figure 19: **Annual odds ratios and means of modified catch distribution for Japanese and CIS vessels for 1991–98 and the day/night effect using the same data.**

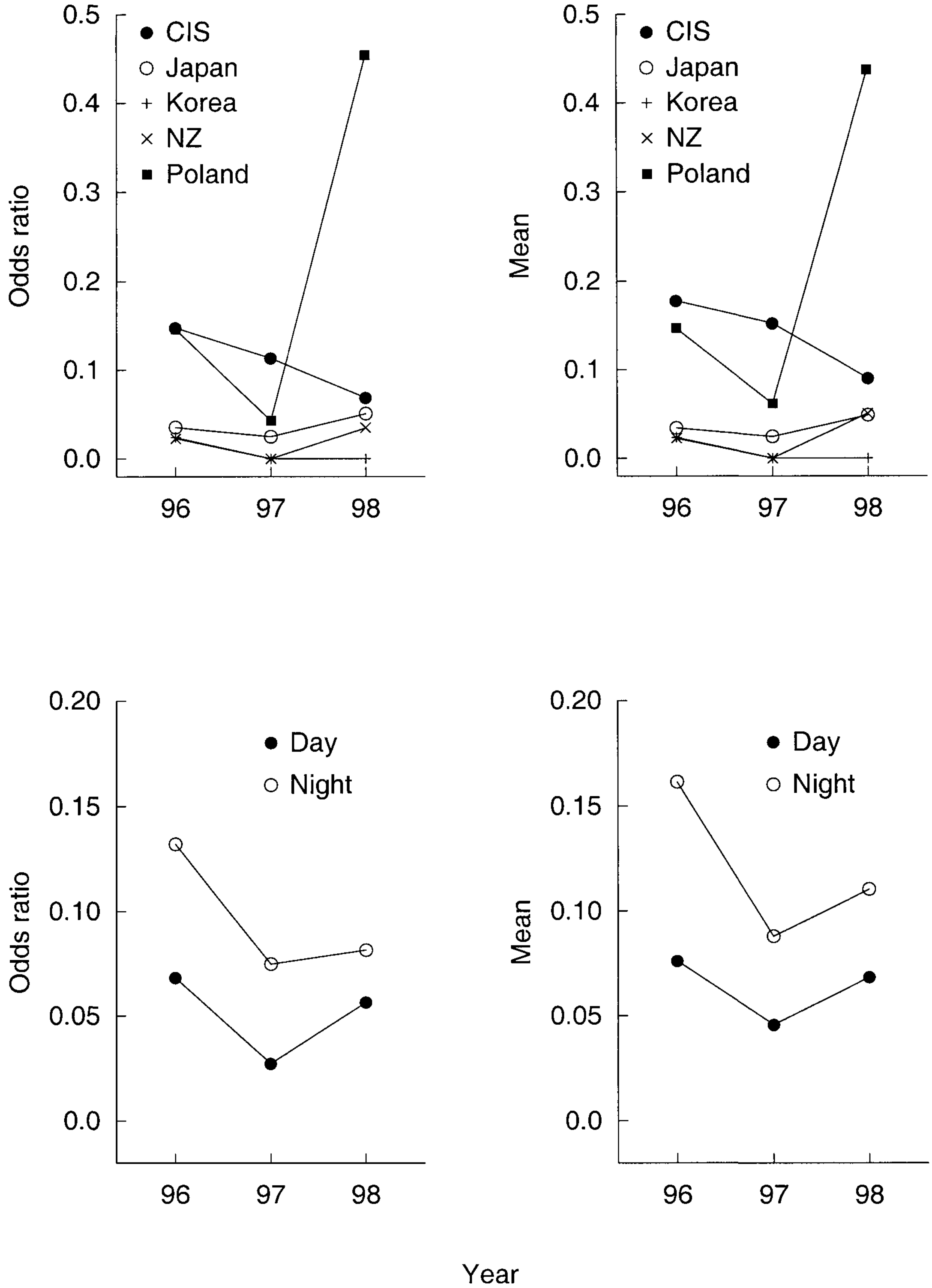

Figure 20: **As for Figure 19, but using the data from all vessels fishing during 1996–98.**

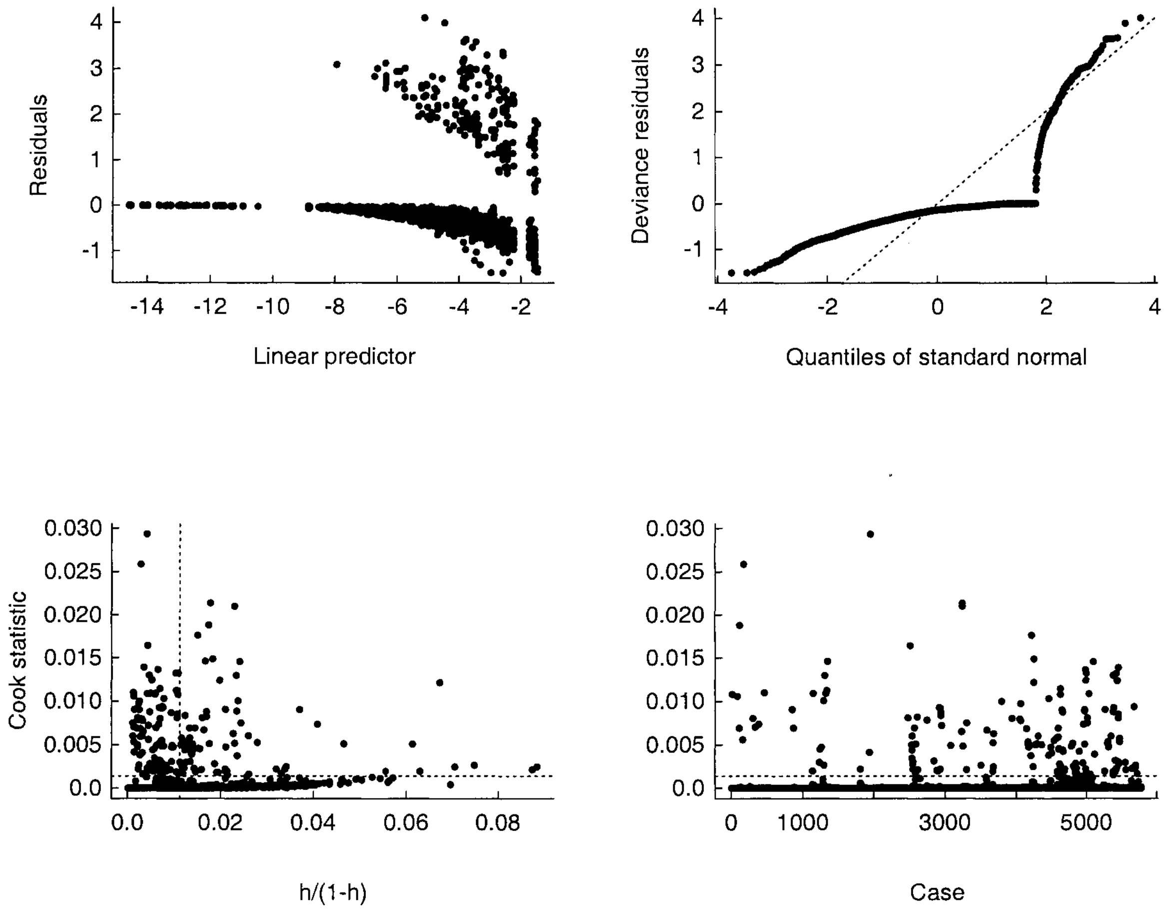

***Figure 21*: Diagnostic plots for Poisson model (2) using CIS and Japanese data. The linear predictor is the logarithm of the predicted value. Both *h/(1-h)* and the Cook statistic are measures of the influence of particular points in the regression. Points with values of h/(1-h) to the right of the vertical dotted line, and points with values of the Cook statistic above the horizontal dotted lines may be influential in the fit (Belsley *et al.* 1980, Cook & Weisberg 1982).**