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New Zealand Fisheries Assessment Research Document 95/26

Analyses of factors which influence seabird bycatch in the Japanese southern bluefin tuna longline fishery in New Zealand waters, 1989–93

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December 1995

Ministry of Fisheries, Wellington

This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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Executive Summary

This paper summarises an analysis of seabird bycatch data collected by the New Zealand Ministry of Agriculture and Fisheries' Scientific Observer Programme from Japanese longline vessels fishing within New Zealand's 200 nautical mile exclusive economic zone between 1989 and 1993. The objective was to assess the influence that 15 monitored environmental and fishery related factors had on seabird bycatch rates, and to gauge the effectiveness of various mitigation measures.

The relationship between seabird bycatch and the monitored factors was examined singly and with the use of generalised linear models.

The following conclusions are supported by both the bivariate and binomial linear modelling analyses.

The factors which have a major influence on rates of seabird bycatch are area, the presence and quality of a tori line, and the phase of the moon for night sets.

The west coast of the South Island has a significantly lower rate of seabird bycatch then other areas.

The effectiveness of tori lines in reducing seabird bycatch rates varies greatly depending on the physical properties of the tori line.

Moon phase has a substantial impact on the seabird bycatch rate for sets made at night. As the moon becomes more full, the rate at which seabirds are caught at night increases. Few birds are caught at night when the moon is less than half full.

More research on seabird bycatch mitigation measures is desirable. There is evidence that the mitigation measures currently in use have reduced the incidence of seabird bycatch, but without the introduction of improved measures no further long term reductions are likely.

2.0 Introduction

2.1 The New Zealand southern bluefin tuna fishery

Japanese longliners have fished within what is now the New Zealand 200 n. mile Exclusive Economic Zone (EEZ) since the 1950's. Foreign licensed Japanese, chartered and domestic longline vessels target southern bluefin tuna (SBT) south of latitude 35°S.

Michael *et al.* (1987) provided a detailed description of the techniques used by Japanese longliners in the SBT fishery within New Zealand's EEZ. Murray *et al.* (1992, 1993) described the general history and method of tuna longlining in the EEZ.

A vessel typically spends 5–6 hours each day setting a single longline 100–140 km long. During this time the vessel steams at a speed of about 10 knots while crew members, on the stern of the vessel, deploy the mainline and attach floats and snoods (30–50 m lengths of line with a single baited hook or lure on the end) at predetermined points. Typically the bait is a whole squid, jack mackerel, or other small fish (about 300 mm long).

Other than the swivels and clips used on the line, no additional weights are attached to make the line sink. The line is usually set so that the hooks are 80–180 m deep.

Once setting is complete, the line is left to soak for a few hours and then hauled. Hauling takes 10–17 h. The whole operation takes about 24 h and is repeated daily.

The SBT fishery typically operates off the South Island in April, May, and June and then off the East Cape in June, July, and August.

Over the past 12 years, fishing effort by Japanese SBT longliners within the New Zealand EEZ has declined. From 1979 to 1983 an average of 21.9 million hooks was set each year. Between 1989 and 1993 this decreased to an average of 8.5 million hooks set per year (Murray *et al.* 1993. unpublished New Zealand MAF Fisheries data).

2.2 Seabird bycatch in the SBT fishery

It is common for seabirds to follow fishing vessels. They may associate fishing vessels with the availability of food. As well as discarding old baits, offal ,and unwanted fish bycatch, fishing vessels may lose small quantities of target fish species during hauling. Brothers (1991) reported an average of 10.8 albatrosses closely following Japanese longliners during setting off Tasmania. Hundreds of small petrels and shearwaters may also be seen following vessels.

During setting, baited hooks are thrown astern of the vessel. Until they sink beyond the reach of a seabird (this varies with species), the baited hooks are vulnerable to being seized by one or more birds. On average, each set comprises 2945 hooks, and one hook is deployed every 7 s. Brothers (1991) observed that over 80 % of the attempts by birds to take baits occurred less than 100 m behind the vessel and that less than 1% occurred more than 200 m behind the vessel.

Some seabirds (particularly petrels) are proficient divers. Albatrosses tend to have a limited diving ability and do not generally dive below 3 m. When more than one bird attempts to take a bait competition occurs, and the more aggressive species (commonly the larger albatrosses) are more likely to take the bait (Brothers 1991). This raises the possibility that the smaller, deeper diving petrels retrieve the baits which are then stolen by the larger albatrosses.

Brother's (1991) observations make it clear that not all attempts by birds to take baits are successful, and that not all birds which take baits become hooked. Larger birds are more likely to become hooked because of their ability to swallow the bait (and hook) whole. Smaller birds, which feed by pecking at a bait, may be less vulnerable to hooking. Birds which do become hooked are dragged below the surface by the weight of the line and drowned.

Brothers (1991) observed that birds are hooked during line setting. The small percentage (4.6%) of birds found by this study to have been retrieved alive supports this observation. If birds were caught during line hauling it would be expected that a higher proportion would be alive when brought aboard the vessel.

The data returned by observers may not represent the total number of seabirds killed. Some birds may fall off the line or be eaten by fish while submerged (Brothers 1991). Some birds may also be discarded by crew members before being recorded by observers. Others escape to die later as a result of injuries sustained (Weimerskirch & Jouventin 1987).

Brothers (1991) estimated the number of albatrosses killed by Japanese longliners in the southern oceans at 44000 per year (based on 1981–86 fishing data). Murray *et al.* (1993) estimated that 9279 seabirds were captured (data includes dead and alive birds) by Japanese tuna longliners within the New Zealand EEZ from 1988 to 1992.

2.3 Mitigation measures

Tomkins (1985), Weimerskirch & Jouventin (1987), and Croxall & Prince (1990) suggested that longline fishing may be a substantial factor in the decline of some seabird populations. Researchers consequently began investigating methods for reducing seabird bycatch in tuna longline fisheries (Brothers 1991, Murray *et al.* 1993).

Bycatch mitigation measures were implemented in New Zealand in 1992 as a part of foreign licence conditions. Night setting or the use of tori lines for daytime fishing were made mandatory. From 1993, the use of tori lines became mandatory for all longline fishing (foreign and domestic) at all times, and night setting was removed as a licence requirement.

As a result of these conditions, longline vessels fishing within the New Zealand 200 n. mile EEZ must now deploy a tori line of the type recommended by the Commission for the Conservation of Antarctic Living Resources (CCAMLR) while longline setting.

2.4 Observer data

Observer coverage of Japanese vessels is summarised in Table 1.

Table 1. Number and percent coverage of Japanese tuna longline sets in the New Zealand EEZ, 1989–93

Year	Number of sets observed	% Sets observed
1989	88	2
1990	154	5
1991	150	2
1992	352	7
1993	421	24

An observer's priority while on board a longliner, is to collect information for the assessment of tuna catch and fishing effort. Included in the data collected are: set start and finish positions and times; the number of hooks deployed; the maximum and minimum depths that the hooks will fish; catch by species (in number and weight), and weather data [wind strength (1991), atmospheric pressure (1991), and percent cloud cover (1991)]. Observers also collect biological samples from selected fish species.

The years given in brackets indicate the first year that these data were recorded. If no year is given then the data collection began in or before 1989. The sample size used in each analysis varied because some data were not available for all years.

Observers also collect information for the analysis of seabird bycatch. This includes the presence or absence of a tori line (1991); tori line length (1991); number of tori line streamers (1991); height of the tori line towing point (1991); horizontal distance from the tori line to the point where baits land in the water (1991); whether the bait was frozen or thawed at time of use (1992); how far from the centre of the vessel's wake the bait landed (1992); how far behind the vessel the bait sink beneath the sea surface (1992); and whether a mechanical bait thrower was used (first used in 1993).

Most data relate to the line haul operation. Observation of line setting is usually limited to the start of the set. Some factors may change during the set. Data related to longline setting include whether a tori line or bait thrower was used, whether the bait was frozen or thawed when used, and weather conditions.

In this study fishing depths, bait sink distance, and the distance from the centre of the vessel's wake to the point where the bait landed were not analysed because of doubt about the quality of the data.

2.5 Overview of the methodology used

It is difficult to measure the true effect of a variable by a simple bivariate analysis because the data have not been collected in a designed experiment. Variables may be partly or completely confounded, may be highly correlated with each other, or may be correlated with variables which were not monitored.

This study adopted a dual approach. Firstly, a bivariate analysis of the 15 monitored factors was carried out. Secondly, a generalised linear modelling analysis was performed to establish the relative importance of these factors. Linear models are mathematical analysis tools which summarise normally distributed data and highlight features of the data (Crosbie & Hinch 1985). Generalised linear models have the same effect, but do not require that the data be normally distributed. Given that the observed data have a specific known distribution, both types of model estimate parameters for each factor involved, and minimise the difference between the observed data values and the data values predicted by the model.

The process of generalised linear modelling is iterative. The S statistical package (Becker *et al.* 1988) used in this analysis first calculates a reasonable set of initial parameters for the factors being studied and then repeatedly refines these to minimise the difference between observed and predicted results.

A year effect was not fitted in the models. Fitting a year effect could mask real changes in catchability due to changes in fishing practices or mitigation technology (which are highly correlated with year).

An individual vessel effect was not fitted because only 9 of the 28 vessels observed were observed in more than one year. It is unlikely that such a model would be able to differentiate between vessel effects and fishing practices or mitigation technology effects. It is also likely that the total sample size (1070 sets) is not large enough to sensibly fit a 28 parameter variable (vessel effect).

3.0 Bivariate analysis

All analyses were carried out using the S statistical package (Becker *et al.* 1988). Standard errors were calculated for the `birds caught per set' analysis by use of a boot-strapping procedure (Efron & Tibshirani 1986) which re-sampled with replacement 200 times. In the case of continuous variables, the main criterion used for selecting grouping categories was the need to keep a reasonable sample size in each group. A summary of the data is given in Table 2.

Information on one bird was lost between the time the bird was recorded caught on a set and the time its individual details were recorded. As a result, some of the analyses show a total of 517 birds caught, others 518.

Table 2. Summary of the data used in this study, 1989–93.

Total number of vessels observed	28
Total number of sets observed	1070
Number of hooks per set - Average	2945
Number of hooks per set - 5 percentile	2500
Number of hooks per set - 95 percentile	3180
Time taken to deploy a set - Average	5.5 h
Time taken to deploy a set - 5 percentile	4.5 h
Time taken to deploy a set - 95 percentile	6.1 h
Sets known to have used a tori line	43.4%
Sets made entirely at night	65.6%
Sets made entirely during the day	2.3%
Number of birds caught	518
Sets which caught birds	18.6%
Average number of birds caught on sets which did catch birds	2.6
Maximum number of birds caught on 1 set	38

3.1 Seabird bycatch rate by year

The seabird bycatch data for each year is summarised in Table 3. The bycatch rate declined from 1989 to 1992, and then increased in 1993.

Table 3. Observed annual seabird bycatch rate, 1989–93

Birds caught per 1,000 hooks deployed

Year	No. of birds	No. of Hooks	No. of Birds per 1000 hooks
1989	123	246 552	0.50
1990	129	447 454	0.29
1991	37	439 144	0.08
1992	14	762 443	0.02
1993	214	1 255 068	0.17

Birds caught per set

Year	No. of birds	No. of sets	No. of birds per set	Std. error
1989	123	88	1.40	0.33
1990	129	154	0.84	0.16
1991	37	150	0.25	0.06
1992	14	257	0.05	0.02
1993	214	421	0.51	0.11

3.2 Seabird bycatch rate by time of day

The exact time when a bird was captured is not known. It can be estimated by assuming that birds are captured by a given hook in the minute or so between that hook being deployed and sinking; that line setting and line hauling rates are constant, and that the line was hauled from the same end throughout the operation.

The technique used to estimate the time of a bird's capture in this study is very similar to that described by Murray *et al.* (1992), the one major change being that actual, rather than average, haul time duration's were used. Capture time was estimated by calculating the proportion of the time through the haul in which the bird was retrieved. This proportion, when considered along with set start time, set finish time, and the end at which hauling began, allows the calculation of the time of deployment of the hook on which the bird was caught.

The number of hooks deployed in each hour was calculated individually using set start times, set finish times, and the number of hooks deployed for each of the 1070 sets made during the study period. It was assumed that line setting takes place at a constant rate.

The estimated hourly catch rate is given in Table 4 and Figure 1a. The bycatch rate is highest in the early afternoon and lowest at night.

Table 4. Number of seabirds caught per 1000 hooks set by time of day (all areas and years combined)

Time	No. of birds	No. of hooks	No. birds per 1000 hooks
0000 - 0059	34	253 599	0.13
0100 - 0159	38	300 675	0.13
0200 - 0259	13	318 208	0.04
0300 - 0359	23	310 025	0.07
0400 - 0459	22	282 408	0.08
0500 - 0559	8	245 953	0.03
0600 - 0659	33	193 067	0.17
0700 - 0759	43	148 928	0.29
0800 - 0859	38	121 466	0.31
0900 - 0959	35	82 252	0.43
1000 - 1059	14	58 421	0.24
1100 - 1159	13	37 498	0.35
1200 - 1259	13	19 743	0.66
1300 - 1359	23	19 275	1.19
1400 - 1459	17	20 707	0.82
1500 - 1559	10	25 700	0.39
1600 - 1659	18	31 894	0.56
1700 - 1759	30	39 170	0.77
1800 - 1859	6	47 494	0.13
1900 - 1959	7	64 847	0.11
2000 - 2059	10	82 453	0.12
2100 - 2159	21	94 025	0.22
2200 - 2259	23	150 927	0.15
2300 - 2359	19	198 927	0.10

The number of birds captured per set is calculated on the basis of set start times i.e., how many birds are caught by sets starting within a given hour-long time segment is given in Table 5 and Figure 1b. This method of assessing the catch rate by time of day is not as accurate as that presented in the previous section, because the set data is an amalgamation of 5 or 6 h data.

Table 5. Number of seabirds caught per set by time of day (all areas and years combined)

Set start time	No. of birds	No. of sets	No. of birds per set	Std. error
0000 - 0059	34	146	0.23	0.06
0100 - 0159	34	122	0.28	0.07
0200 - 0259	33	55	0.60	0.23
0300 - 0359	40	86	0.47	0.12
0400 - 0459	34	45	0.76	0.26
0500 - 0559	33	62	0.53	0.24
0600 - 0659	15	19	0.79	0.54
0700 - 0759	7	12	0.58	0.35
0800 - 0859	0	4	0.00	0.00
0900 - 0959	7	5	1.40	0.20
1000 - 1059	3	10	0.30	0.29
1100 - 1159	9	7	1.29	0.55
1200 - 1259	10	6	1.67	0.88
1300 - 1359	38	12	3.17	1.89
1400 - 1459	14	6	2.33	1.78
1500 - 1559	9	20	0.45	0.25
1600 - 1659	27	21	1.29	0.36
1700 - 1759	16	22	0.73	0.22
1800 - 1859	21	26	0.81	0.30
1900 - 1959	60	56	1.07	0.74
2000 - 2059	30	32	0.94	0.30
2100 - 2159	9	60	0.15	0.04
2200 - 2259	17	143	0.12	0.04
2300 - 2359	18	93	0.19	0.07

3.3 Seabird bycatch rate by Day/night

The estimated time of capture for each bird was compared to the sunrise and sunset time at its capture. Birds were caught predominantly in two areas: off the East Cape, and the West Cape/Fiordland trench. The sunset/sunrise times used were those for Invercargill (46° 26' S, 168° 24' E) and East Cape (38° 05' S, 178° 35' E). Each bird was classified as being caught either during the day (between dawn and dusk) or at night (after dusk and before dawn inclusive). Similar calculations were done for each set to estimate the number of hooks deployed during the night and during the day. This allows for the estimation of the number of birds caught per 1000 hooks during daylight or night hours.

Sets often extend across dawn or dusk boundaries, so the number of birds caught per set during day light hours cannot be accurately calculated. The number of birds caught per set for sets made exclusively at night (after dusk and before dawn) and for sets made at least partially during the day (referred to as day/mix) is presented as an alternative.

Table 6 gives seabird bycatch rates for day and night. Significantly lower bycatch rates occur for sets made wholly at night.

Table 6. Seabird bycatch rate per 1000 hooks and per set, for all areas and all years (1989–93) combined.

Birds caught per 1000 hooks deployed

	No. of birds	No. of hooks	No. of birds per 1000 hooks
Day	203	471 638	0.43
Night	314	2 679 023	0.12

Birds caught per set

	No. birds	No. sets	No. of Birds per set	Std. error
Day/mix	297	368	0.81	0.11
Night	221	702	0.31	0.06

The birds caught per set calculation is a less accurate measure of the Day/night effects on seabird bycatch rates than the seabirds caught per 1000 hooks analysis.

3.4 Seabird bycatch rate by time taken for line setting

It might be expected that sets which take longer to deploy would catch more seabirds. Table 7 gives the relationship between bycatch rate and set duration. There is no significant trend in the bycatch rate with respect to how long a set takes to deploy.

Table 7. Seabird bycatch rate as a function of longline setting time, all areas and years combined

Birds caught per 1000 hooks deployed

Setting time (h)	No. of birds	No. of hooks	Birds per 1000 hooks
< 4	5	28 998	0.17
4.0 - 4.9	61	302 863	0.20
5.0 - 5.9	369	2 473 097	0.15
> 6	83	342 703	0.24

Birds caught per set :

Setting time (h)	No. of birds	No. of sets	No. of birds per set	Std. error
< 4 h	5	15	0.33	0.24
4.0 - 4.9 h	61	116	0.53	0.14
5.0 - 5.9 h	369	827	0.45	0.05
> 6 h	83	111	0.75	0.38

3.5 Seabird bycatch rate by area

An approach similar to that for estimating time of capture was used to estimate the location of seabird capture. An additional assumption, that longline setting takes place in a straight line between the set start and set finish locations, was made for this analysis.

The estimated capture locations for the 517 birds caught during the study period are shown in Figure 2. Locations for the birds caught during each year of the study are given in Figures 3–7. Comparable plots of observed longline set positions are shown in Figures 8–14.

A plot of relative seabird bycatch rates by 1 degree squares and the areas used in this study is provided in Figure 14. The areas are the same as those used by Murray *et al.* (1993) except that their Area 4 was divided roughly in half along latitude 45.5° S and the new area created north of this line was called area 6. Catch rates by area are given in Table 8. Area 6 has a significantly lower bycatch rate.

Table 8. Seabird bycatch by area (Figure 14 for areas), all years combined

Birds caught per 1000 hooks deployed

Area	No. of birds	No. of hooks	No. of birds per 1000 hooks
Area 1	193	1116 991	0.17
Area 2	86	109 014	0.79
Area 3	21	123 832	0.17
Area 4	182	691 872	0.26
Area 5	12	79 276	0.15
Area 6	23	1029 676	0.02

Birds caught per set

Area	No. of birds	No. of sets	No. of birds per set	Std. error
Area 1	194	392	0.49	0.06
Area 2	86	40	2.15	0.76
Area 3	21	41	0.51	0.18
Area 4	182	228	0.79	0.19
Area 5	12	26	0.46	0.12
Area 6	23	343	0.07	0.01

3.6 Seabird bycatch rate by moon phase

Moon phase was determined for every set made. The value used to describe the phase of the moon was the proportion of its face that was illuminated, i.e. 0 represents new moon and 1.0 full moon. In the `birds caught per 1000 hooks deployed' analysis, only birds caught on hooks set at night were included. For the `birds caught per set' analysis, only birds caught on sets made entirely at night were included.

The capture rates by moonlight index are summarised in Table 9. Generally bycatch rate at night increases as moonlight increases.

Table 9. Seabird bycatch as a function of amount of moonlight for night sets, all years and areas combined

Birds caught per 1000 hooks deployed

Moonlight index	No. of birds	No. of hooks	No. of birds per 1000 hooks
0.0-0.13	34	557 508	0.06
0.14-0.38	14	446 414	0.03
0.39-0.66	48	488 654	0.10
0.67-0.90	64	541 844	0.12
0.91-1.00	154	644 603	0.24

Birds caught per set

Moonlight index	No. of birds	No. of sets	No. of Birds per set	Std. error
0.0-0.13	14	139	0.10	0.04
0.14-0.38	2	116	0.02	0.01
0.39-0.66	22	133	0.17	0.05
0.67-0.90	45	148	0.30	0.06
0.91-1.00	138	166	0.83	0.25

3.7 Seabird bycatch rate by tori line presence

Tori line data has been collected by observers since 1991. Catch and effort data from 1989 and 1990 are not included in the following analysis.

Table 10a. Seabird bycatch rate by tori line presence, for all area and years (1991-93) combined

Birds caught per 1000 hooks deployed

	No. of birds	No. of hooks	No. of birds per 1000 hooks
No tori line	95	1049 497	0.09
Tori line	167	1386 638	0.12

Birds caught per set

	No. of birds	No. of sets	No. of Birds per set	Std. error
No tori line	95	357	0.27	0.10
Tori line	167	464	0.35	0.06

Seabird bycatch rate by tori line presence and Day/night

The effectiveness of a tori line is likely to be influenced by a seabird's ability to see it, so the analysis was separated into day and night setting operations. Table 10b summarises bycatch rates during the day and night with and without tori lines. The presence or absence of a tori line has no statistically significant effect on seabird bycatch rate during either the day or night.

Table 10b. Seabird bycatch rate by daylight and tori line use, all areas and years (1991–93). combined

Birds caught per 1000 hooks deployed

	No. of birds	No. of hooks	No. of birds per 1000 hooks
Day + no tori	6	21 401	0.28
Day + tori	51	252 459	0.20
Night + no tori	89	1 028 096	0.09
Night + tori	116	1 134 179	0.10

Birds caught per set

	No. of birds	No. of sets	No. of Birds per set	Std. error
Day/mix + no tori	9	20	0.45	0.13
Day/mix + tori	79	204	0.39	0.09
Night + no tori	86	337	0.26	0.11
Night + tori	89	260	0.34	0.06

3.8 Seabird bycatch rate by number of tori line streamers

Japanese longliners operate in the New Zealand EEZ under a licence which, since 1991, has specified that a vessel must tow a CCAMLR-specified tori line with 10 side streamers (5 pairs) when setting a line during daylight. However, the number of streamers used has varied considerably. The bycatch rates on sets where tori lines (with different numbers of streamers) were observed in use are given in Table 11. Fewer birds were caught when tori lines with more than 30 streamers were used, though this effect is not statistically significant.

Table 11. Seabird bycatch rate as a function of the number of streamers on a tori line, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed by number of streamers

No. of Streamers	No. of birds	No. of hooks	No. of birds per 1000 hooks
0 - 5	95	652 179	0.15
6 - 10	50	312 942	0.16
11 - 30	16	116 837	0.14
> 31	5	290 520	0.02

Birds caught per set by number of streamers

No. of Streamers	No. of birds	No. of sets	No. of Birds per set	Std. error
0 - 5	95	221	0.43	0.09
6 - 10	51	108	0.47	0.12
11 - 30	16	39	0.41	0.25
> 31	5	91	0.05	0.03

3.9 Seabird bycatch rate by length of tori line

Although the CCAMLR specification requires that a tori line be 150 m or more long, the length has varied considerably. The bycatch rates for tori lines of different lengths are summarised in Table 12. Tori lines greater than 160 m long catch fewer birds, but this is not statistically significant.

Table 12. Seabird bycatch rate as a function of tori line length, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed

Length of line (m)	No. of birds	No. of hooks	No. of birds per 1000 hooks
< 81	11	77 580	0.14
81 - 120	36	421 920	0.09
121 - 160	111	641 226	0.17
> 161	8	240 632	0.03

Birds caught per set

Length of line (m)	No. of birds	No. of sets	No. of Birds per set	Std. error
< 81	11	26	0.42	0.37
81 - 120	36	138	0.26	0.13
121 - 160	112	220	0.51	0.07
> 161	8	78	0.10	0.04

3.10 Seabird bycatch rate by height above the water of the tori line.

The CCAMLR specifications require that the height above the water at which a tori line connects to the tori pole be about 4.5 m. The bycatch rates for sets with tori lines positioned at different heights above the water are summarised in Table 13. Tori lines towed from a height of 8 m or less above the water line catch fewer birds. Tori lines towed from a height of 4 m or less above the water line catch significantly fewer birds still.

Table 13. Seabird bycatch rate as a function of height of attachment of the tori line above the water, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed

Height (m) above water	No. of birds	No. of hooks	No. of birds per 1000 hooks
1 - 4	2	152 166	0.01
5 - 8	84	908 741	0.09
9 - 12	33	74 904	0.44
13 - 16	33	138 961	0.24

Birds caught per set

Height (m) above water	No. of birds	No. of sets	No. of Birds per set	Std. error
1 - 4	2	49	0.04	0.04
5 - 8	84	299	0.28	0.07
9 - 12	34	27	1.26	0.31
13 - 16	33	50	0.66	0.17

3.11 Seabird bycatch rate by horizontal distance from bait entry point to tori line

The CCAMLR specifications require that tori lines be located directly above the point where baits enter the water. The bycatch rates for sets with different bait entry points are summarised in Table 14. Fewer birds are caught when the bait enters the water within 3 m of a tori line, though this effect is not statistically significant.

Table 14. Seabird bycatch rate as a function of the distance between the point where bait enters the water and the tori line, all years and areas (1991–93) combined

Birds caught per 1000 hooks deployed

Distance (m)	No. of birds	No. of hooks	No. of Birds per 1000 hooks
0 - 1	31	606 509	0.05
2 - 3	40	408 684	0.10
4 - 5	67	175 219	0.38
6 or more	14	42 300	0.33

Birds caught per set

Distance (m)	No. of birds	No. of sets	No. of birds per set	Std. error
0 - 1	31	203	0.15	0.03
2 - 3	40	134	0.30	0.06
4 - 5	68	59	1.15	0.33
6 or more	14	15	0.93	0.58

3.12 Seabird bycatch rate by bait being thawed or frozen

Brothers (1991) suggested that birds are more likely to take frozen bait rather than thawed bait because the air trapped within the frozen bait keeps it afloat longer. In 1992 New Zealand observers began collecting data on whether or not baits were thawed or frozen. Seabird bycatch rates by bait thaw state are summarised in Table 15. There is a lower bycatch rate when thawed baits are used, though this is not statistically significant.

Table 15. Seabird bycatch rate as a function of bait thaw state, all areas and years (1992–93) combined

Birds caught per 1000 hooks deployed

	No. of birds	No. of hooks	No. of birds per 1000 hooks
Frozen	98	374 216	0.26
Thawed	129	1 542 611	0.08

Birds caught per set

	No. of birds	No. of sets	No. of Birds per set	Std. error
Frozen	98	126	0.78	0.33
Thawed	129	519	0.25	0.04

3.13 Seabird bycatch rate by bait thrower presence

Brothers (1991) suggested that birds were more likely to take baits which landed close to the vessel because turbulence from the ship's propeller keeps the bait near the surface. He proposed that bait throwing be mechanised to ensure that baits land clear of the vessel's wake. In 1993 two vessels operating within the New Zealand EEZ used mechanical bait throwers. Bait throwers significantly reduce levels of bycatch.

Table 16. Seabird bycatch rate on vessels with and without bait throwing machines, all areas combined

Birds caught per 1000 hooks deployed

	No. of birds	No. of hooks	No. of birds per 1000 hooks
No bait thrower	209	1 090 422	0.19
Bait thrower	6	164 646	0.04

Birds caught per set

	No. of birds	No. of sets	No. of birds per set	Std. error
No bait thrower	208	370	0.56	0.14
Bait thrower	6	51	0.11	0.07

3.14 Seabird bycatch rate by wind strength

Brothers (1991) observed that birds were less likely to follow longline vessels when the wind strength was Beaufort force 2 or below, perhaps because in low winds the crew could throw baits clear of the vessel's wake, allowing them to sink faster. Imber (1994) observed that in wind strengths above 20 knots (force 6), turbulence from the vessel's propeller was greater and baits tended to stay on the surface for longer.

Observers have collected data on wind strength since 1991 and bycatch rates by wind strength are summarised in Table 17. There is no obvious relationship between levels of bycatch and wind strength.

Table 17. Seabird bycatch rate as a function of wind speed, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed

Wind speed (knots)	No. of birds	No. of hooks	No. of birds per 1000 hooks
4–6	56	472 488	0.12
7–10	77	455 467	0.17
11–16	39	510 873	0.08
17–21	34	488 768	0.07
22–27	58	498 669	0.12

Birds caught per set

Wind speed (knots)	No. or birds	No. or sets	No. or birds per set	Std. error
4-6	56	157	0.36	0.12
7-10	78	152	0.51	0.24
11-16	39	171	0.23	0.07
17-21	34	164	0.21	0.04
22-27	58	174	0.33	0.08

3.15 Seabird bycatch rate by atmospheric pressure

The barometric pressure at the beginning of each set has been recorded by observers since 1991. Seabird bycatch as a function of atmospheric pressure is given in Table 18. Barometric pressures of less then 1015 hpa are likely to be associated with unsettled weather; those over 1025 hpa are indicative of settled weather. The bycatch rate was higher in very low atmospheric pressure, although this effect is not statistically significant.

Table 18. Seabird bycatch rate as a function of atmospheric pressure, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed

Atmospheric pressure (hpa)	No. Birds	No. Hooks	No. Birds per 1000 hooks
up to 1004	75	356 201	0.21
1005 - 1014	35	597 821	0.06
1015 - 1024	114	930 278	0.12
1025 or more	41	551 615	0.07

Birds caught per set

Atmospheric pressure (hpa)	No. of birds	No. of sets	No. of birds per set	Std. error
up to 1004	75	122	0.61	0.31
1005 - 1014	35	203	0.17	0.04
1015 - 1024	114	311	0.37	0.07
1025 or more	42	185	0.23	0.05

The unsettled and settled weather interpretations for atmospheric pressure are a generalisation. Winds are usually associated with unsettled weather, although they can occur with high atmospheric pressures. Therefore, atmospheric pressures should not be used to interpret wind conditions or cloud cover.

3.16 Seabird bycatch rate by percentage cloud cover

Percentage cloud cover at the beginning of each set has been recorded by observers since 1991. Seabird bycatch as a function of cloud cover is given in Table 19. Bycatch rates were lower when there is over 60 % cloud cover, but this effect is not statistically significant.

Table 19. Seabird bycatch rate as a function or percentage cloud cover, all areas and years (1991–93) combined

Birds caught per 1000 hooks deployed

Cloud cover (percentage)	No. of birds	No. of hooks	No. of birds per 1000 hooks
0 – 30	88	480 052	0.18
31 – 60	53	327 882	0.16
61 – 90	46	646 923	0.07
91 or more	72	799 985	0.09

Birds caught per set

Cloud cover (percentage)	No. of birds	No. of sets	No. of birds per set	Std. error
0 – 30	88	161	0.55	0.23
31 – 60	53	111	0.48	0.12
61 – 90	46	217	0.21	0.05
91 or more	72	270	0.27	0.06

4.0 Generalised Linear Modelling

In this study, the bivariate analysis was used to assess the importance of monitored factors which may influence seabird bycatch rates. It was necessary to establish which of these factors were most important, which were of minor importance, and which appeared of being important because of correlation with other monitored factors. This was done by considering all factors simultaneously within the framework of a generalised linear model (GLM).

For a GLM to be accurate, the distribution of the data must be known. Murray *et al.* (1993) compared the observed frequency distribution of seabird bycatch on Japanese longlines with a negative binomial distribution and found no significant difference. Negative binomial distributions are characterised by being strongly skewed towards one extreme value and being attenuated in the opposite direction. In the seabird bycatch data, most sets (81.4%) did not catch seabirds, but, large numbers of seabirds (up to 38 in one set) are occasionally caught. Attempts to model seabird bycatch with a negative binomial linear model failed because of the divergence of parameter estimates at each iteration. As an alternative to the negative binomial distribution, bycatch was modelled in stages with the use of different distributions.

Binomial distributions apply when the result is either the occurrence or non-occurrence of an event, and where the outcome of one event is independent of another. Whether or not seabirds are caught on a longline meets the first criterion for being binomially distributed, observations on whether sets did or did not catch seabirds may not meet the second criterion. Once an observer is on board a vessel he/she typically stays with that vessel for several weeks. If vessel-specific factors influence the likelihood of seabird bycatch then the events being studied (whether or not a set catches birds) will not be truly independent of each other. This would not bias the binomial linear modelling analysis but may result in artificially inflated measures of the model's accuracy.

Binomial linear models of seabird bycatch can provide information only on whether or not seabirds were caught. They predict the number of seabirds that will be caught. As a supplement to each binomial linear model two Poisson linear models of the number of seabirds caught were also produced: one model considered all the sets and the other only the sets that caught one or more seabirds.

Poisson distributions are most commonly used for modelling events in which the outcome is an integer, e.g., the number of seabirds caught on a longline set. Preliminary investigations showed that the seabird bycatch data contained too many zero values to conform to a Poisson distribution. However, if all zero values are excluded so that only sets catching one or more seabirds are considered, then the data had too few zeros to be Poisson distributed.

To provide information on what factors affect the number of seabirds caught, both types of Poisson linear model were generated. Neither model will be correct in its own right, but it is likely that any factor which is shared by both Poisson models will have an influence on rates of seabird bycatch. As such the results of the Poisson linear modelling analysis need to be treated with caution. In drawing conclusions to this study, the only factors used were those deemed significant by either the bivariate or binomial linear modelling analyses. The Poisson linear models are presented only as a supplement to the binomial linear modelling analysis.

Model building procedures

A standardised process was used to build the Poisson and binomial models used in this study.

Night setting was selected as the initial model because the bivariate analysis suggested that it had a strong influence on seabird capture rates and it allowed moon phase to be modelled as a nested component of the Day/night effect.

The initial model and the data on all of the monitored factors were analysed using the S stepwise model building procedure. This software constructed a model of seabird bycatch by taking the initial model and determining which factor, when added to the model, improved it the most (i.e., reduced the deviance between observed and predicted values by the largest amount). This factor was then added to the model and the process was repeated. A check was also made to determine whether the current model could be most improved by removing an existing factor rather than adding a new factor. The decision as to whether a factor was added or removed was determined by each factor's *Cp* statistic, as defined by Mallows (1964). The stepwise model building process was halted when the addition of a new factor or subtraction of an existing factor could not improve the current model's Akaike Information Criterion Statistic (Akaike 1970).

The factors used in the modelling process were these.

Area – a factor which recorded the location of the start of a set (*see* Figure 14).

Day/night – a Boolean factor where a "night" set was defined as one which started after dusk and finished before dawn. A set in which any hooks were deployed during the day was termed a "Day/mix" set.

Moonlight index – a value between 0 and 1 which defined the stage of the moon on the day on which the set was made, modelled as a nested term of both "Night" and "Day/mix". Moon phase was modelled as a quadratic because the bivariate analysis suggested that the relationship between catch rate and moon phase was not linear.

Wind strength – a value (Beaufort scale) between 0 and 12 which gave the wind strength at the start of the set, modelled as a quadratic.

Atmospheric pressure – the atmospheric pressure at the start of the set, modelled as a quadratic.

Cloud cover – the percentage cloud cover at the start of the set, modelled as a quadratic.

Set start time – modelled as a cubic to allow an approximation of the curve in Figure 1a.

Set duration – the number of hours which were taken to deploy the set, modelled as a quadratic.

Bait thrower – a Boolean factor set to "Y" if a bait thrower was used during the set, "N" otherwise.

Length of tori line – the length (in metres) of the tori line used during the set, modelled as a quadratic.

Number of tori streamers – the number of streamers attached to the tori line, modelled as a quadratic.

Height of tori line – the height (in metres above sea level) of the tori line, modelled as a quadratic.

Tori line to bait distance – the horizontal distance (in metres) between the point where the bait enters the water and the tori line, modelled as a quadratic.

Bait thaw status – a Boolean factor set to "T" if the bait was thawed before being used, "F" if it was still frozen.

Tori score – a factor which represented the presence or absence of a tori line during setting and, when present, the quality of that tori line (see sections 4.2 and 4.3).

Continuous variables (except set start time) were modelled as quadratic functions, because, for some factors, the bivariate analysis suggested a non linear relationship between the factor and seabird bycatch rate. Where possible the other variables were also modelled as quadratic functions to ensure that no bias could exist within the modelling procedure as a result of modelling different variables in different ways. Within each model only sets for which all required data were present were analysed.

The model produced by the stepwise procedure was taken as the starting point for a series of further steps which were repeated iteratively until each of the following steps could be carried out without the model changing.

1. An analysis of variance test was performed on the model and the least significant factor was removed unless that factor was significant at the 95 % level (as defined by a chi square test for the binomial models and an *F* test for the Poisson models). This was repeated until all the remaining factors were significant. At this stage the factor initially used to start the model building process (night setting) could have been removed if neither it nor moon light index were significant.

2. One of the factors not in the model was temporarily added to it and an analysis of variance test was carried out on the temporary model. If the temporarily added factor increased the deviance accounted for by 1 % or more, and was significant at the 95 % level, then this was noted. The temporary factor was then removed and another temporary factor added to the model, until all the factors not included in the current model had been tested with it. The current model was then redefined to include all the factors which had been significant and had increased the deviance accounted for by more than 1 %.

3. Steps 1 and 2 were then repeated.

4.1 Interpretation of generalised linear modelling analysis

The way in which each factor affected the number of seabirds caught was assessed. The modelling procedure defined a group of parameters which estimated the influence that each factor had on seabird capture rates, as well as the uncertainty in each of these estimates.

The importance of any individual factor within a model is determined by the proportion of the observed result which is explained by that factor on its own. Important factors will explain a higher proportion of the observed results than minor factors.

Three outputs are given for each of the models.

1. An estimate of the proportion of the variance in the observed data which can be explained by the model.

2. An estimate of the proportion of the variance explained by each factor.

3. A plot for each factor showing the relationship between the factor and the Catch Odds Ratio (for binomial models), or between the factor and the Relative Catch Rate (for Poisson models).

   These figures are presented as natural logs where the average likelihood of a set capturing seabirds (for binomial models), or the average seabird catch rate (for Poisson models), is zero.

   Uncertainty estimates for each parameter are marked on the plots. These vertical lines represent one standard error.

On a natural log scale, a "Catch Odds Ratio = 1" means that the likelihood of a set capturing seabirds for that particular value of a factor is 2.7 times higher than average. Similarly, a "Relative Catch Rate = 1" means that for the particular value of a factor, the seabird bycatch rate for that particular value of a factor is 2.7 times higher than average.

A guide to interpreting the Catch Odds Ratio for a factor :

Catch Odds Ratio (log)	3	20.1 times above the average
	2	7.3 times above the average
	1	2.7 times above the average
	0	Average for the sample
	- 1	2.7 times below the average
	- 2	7.3 times below the average
	- 3	20.1 times below the average

Relative Catch Rate may be interpreted similarly.

All of the plot figures for one model are shown on one page. The most important factors, as determined by the proportion of the observed results explained by that factor, are plotted first.

4.2 Generalised linear models of tori line effects on seabird bycatch

The purpose of this first modelling analysis is to gain some information on what constitutes an effective tori line, i.e., one which significantly reduces the seabird bycatch rate. Only sets which are known to have used a tori line were included in this analysis.

Tori line effects on bycatch - Binomial GLM

A binomial model of whether or not a set catches seabirds was derived from data for 399 sets made during 1992 and 1993 which were known to have used a tori line. The model accounted for 37.3% of the null deviance. This percentage consisted of the following factors:

Area	16.9%
Height of tori line above sea level	6.3%
Moon phase as nested term of Night and Day/mix	4.2%
Length of tori line	4.0%
Atmospheric pressure	2.8%
Number of tori line streamers	2.7%
Night or Day/mix	0.4%

The Night or Day/mix factor was not significant at the 95 % level, but was retained in the model because moon phase was modelled as a nested component of this factor and was highly significant. This nested term was used throughout the modelling analysis. Night and day/mix were retained whenever moon phase was found to be significant.

Plots of the relationships between the seven factors selected by the model are presented in Figures 15–21.

Of the 14 factors analysed, area (Figure 15) accounted for the highest portion of the null deviance (16.9%). Area was more important in the prediction of the occurrence of seabird bycatch than the four tori line factors combined. The horizontal distance from the tori line to the bait landing point is absent from the model because the analysis of variance suggested that it was not significant at the 95 % level.

Area 3 had the highest predicted seabird bycatch. However, this result should be viewed with caution because the standard deviation is large.

Area 6 had the lowest Catch Odds Ratio and a short error bar, which suggests that sets in this area were less likely to catch seabirds than sets in other areas. The error bars for the other areas tend to overlap, which suggests that their Catch Odds Ratios may not be significantly different.

The next most important factor was the height above the water line which the tori line was towed from (Figure 16). The model suggests that vessels with low tori lines had significantly less chance of catching seabirds. This supports the results of the single factor analysis which showed that vessels with tori lines towed from a height of 4 m or less caught only 0.04 seabirds per set.

The percentage of null deviance accounted for by the moonlight index suggests that this was the third most important of the monitored factors in influencing whether or not seabirds were caught (Figure 17). The lighter of the two lines plotted on this graph is the effect of moonlight index during day or mixed sets. Here the error bars are large, suggesting that moonlight has little or no effect on seabird bycatch rates during the day. However, for sets made entirely at night, the seabird bycatch rate increased dramatically as the moon became more full. The length of the error bars, when compared with the magnitude of the increase in likelihood of bycatch, suggests that this is a statistically significant effect.

Length of tori line (Figure 18) was determined to be almost as important as moonlight index. Sets with longer tori lines were less likely to catch seabirds. The likelihood of a set catching seabirds also seemed to decrease if the tori line was very short, though the error bars suggest that this decrease is probably not significant.

Seabirds were more likely to be captured when barometric pressure was low or high (Figure 19), rather than when it was intermediate (around 1010). However, the large error bars make interpretation of these results difficult.

The number of streamers present on the tori line appeared to have a lesser effect on whether or not seabirds were caught (Figure 20). Vessels with tori lines with more streamers were less likely to catch seabirds. However, there appears to be an upper limit on this effect, with no apparent improvement taking place when more than 30 streamers are used. The large error bars suggest that for vessels with tori lines with more than 50 streamers the increase in the likelihood of seabirds being caught is probably not statistically significant.

It is equally important to consider the factors which were not selected for inclusion in the model. Several factors which appeared important in the bivariate analysis were found not to be significant in the GLM. These included the presence or absence of a bait thrower, whether bait was frozen or thawed, and the horizontal distance between the bait landing point and the tori line. It is probable that these factors were partially correlated with the other factors which were identified as being significant and included in the model.

Tori line effects on bycatch – Poisson (with zeros) GLM.

A Poisson model of the number of seabirds caught by a set was estimated from data for 399 observed longline sets made in 1992 and 1993. The model accounted for 54.9% of the null deviance. This percentage consisted of the following factors.

Area	20.4%
Moon phase as nested term of Night and Day/mix	7.7%
Height of tori line above sea level	7.7%
Number of tori line streamers	6.7%
Distance from tori line to bait landing point	4.8%
Time spent setting	4.4%
Wind strength	3.1%
Night or Day/mix	0.1%

The plots of the relationships between the eight factors selected and seabird bycatch rate are shown in Figures 22–29.

Tori line effects on bycatch – Poisson (without zeros) GLM.

A Poisson model of the number of seabirds caught by sets which caught seabirds was estimated from data for 65 observed longline sets made in 1992 and 1993. The model accounted for 53.5% of the null deviance:

Time spent setting	25.8%
Wind strength	20.0%
Number of tori line streamers	7.7%

The plots of the relationships between the three factors selected for inclusion in the model are shown in Figures 30–32.

The factors shared by the two Poisson models are the number of tori line streamers, the time spent setting, and wind strength. Both models indicate that seabird bycatch rate decreases as the number of tori line streamers increase (Figures 25 and 32). Figure 25 indicates that bycatch rate increases if the number of streamers is very high, but the error bars associated with these estimates are large.

More seabirds seem to be caught on sets which take longer to deploy (Figures 27 and 30), a result which did not appear as a significant factor in the binomial model (section 4.2.1).

These models suggest that seabird bycatch rates may be lowest around wind strength 4 (Figures 28 and 30). Because this model covers only sets for which a tori line was deployed. It may be that tori lines are most effective at middling wind strengths (too little wind might prevent the streamers flapping about and scaring birds, too much wind may blow the line away from the bait).

What constitutes a good tori line

Of the four tori line characteristics which have been monitored, the most important one for reducing the incidence of seabird bycatch is the height above the water line at which the tori line is attached to the tori pole. Assuming that the height effect observed in the 49 sets where the vessel end of the tori line was towed from a height of 4 m or less was not correlated with other unmonitored factor(s) which reduce seabird bycatch, it is reasonable to conclude that the effectiveness of a tori line is enhanced when the line is attached 3–4 m above sea level.

The length of a tori line is related to its effectiveness: the results suggest that a tori line should be at least 175 m long.

The number of streamers attached to a tori line appears to affect seabird bycatch: when more streamers are used seabird bycatch is lower. The results of this analysis suggest that a tori line should have at least 20 streamers.

Perhaps the most surprising result from this section of the study is that the horizontal distance between the tori line and the point where the bait lands in the water does not appear to be a major factor influencing seabird bycatch rates.

Whether the bait was frozen or thawed was not selected as an important factor by any of the models, and bait thaw status was dropped from subsequent modelling. This allowed the inclusion of an extra year's (1991) data.

These results were used as the basis for a new factor called tori score which was assigned to each set as a categorical variable.

A tori score of 0 was allocated if a tori line was not used during the set. A value of 1 was given if any tori line was used. A further 1 point was added to a set's tori score for each of the following:

- tori line was attached at a height of 5 m or less;
- tori line was 175 m or more in length;
- tori line had 20 or more streamers.

None of the sets in the data used a tori line for which all three of the above characteristics were present. The highest tori score obtained by any set was 3. Tori scores are summarised below.

- Tori score 0: No tori line was used;
- Tori score 1: A tori line without any of the "good" characteristics was used;
- Tori score 2: A tori line with 1 "good" characteristic;
- Tori score 3: A tori line with 2 "good" characteristics.

Tori scores were used in the next step of the modelling analysis to identify which of the factors monitored had the largest impact on seabird bycatch rates. These analyses included sets which did not use a tori line.

4.3 General influences on seabird bycatch

General influences on bycatch - Binomial GLM.

A binomial linear model of whether a set does or does not catch seabirds was estimated from data for 713 longline sets during 1991–93.

The percentage of the null deviance accounted for by the model was 27.9 %. The percentage accounted for by individual factors within the model as follows.

Area	11.0%
Tori score	9.8%
Moon phase as nested term of Night and Day/mix	6.7%
Night or Day/mix	0.4%

The plots of the relationships between the four factors selected for inclusion in the model are shown in Figures 33–36.

Area remained the most important factor in determining whether or not seabirds were caught. There appears to be a significantly reduced likelihood of catching seabirds in area 6 compared with areas 1–5 (Figure 33).

Tori score is nearly as important as area. Sets which used a "very good" tori line (tori score of 3) were much less likely to catch seabirds than sets which did not (Figure 34). Sets with a "poor" tori line (tori score of 1) seemed more likely to catch seabirds than sets without a tori line.

Moonlight index is an important factor during night sets. There is a strong increase in the likelihood that seabirds will be caught as the moon becomes full.

General effects on bycatch - Poisson (with zeros) GLM.

A Poisson model of the number of seabirds caught was estimated from 713 observed longline sets made during 1991–93.

The percentage of the null deviance accounted for by the model was 51.9%. The percentage accounted for by individual factors within the model was as follows.

Tori score	15.5%
Area	14.3%
Moon phase as nested term of Night and Day/mix	12.3%
Set start time	4.0%
Time spent setting	3.8%
Cloud	1.8%
Night or Day/mix	0.2%

The plots of the relationships between the seven factors selected for inclusion in the model are shown in Figures 37–43.

General effects on bycatch – Poisson model (without zeros)

A Poisson model of the number of seabirds caught by sets which did catch seabirds was estimated from data for 98 observed longline sets made from 1991 to 1993.

The percentage of the null deviance accounted for by the model was 65.1%. The percentage accounted for by individual factors within the model was as follows.

Time spent setting	47.1%
Wind strength	9.3%
Atmospheric pressure	8.7%

The plots of the relationships between the three factors selected for inclusion in the model are shown in Figures 44–46.

Time spent setting is the only factor shared by the Poisson models. As such it is reasonable to conclude that this does have a significant effect upon levels of seabird bycatch.

Conclusions – General effects on seabird bycatch

1. Area, tori line presence or quality, and moonlight index affected rates of seabird bycatch.

2. Area 6 had a lower catch rate than other areas.

3. The difference in bycatch rates between sets which used no tori line and sets which used a "poor" tori line is not significant. Sets which used a tori line with "good" characteristics were significantly less likely to catch seabirds than sets which used a "poor" tori line or no tori line.

4. When fishing at night, significantly more seabirds are likely to be caught when the moon is full, or nearly full, than during other moon phases.

4.4 Revised effects on seabird bycatch

The tori score system used in the previous three models assumed that any tori line is better than no tori line. The results of the previous modelling analysis suggest that this may not be true. This raises the question of whether the results would have been different if sets which used no tori line or a poor tori line had been allocated the same tori score. To address this issue, a final set of models was generated in which revised tori scores were used. The following scores were assigned:

Tori score 0: no tori line or a tori line without "good" characteristics was used.

Tori score 1: a tori line with 1 "good" characteristic was used.

Tori score 2: a tori line with 2 "good" characteristics was used.

"Good" tori line characteristics are the same as those described previously.

Revised effects on bycatch – Binomial GLM.

A binomial model of whether a set does or does not catch seabirds was estimated from data for 713 longline sets made from 1991 to 1993.

The percentage of the null deviance accounted for by the model was 23.4%. The percentage accounted for by individual factors within the model was as follows:

Area	11.0%
Tori score	6.8%
Moon phase as nested term of Night and Day/mix	5.2%
Night or Day/mix	0.4%

The plots of the relationships between the four factors selected for inclusion in the model are shown in Figures 47–50.

The factors selected were the same as those selected in the previous binomial model with area being the most important factor examined. Sets made in area 6 were significantly less likely to catch seabirds than sets made in areas 1–5 (Figure 47).

Sets made using a tori line with one "good" characteristic are significantly less likely to catch seabirds than sets made using no tori line or a tori line with no "good" characteristics (Figure 48). Sets made using a tori line with two "good" characteristics are even less likely to catch seabirds. The likelihood of catching seabirds on sets made at night increases as the moon becomes more full (Figure 49).

Revised effects on seabird bycatch – Poisson (with zeros) GLM

A Poisson model of the number of seabirds caught by a set was estimated from data for 713 observed longline sets made from 1991 to 1993.

The percentage of the null deviance accounted for by the model was 49.3%. The percentage accounted for by individual factors within the model was as follows:

Area	14.3%
Tori score	13.2%
Moon phase as nested term of Night and Day/mix	10.5%
Set start time	4.2%
Time spent setting	3.9%
Cloud cover	1.8%
Wind Strength	1.2%
Night or Day/mix	0.2%

The plots of the relationships between the eight factors selected for inclusion in the model are shown in Figures 51–58.

Revised effects on seabird bycatch - Poisson (without zeros) GLM

A Poisson model of the number of seabirds caught by sets which did catch seabirds was estimated from data for 98 observed longline sets made from 1991 to 1993.

The percentage of the null deviance accounted for by the model was 67.7%. The percentage accounted for by individual factors within the model was as follows:

Time spent setting	47.1%
Wind strength	9.3%
Atmospheric pressure	8.7%
Tori score	2.6%

The plots of the relationships between the 4 factors selected for inclusion in the model are shown in Figures 59–62.
Time spent setting and wind strength are shared by this and the preceding Poisson model. It is therefore probable that these two factors do have a significant influence upon levels of seabird bycatch.

Conclusions - influences on seabird bycatch (revised)

The conclusions reached from this modelling analysis are almost identical to those from the previous analysis which used the original tori scores: the only differences were that the relative importance of the area effect increased, and that wind strength was selected by the Poisson models as a factor of minor importance.

Wind strength occurs in both Poisson models and it appears that bycatch rate is lower at intermediate wind strengths (Beaufort scale force 4 and 5).

Sets which used tori lines with one "good" characteristic caught significantly fewer seabirds than sets which used no tori line or a tori line with no “good” characteristics. Tori lines with 2 "good" characteristics caught fewer seabirds still.

5.0 Conclusions

The following conclusions are supported by both the bivariate analyses and the binomial linear modelling analysis.

Three of the factors monitored had a major effect on seabird bycatch: the area in which the set was made, the quality of the tori line, and the phase of the moon for sets made at night. Area is the most important of these factors.

This study did not identify any definite areas of high bycatch, though Area 3 is a possibility. Area 6 of the west coast of the South Island and north of latitude 45° 30'S was identified as an area with low seabird bycatch.

About half the tori lines included in this study appeared to have little or no effect in reducing the seabird bycatch rate. The others were effective and resulted in significant reductions in seabird bycatch. Some elements of a good tori line have been identified and this study suggests that tori lines should be towed from less then 5 m above the water and should be 175 m long and have at least 20 streamers.

When setting at night, substantially more seabirds are caught as the moon becomes full. Figure 63 shows the capture time relative to dawn and dusk for each of the seabirds caught at night, and the phase of the moon on the night of capture. At night, when the moon is less than half full, birds are almost always caught near dawn and dusk.

The binomial linear models of bird bycatch suggest a slight increase in the rate of bird capture at night around the new moon when compared with capture during a quarter moon. The data in Figure 63 suggest that this could be an aberration caused by an unusually large number of birds being caught around sunrise during the new moon.

The time spent setting occurred in all the Poisson linear models, suggesting that it does have some influence on seabird bycatch rate. Wind strength appeared in five of the six Poisson linear models indicating that it also probably has an effect on seabird bycatch rate. Atmospheric pressure and percentage cloud cover appeared in a few of the models: they may have a minor influence on bycatch rates.

Bait thaw state, use of a bait thrower, or the distance between the tori line and the bait landing point had no significant effect on seabird bycatch. The use of a bait thrower was determined by bivariate analysis to significantly reduce levels of seabird bycatch. However, only two vessels in the study were equipped with bait throwers and as these vessels also had very long tori lines it is possible that some of the tori line effect may be a bait thrower effect. More data are needed before any conclusions about bait throwers can be made.

6.0 Discussion

A likely explanation for the conclusion that tori lines should be towed from a low height is that the tori line streamers were too short and that birds were not deterred from flying underneath them. The side streamers of future models of tori line should be long enough to just skim above the water when the vessel is moving at normal line setting speed on a calm day.

There are strong indications from the bivariate analysis (see Figure 1a) that set start time and, in particular, whether or not a set takes place entirely within the hours of darkness have a major influence upon levels of seabird bycatch. By representing moon phase as a nested component of Day/night in the modelling analysis the "time of day" effect could have been obscured. This could be verified by conducting a similar of analysis which excluded moon phase.

It is possible that the effect of weather was not detected in the analysis because of the way in which weather data were collected. Data on weather were recorded at the start of each set. Any of the three monitored weather factors could have changed dramatically over the 5–6 h that it typically takes to set a longline. Bait thaw state could also have changed during setting.

Wind strength may have a substantial effect on tori line function and it could be that this is what is being detected in five of the six Poisson linear models. More research is needed to verify this.

The drop in the rate of seabird bycatch in 1991, 1992, and 1993, compared with 1989 and 1990 was primarily due to the increased use of night setting and tori lines from 1991 onwards.

The major contributing factor to the extremely low levels of bycatch reported in 1992 was the substantially increased proportion of fishing which occurred in Area 6 in 1992 (*see* Figure 12).

Fishing in Area 6, which this study has identified as an area with a low incidence of seabird bycatch, accounts for about half of the reduction in the rate of seabird bycatch recorded in 1992 in comparison to other years. What accounts for the remainder is unknown.

If current bycatch mitigation measures (optional night setting and the compulsory use of tori lines) are maintained, it can be expected that yearly seabird bycatch rates will continue to vary, though they will probably remain lower than pre-1991 levels. These variations will reflect the proportion of the sets made each year in Area 6, the timing of line setting, and the influence of other as yet unidentified factors.

Although current seabird bycatch mitigation measures are reducing bycatch, substantial variations in bycatch rates will still result from variations in environmental factors and yearly changes in the location and timing of the longline fishery.

There are reliable data to suggest that tori lines can function as effective seabird bycatch mitigation devices under some circumstances. However, they must be properly designed and constructed. Although this study has provided information on some aspects of tori line design, this information needs to be verified by trials at sea.

There are several tori line characteristics which are likely to be critical to their ability to function effectively. Data on some of these characteristics have not been collected in New Zealand. The following research would assist tori line development.

Establish whether tori lines should be towed from a low height or whether tori lines can be towed from any height as long as their side streamers are of an appropriate length.

Verify that tori lines are most effective if over 175 m in length.

Verify that tori lines are most effective if 20 or more streamers are present.

Verify that as long as the distance between the tori line and the bait landing point is 3 m or less, this distance is not significant.

Determine of the optimum thickness of the tori line backbone.

Determine the optimum colour for the backbone and side streamers.

Determine whether tori line streamers should be weighted or not.

Determine the effect of wind direction and strength on tori lines.

Determine the effectiveness of tori lines used at night by moon phase.

Establish whether some species of seabird are less deterred by tori lines than others.

In addition to the suggested tori line research, studies could be undertaken to measure the effectiveness of other types of bycatch mitigation measures. These include the use of types of bait that sink faster, the use of weighted hooks or branch lines, deployment of baits beneath the sea surface, and/or the use of bird scaring devices other than tori lines.

Further research is also desirable to determine the effectiveness of bait throwers.

Research into several of these mitigation measures has begun, or is about to begin in Australia, though it could take some time for the results to become available.

There have been suggestions from New Zealand fisheries observers that squid bait catches more birds than other types of bait. Given that seabirds hunt visually, it would seem likely that a white squid would be more easily detected in the water than a blue/green mackerel, especially at night.

This study did not attempt to analyse bycatch by area on a fine scale. This may be possible for the most heavily fished parts of the EEZ.

There was no comprehensive investigation of the factors affecting bycatch on a species basis was performed. This was because too few birds had been accurately identified. However, a simple analysis which used available data for the four main bycatch species is given in Appendix 1.

It is probably overly simplistic to say that all seabirds are affected by fishing in the same way, so it is important to identify wherever possible, the exact species or sub-species affected. Ultimately species/area, species/moon-phase, and species/tori-line effects should be established.

Moon phase during night sets should be examined with respect to cloud cover because this could provide confirmation that bycatch increases on nights with a full moon simply because more light is available for the birds to feed by.

It would be worth modelling seabird bycatch without a moon phase factor to determine whether this is what prevents set start time from being selected as a factor of major significance.

Because fisheries observers are not present on all longline vessels, it is essential that some means of ensuring the use of bycatch mitigation measures is in place. If a bycatch mitigation device is effective and easy to use, it is likely to be adopted voluntarily by a significant proportion of longline fishers.

No mention has been made of seabird bycatch in other longline fisheries or by nations other than Japan, not because the Japanese SBT longline fishery catches more birds, but because this is the only fishery, within the New Zealand EEZ for which adequate data on seabird bycatch have been collected. Very little information has been collected on levels of seabird bycatch in the domestic tuna longline fishery or other longline fisheries.

Seabird bycatch is probably a feature of all longline fisheries. It is a global, rather than a local, problem. The decisions made and research undertaken with respect to longline vessels within the EEZ will have implications well beyond New Zealand, and there is a special need to develop effective mitigation measures for high seas areas where by far the greatest longline fishing effort takes place.

Acknowledgments

All aspects of this study have benefited from the guidance of Talbot Murray (MAF Fisheries) and Kirsty Johnston (DOC), Ross Pickard (DOC), Jonathan Peacey (FIB), Andrew Branson (FIB) and Mike Imber (DOC), who were all members of the Supervisory Group that was set up to oversee the research project.

Talbot and Kirsty, in particular, put considerable time and effort into transforming the draft manuscript into a readable form.

Mike Imber (DOC) ensured that aspects of seabird biology were not lost beneath an avalanche of graphs.

Ministry of Fisheries Scientific Observers collected the raw data.

Stephanie Kalish (MAF Fisheries) retrieved the data from the MAF Fisheries data base, provided historical information on the SBT fishery and observer operating procedures.

Elizabeth Bradford (MAF Fisheries) experimented with fitting seabird bycatch data to a negative binomial GLM.

Marianne Vignaux (MAF Fisheries) provided daily advice on the most appropriate techniques for analysing the data. This study could not exist in its current form without the generosity with which she shared her skills.

My sincere thanks to everyone who contributed to this study and apologies for all the work I created for you.

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Appendix 1 – Bycatch profiles of four species

No attempt has been made to differentiate the factors affecting seabird bycatch by species. Insufficient data were available to attempt such an analysis. However, it was possible to present a bycatch profile for four species of which more than 20 individuals were returned to the Natural History Unit of the Museum of New Zealand for identification following their deaths on Japanese SBT longline vessels between 1989 and 1993 inclusive.

For these species the following information is provided.

1. A plot of capture locations for each individual based on the estimation techniques described in section 3.5 (Figures 64, 68, 72, and 76).

2. A histogram of the days of the year on which the capture occurred (Figures 65, 69, 73, and 77).

3. A histogram of the estimated times of capture for each bird expressed relative to sunrise and sunset times (see Figures 66,70,74, and 78). This was achieved by calculating the time of capture for each of the birds using the techniques described in section 3.2, determining whether this time was before or after sunset, and then expressing the estimated capture time either as a ratio of the time between sunrise and sunset, or as a ratio of the time between sunset and sunrise. Within the histogram 10, intervals of even length exist between sunrise and sunset, and between sunset and sunrise.

4. A plot for birds caught at night showing their estimated time of capture (using the technique described in section 3.2) against the phase of the moon on the night that they were captured.

   Capture time is again expressed relative to sunset and sunrise. "Mid-night" in this plot is the point in time exactly half way between sunset and sunrise and not necessarily 2400 hours.

   These plots provide an insight into the light conditions required for birds of a particular species to feed at night (See Figures 67, 71, 75, and 79).

Fishing effort has not been compensated for in the presentation of this data.

Appendix 2 – Potential bycatch mitigation strategies

Mitigation measures could include any action which would interfere with or reduce a bird's ability to follow a vessel, detect a bait in the water, take a bait, or become hooked. The following mitigation strategies are suggested for reducing the seabird bycatch rate. Few of these strategies have been tested: others exist.

<u>Strategies to prevent birds from following vessels</u>

- Prevent vessels from fishing in areas (or areas at specific times) where there is known to be a bird interaction and bycatch problem.
- Reduce the incentive for birds to follow vessels by reducing the amount of offal, used baits or other food scraps being discarded at sea in areas or at times of seabird interaction.
- Use gas guns similar to those used on land by horticulturalists to deter birds from following vessels.
- Set lines at night when some species of birds may be less active.

<u>Strategies to prevent birds from detecting the baits</u>

- Set lines at night when the birds' visual recognition of baits may be difficult (taking into account moon phase light conditions).
- Minimise the amount of light emitted from the stern of the vessel.
- When setting at night, operate a strobe light on the rear of the vessel to interfere with the birds' ability to see the bait.
- Use bait types which are harder for a bird to visually detect (may be more relevant at night).
- Use mechanisms which obscure the visibility of baits in the water.

<u>Strategies that reduce bird's opportunity to take baits</u>

- Alter the construction of lines or add weights to lines to make the hook and bait sink faster.
- Use only thawed baits which sink faster than frozen baits. Place the hooks through baits in such a way so as to minimise the amount of air that will be trapped inside them causing them to float.

- Deflate the swim bladders of fish baits.

- Use a bait deploying mechanism that releases the baits several metres below the sea surface.

- Use a bait throwing device which hurls the bait well away from the vessel and thereby reduces the likelihood that turbulence from the ships propeller will keep it on the surface.

Strategies that prevent birds from attempting to take the bait

- Tow a bird scaring tori line (a long cable with side streamers attached) or some other physical or psychological barrier from the vessel.

Strategies that prevent birds from becoming hooked

- Alter the shape or size of hooks to lessen the likelihood of birds becoming hooked.

Fig 1a. Bycatch rate by hook deployment time

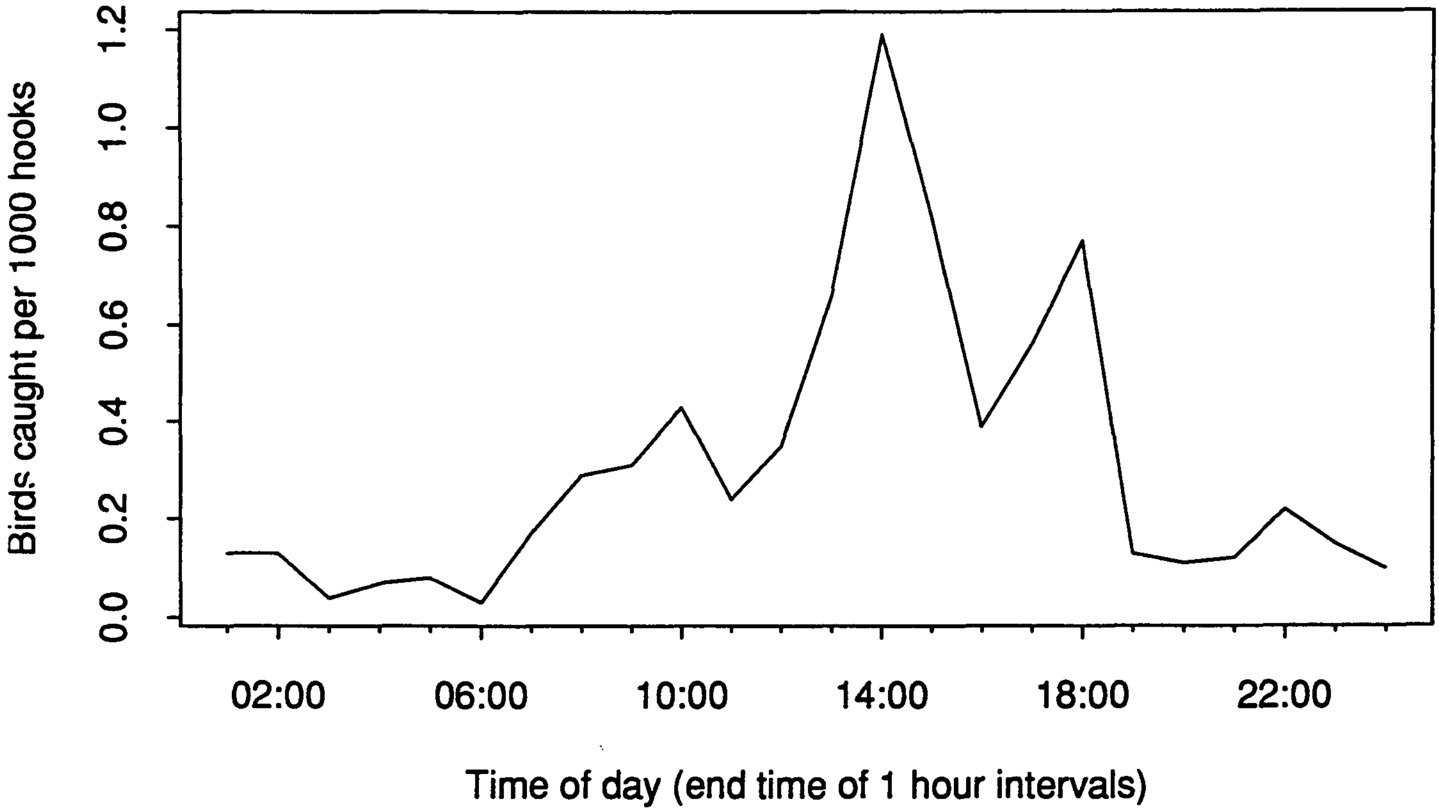
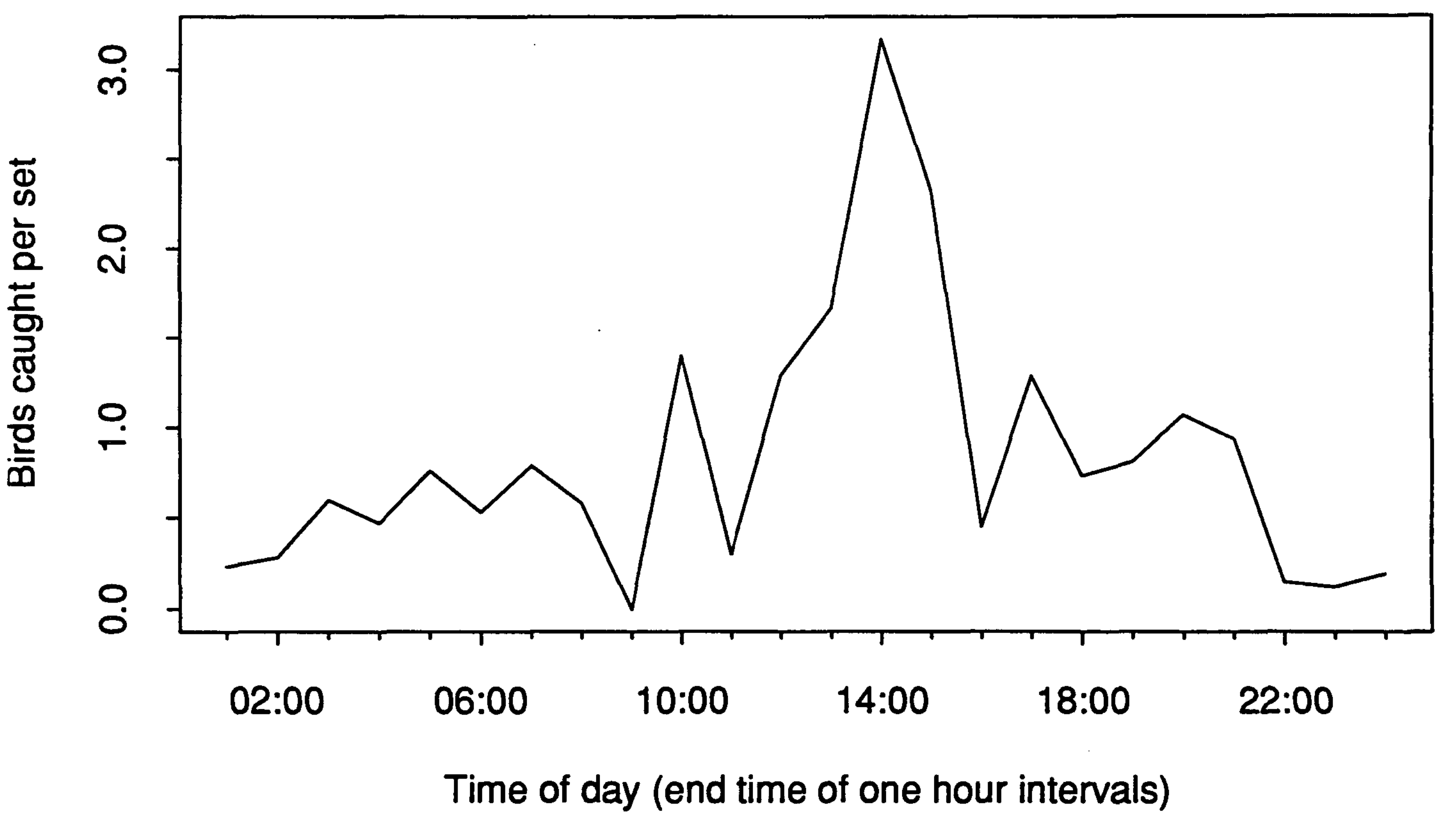


Fig 1b. Bycatch rate by set start time



Japanese SBT longline bird bycatch

Fig 2. 1989 to 1993

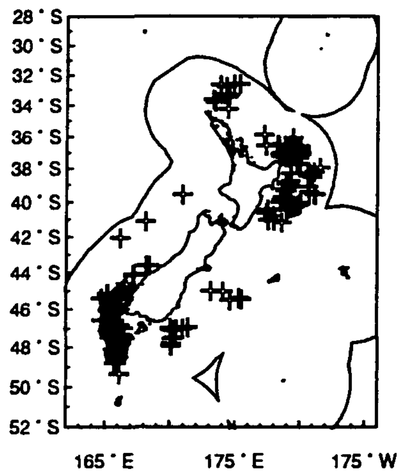


Fig 3. 1989

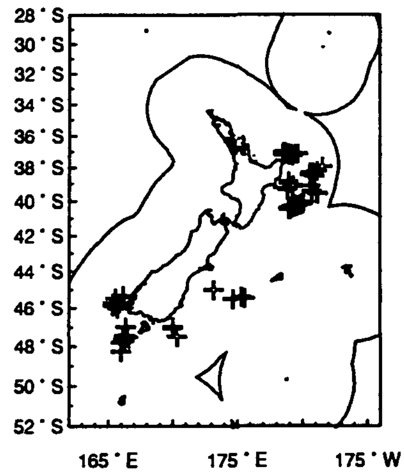


Fig 4. 1990

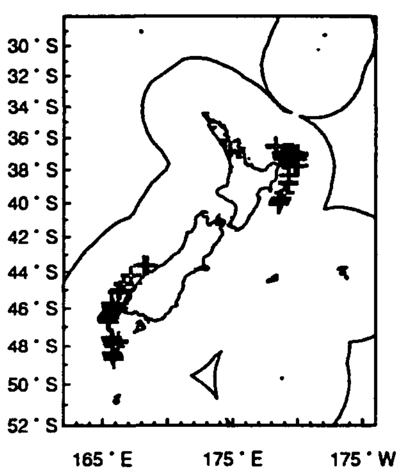


Fig 5. 1991

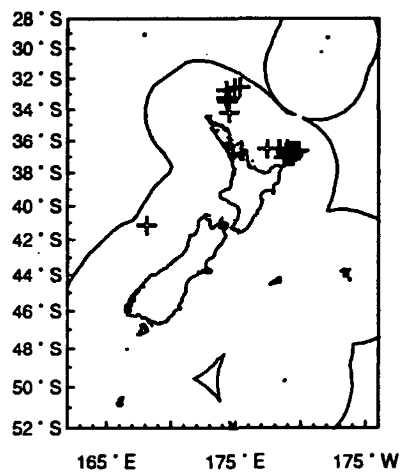


Fig 6. 1992

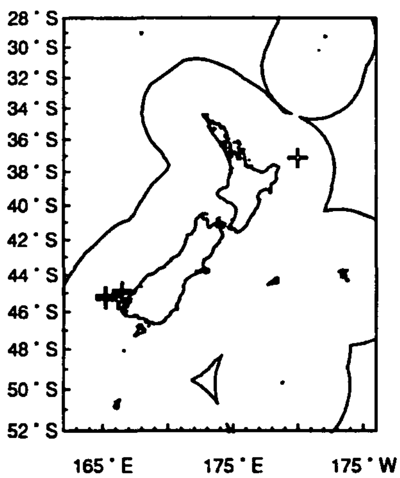
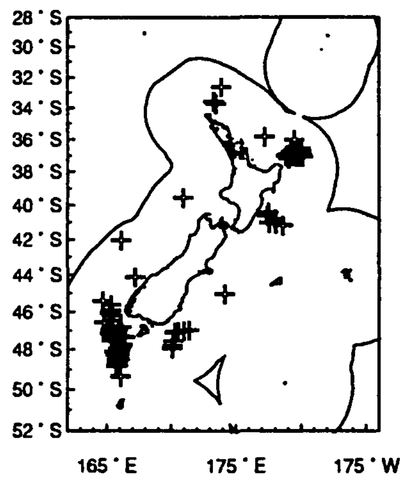


Fig 7. 1993



Observed Japanese SBT longline sets

Fig 8. 1989 to 1993

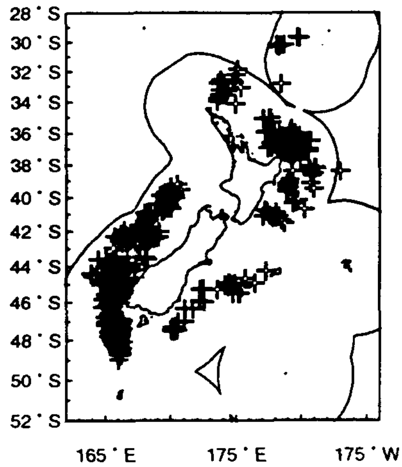


Fig 9. 1989

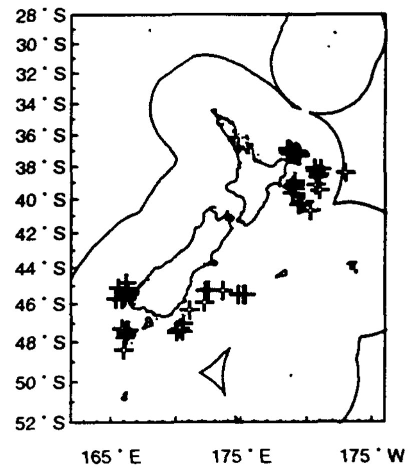


Fig 10. 1990

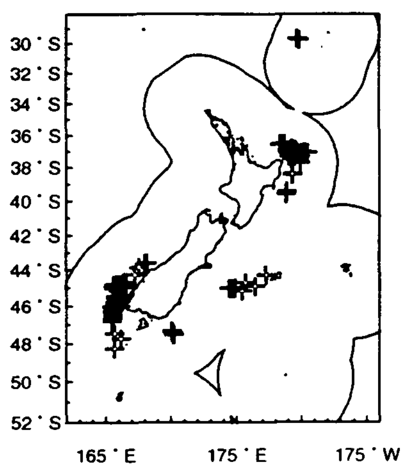


Fig 11. 1991

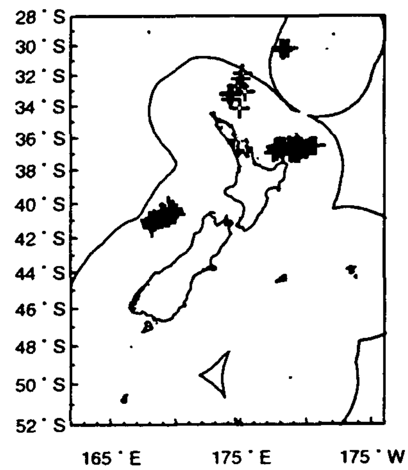


Fig 12. 1992

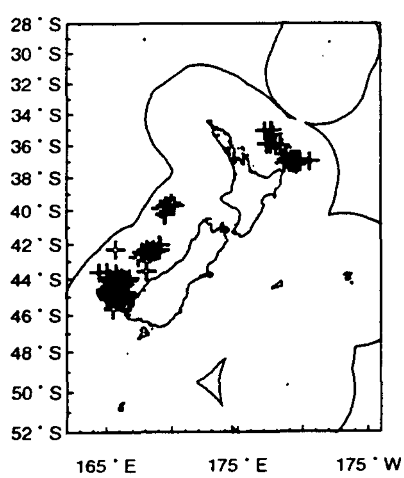


Fig 13. 1993

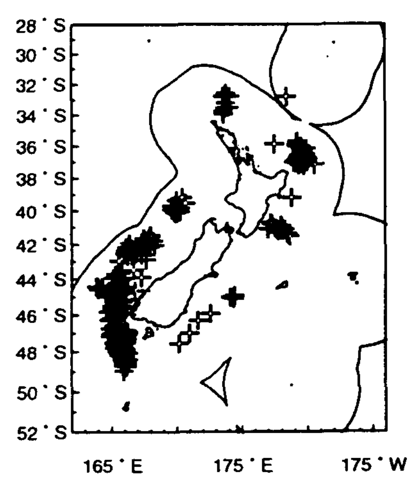
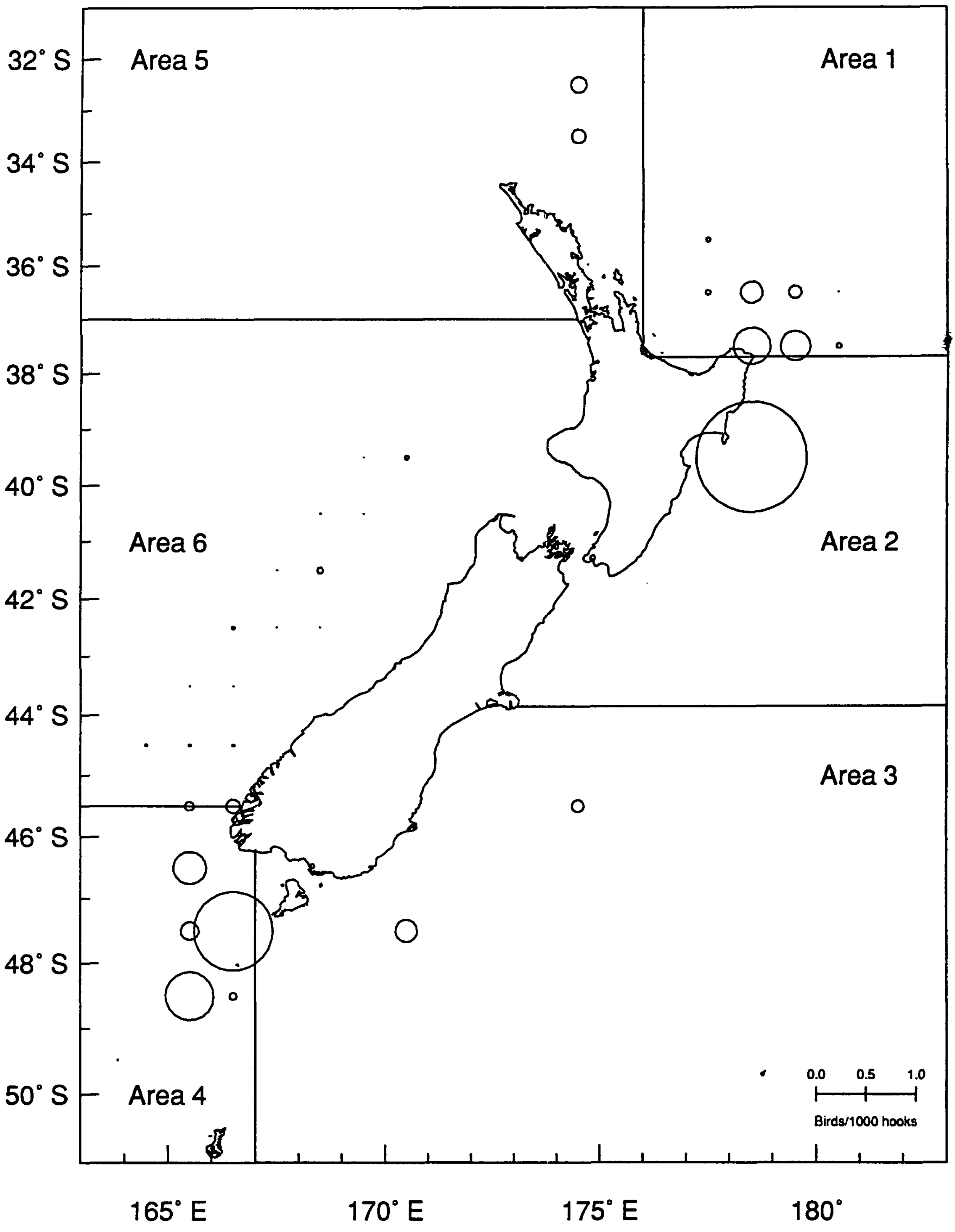


Fig 14. Japanese SBT longline - bird bycatch by area



1 degree grids in which 15,000 or more observed hooks have been deployed

Tori Line Effects on Bycatch - Binomial G.L.M.

Figure 15

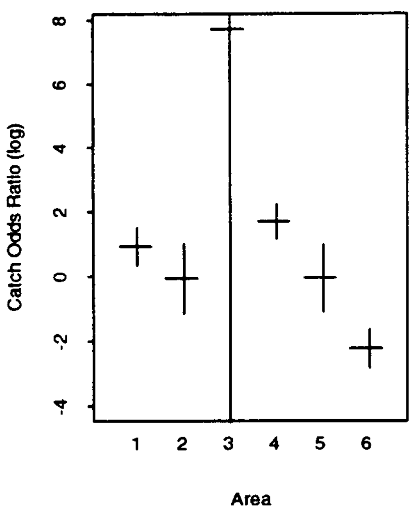


Figure 16

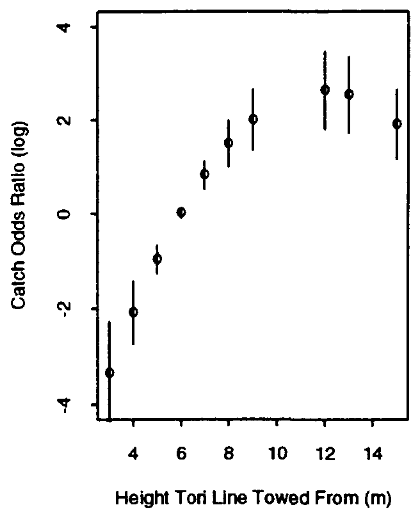


Figure 17

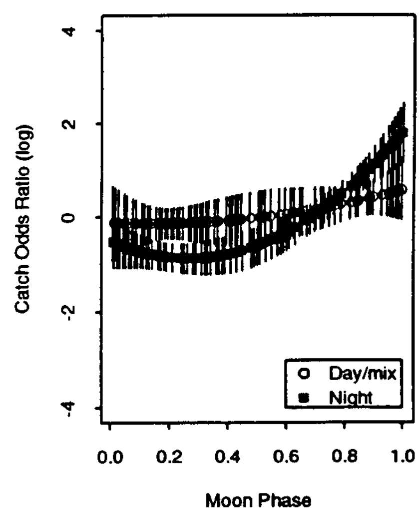
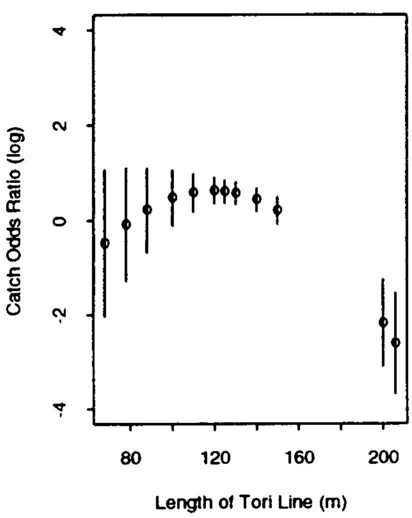


Figure 18



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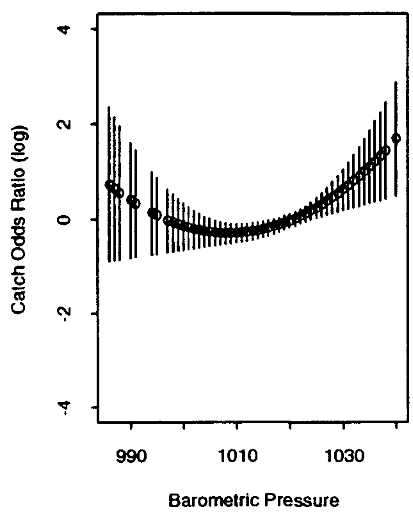


Figure 20

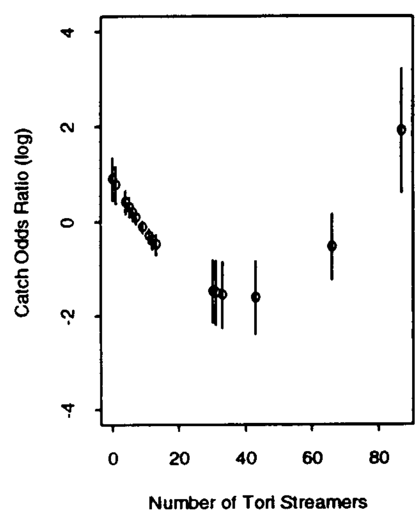
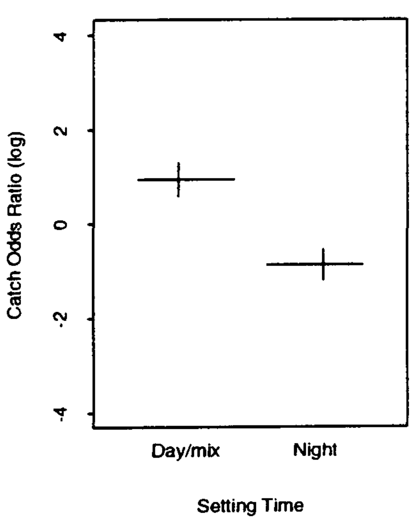


Figure 21



Tori Line Effects on Bycatch - Poisson (with 0's) G.L.M.

Figure 22

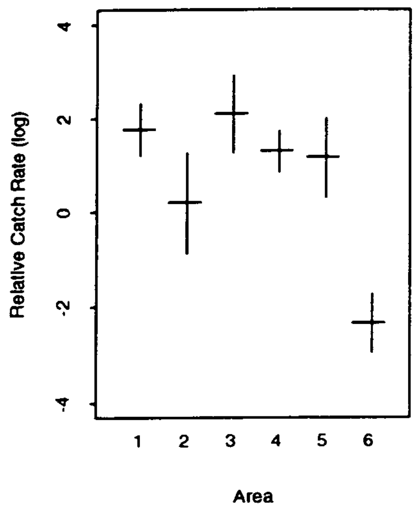
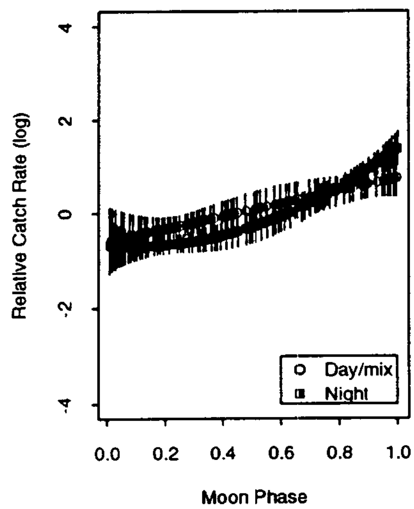


Figure 23



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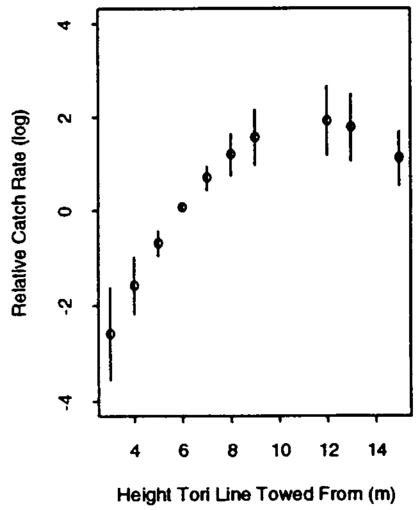


Figure 25

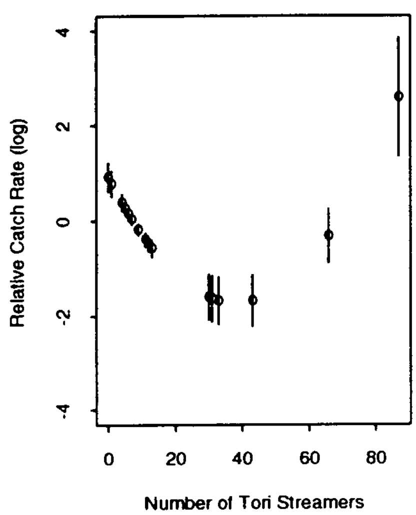


Figure 26

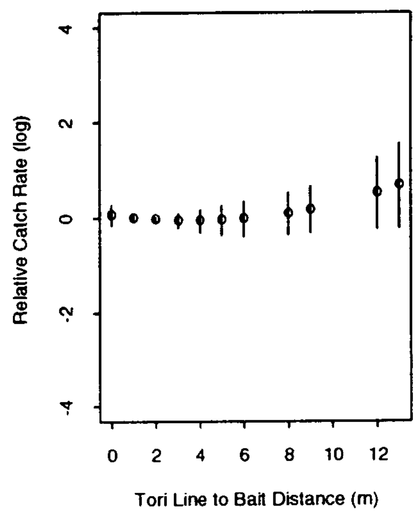


Figure 27

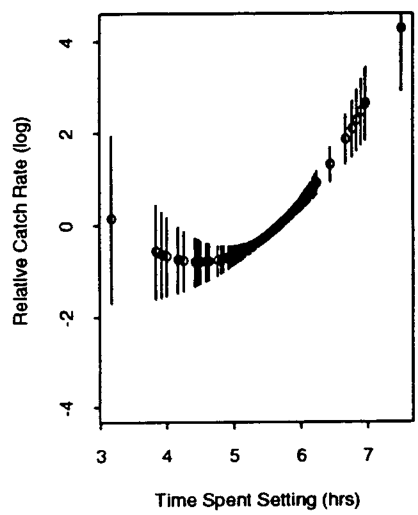


Figure 28

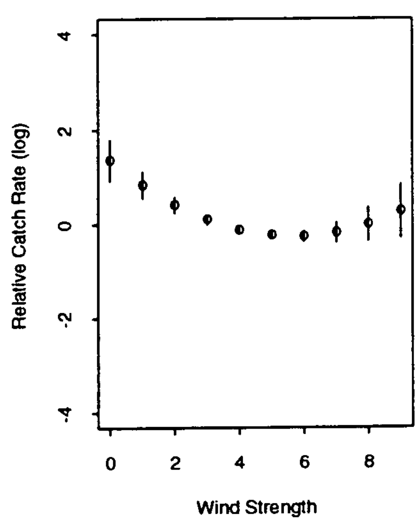
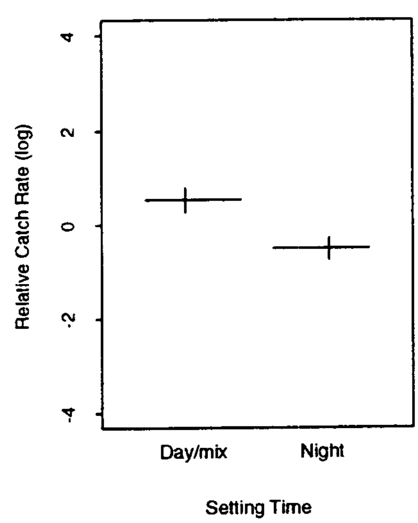


Figure 29



Tori Line Effects on Bycatch - Poisson (without 0's) G.L.M.

Figure 30

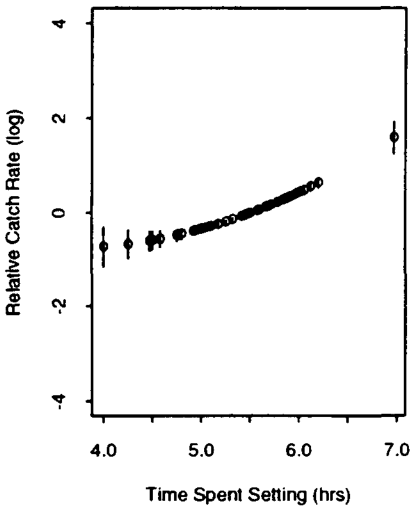


Figure 31

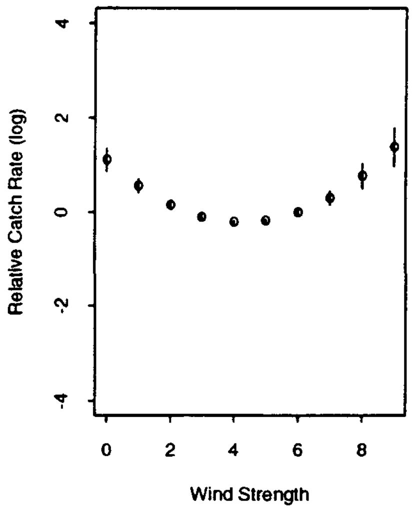
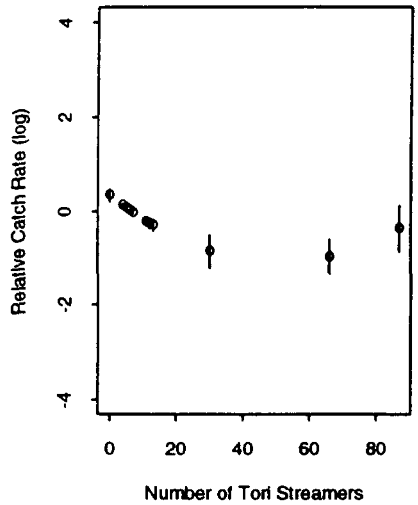


Figure 32



General Effects on Bird Bycatch - Binomial G.L.M.

Figure 33

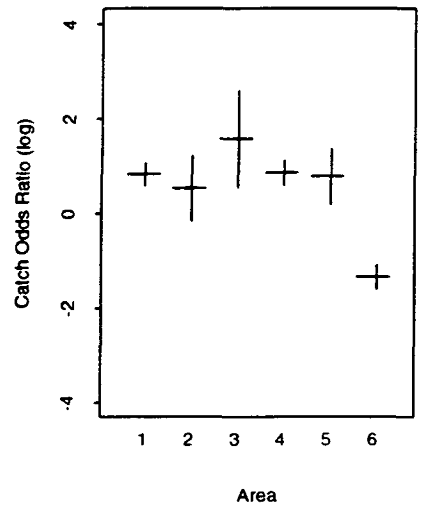


Figure 34

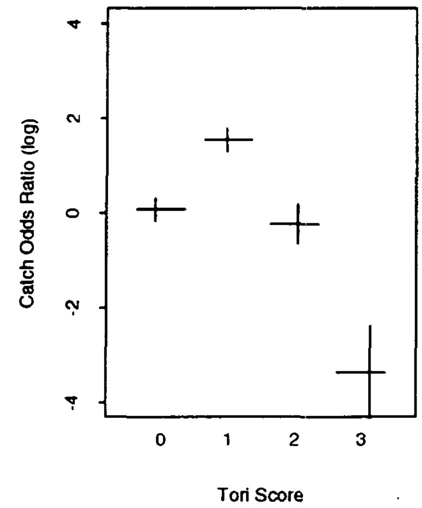


Figure 35

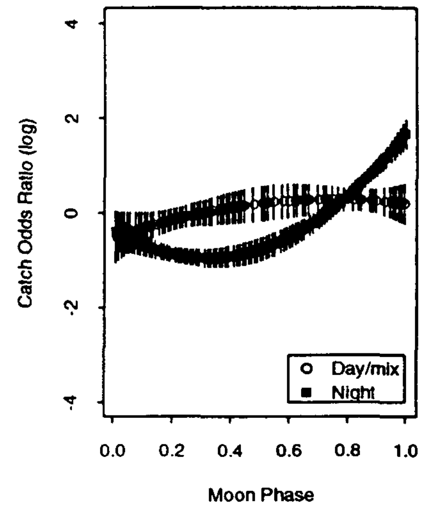
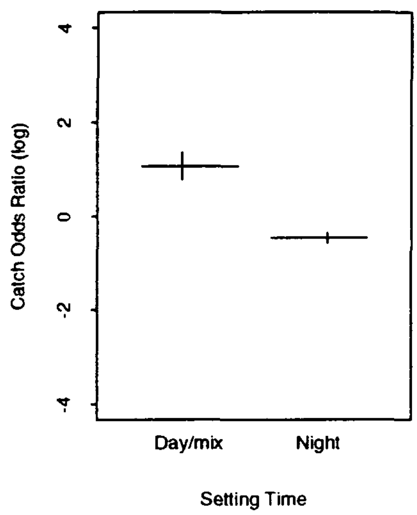


Figure 36



General Effects on Bird Bycatch - Poisson (with 0's) G.L.M.

Figure 37

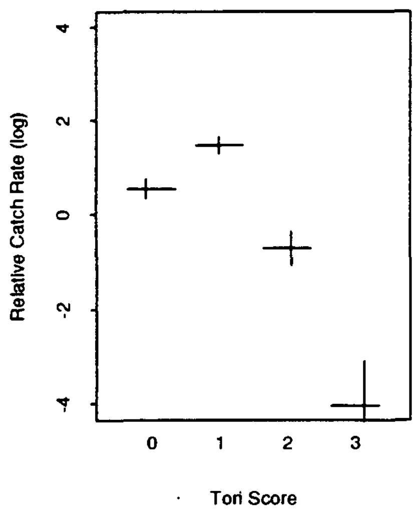


Figure 38

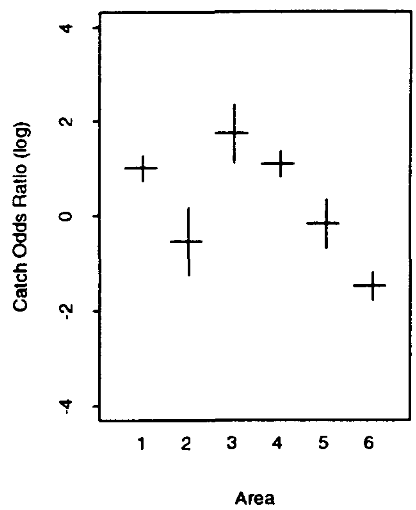


Figure 39

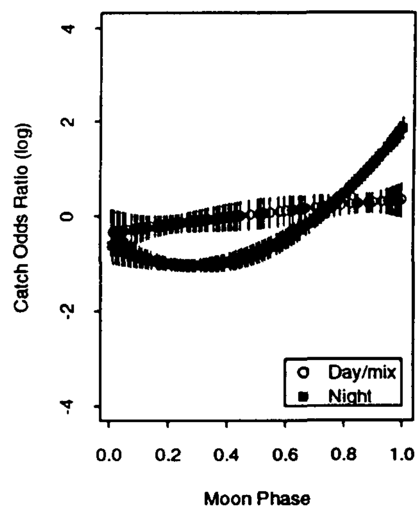


Figure 40

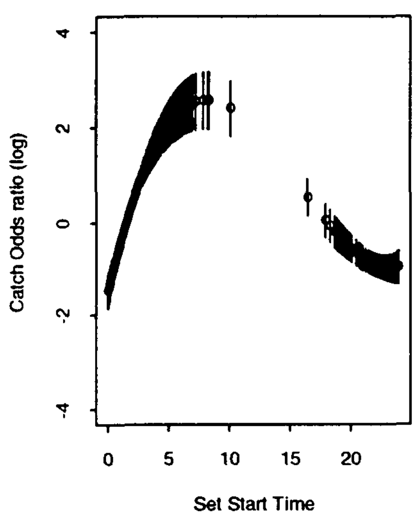


Figure 41

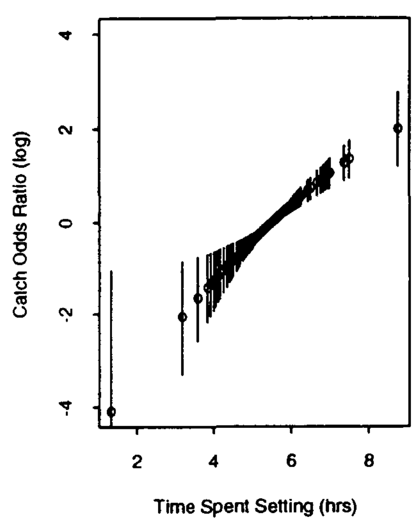


Figure 42

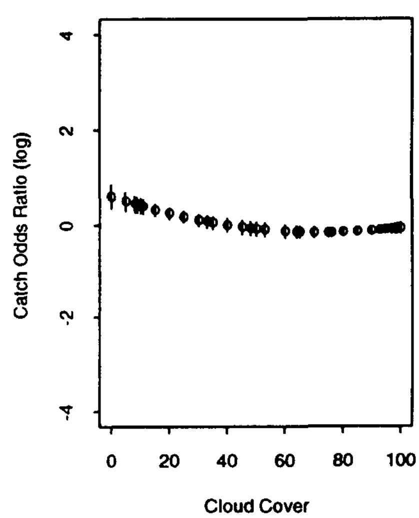
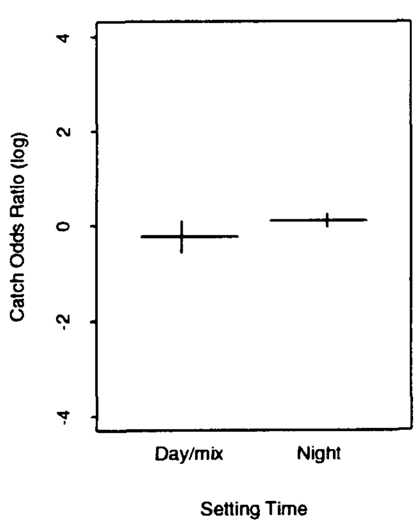


Figure 43



General Effects on Bird Bycatch - Poisson (without 0's) G.L.M.

Figure 44

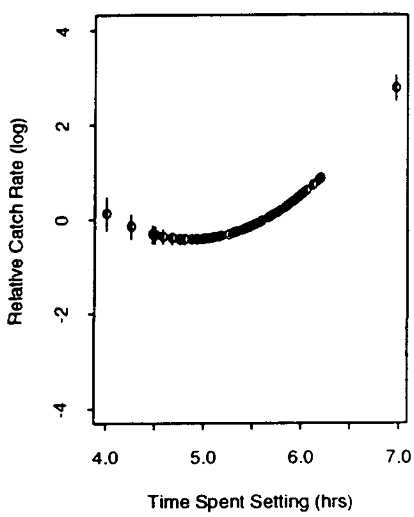


Figure 45

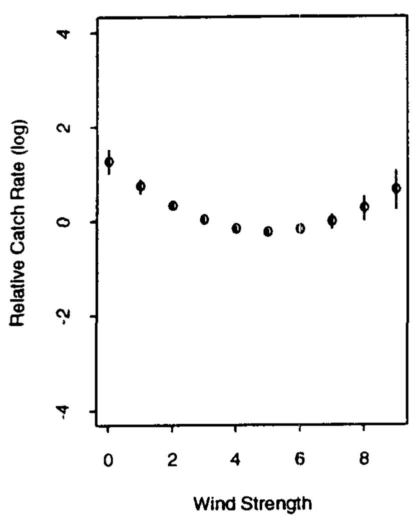
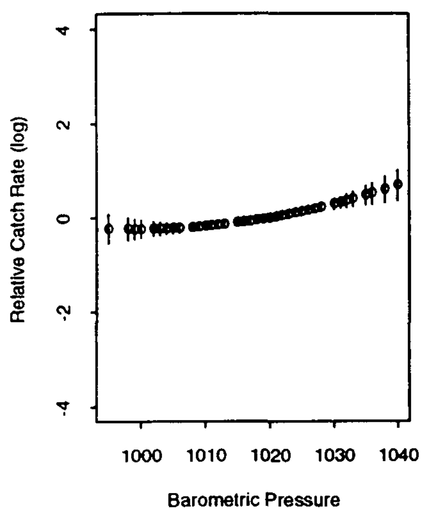


Figure 46



Revised Effects on Bird Bycatch - Binomial G.L.M.

Figure 47

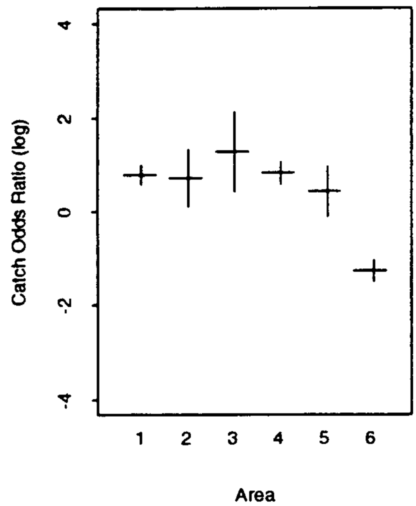


Figure 48

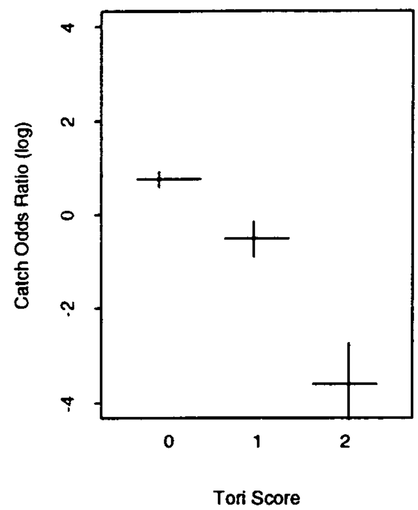


Figure 49

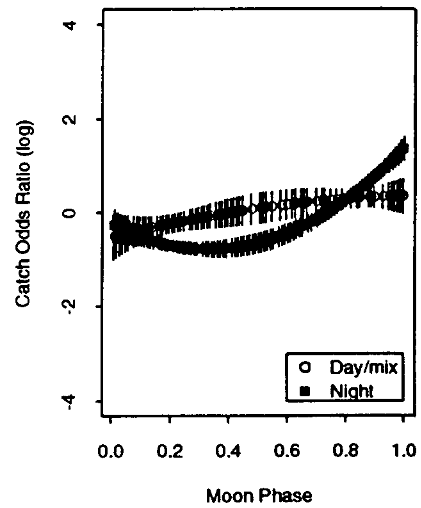
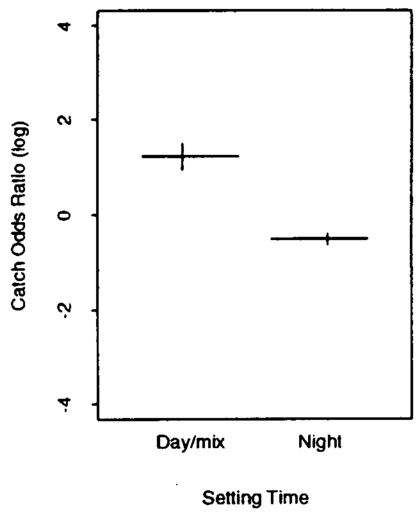


Figure 50



Revised effects on Bird Bycatch - Poisson (with 0's) G.L.M.

Figure 51

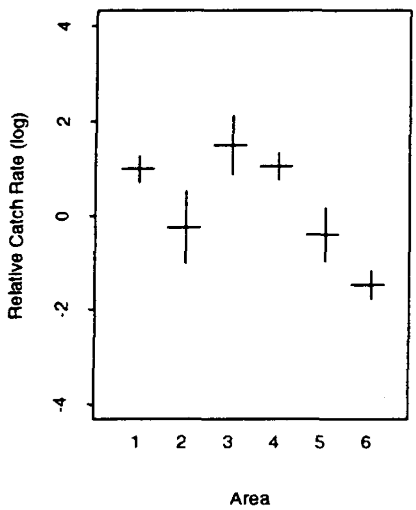


Figure 52

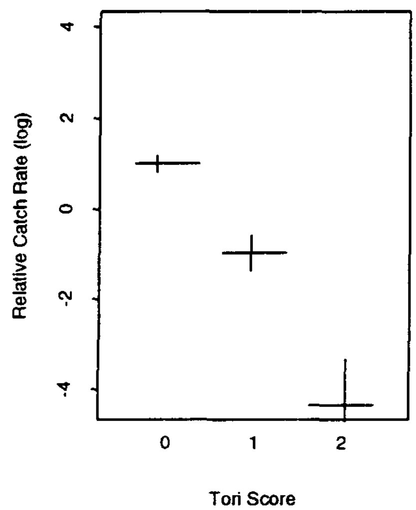


Figure 53

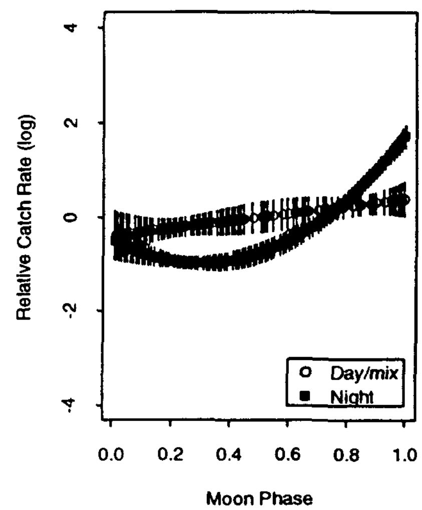


Figure 54

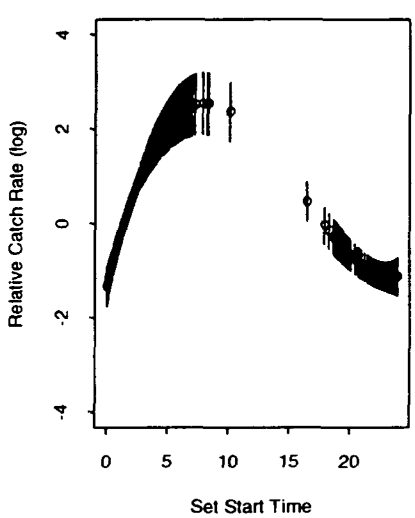


Figure 55

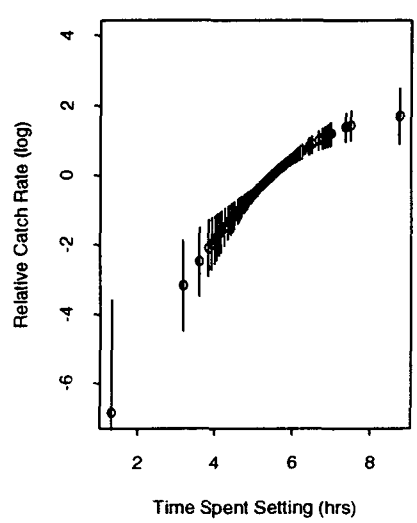


Figure 56

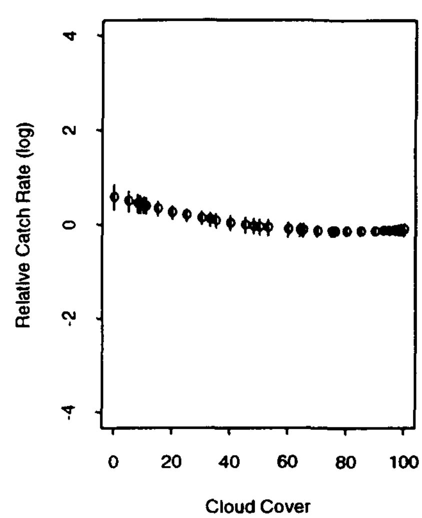


Figure 57

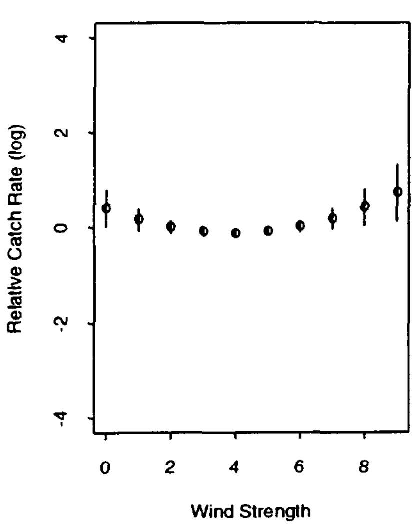
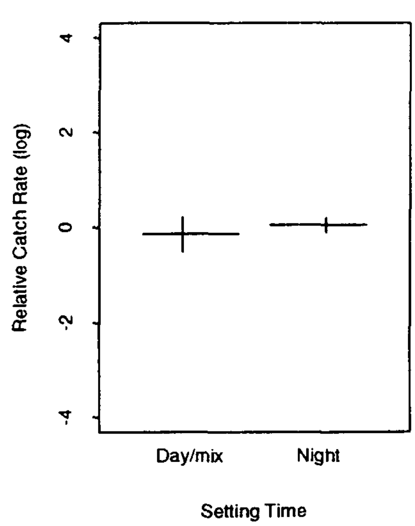


Figure 58



Revised effects on Bird Bycatch - Poisson (without 0's) G.L.M.

Figure 59

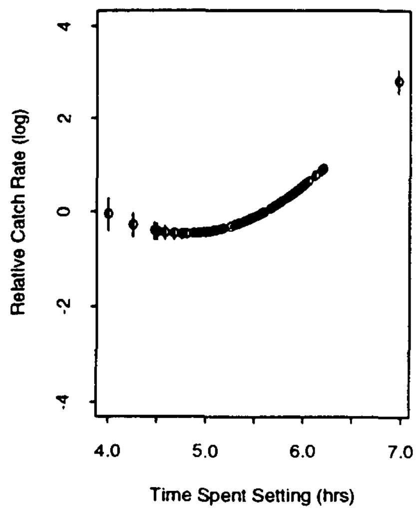


Figure 60

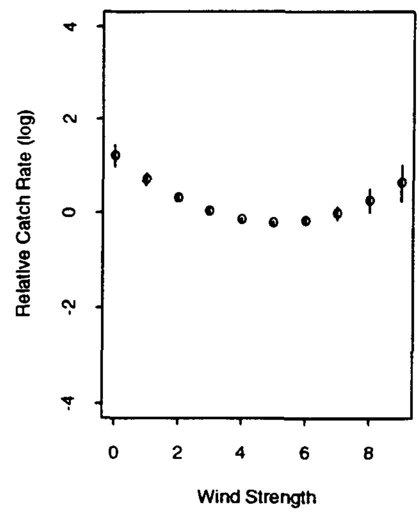


Figure 61

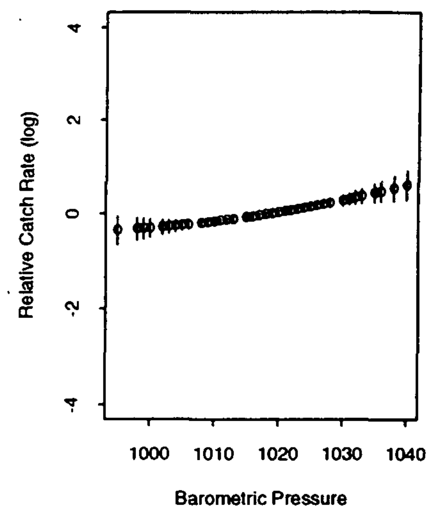


Figure 62

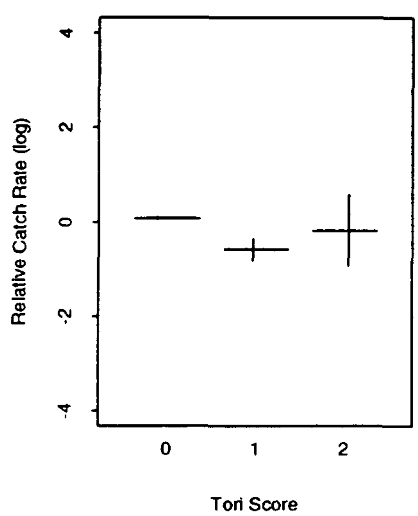
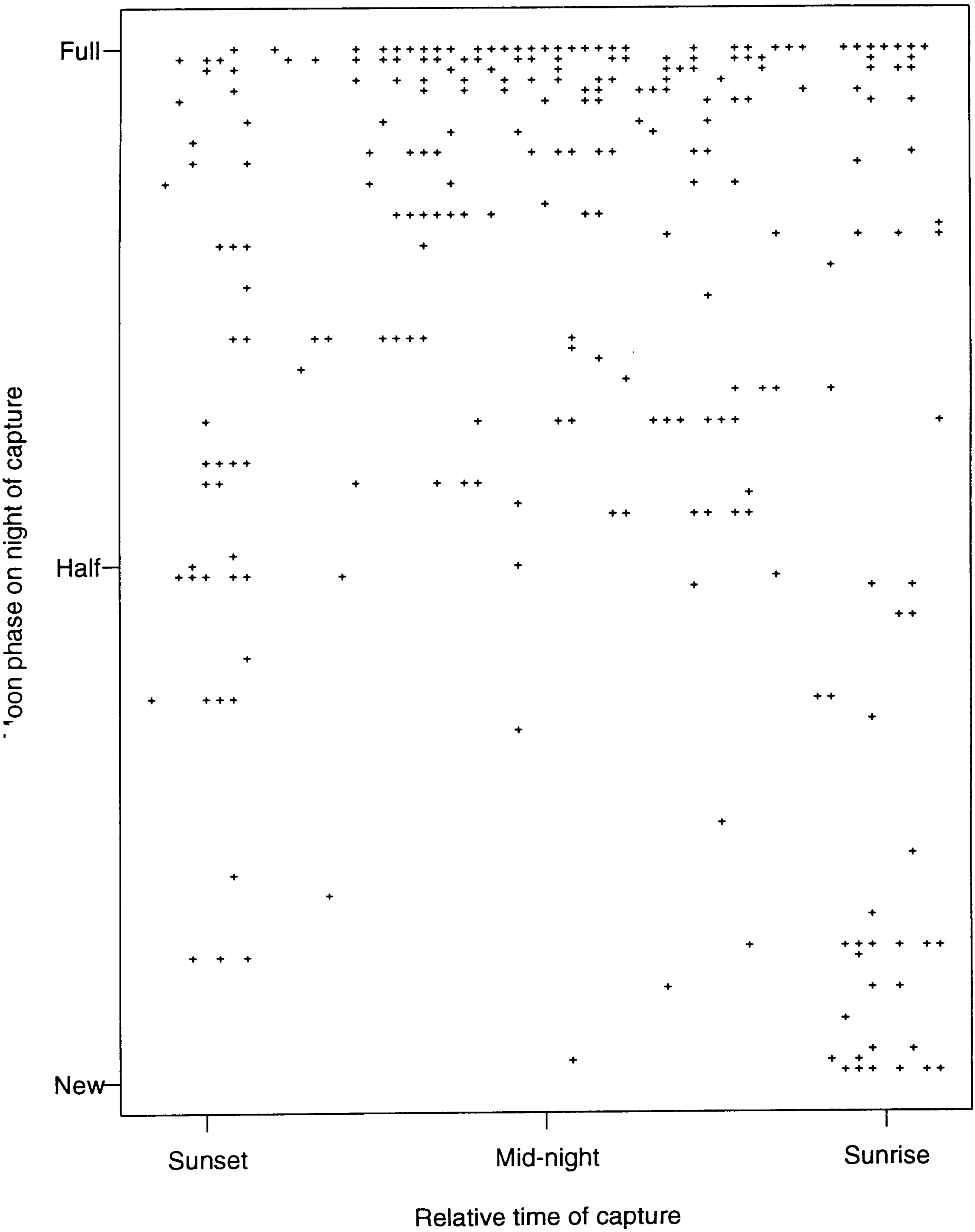


Fig 63. Light conditions at time of capture



Black Browed Albatross - Capture profile (34 birds)

Fig 64. Capture location

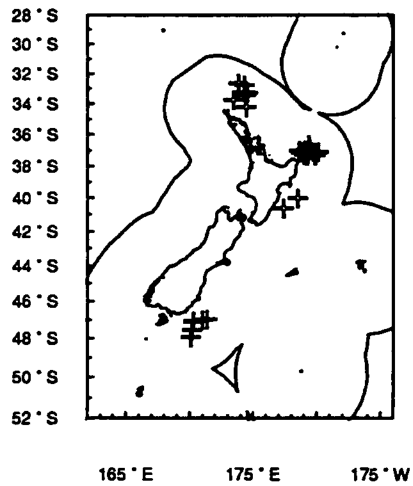


Fig 65. Day of capture

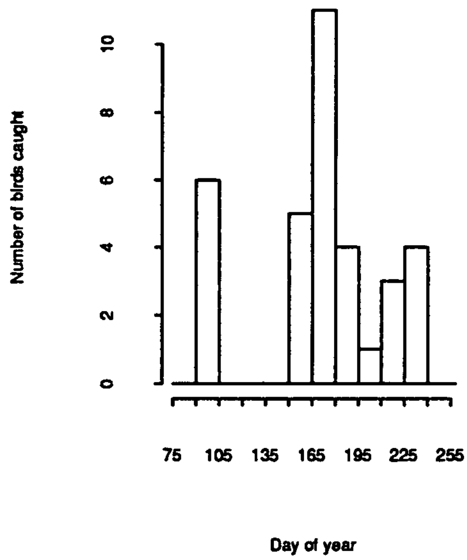


Fig 66. Time of capture

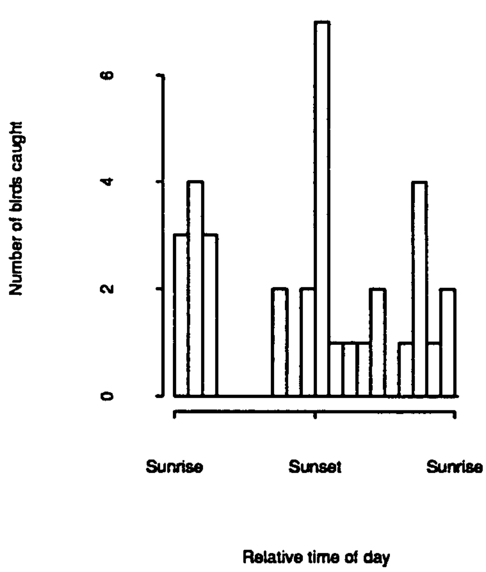
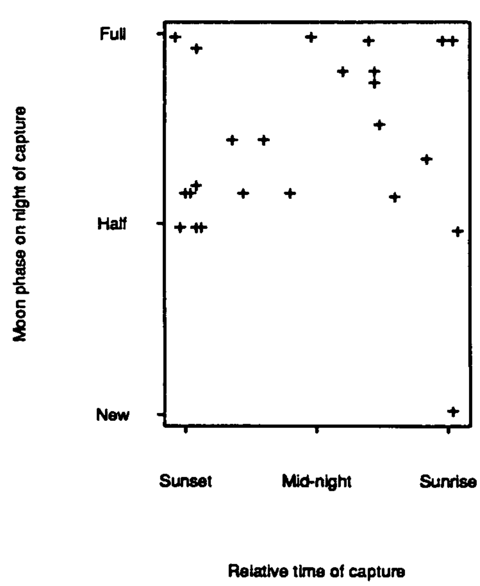


Fig 67. Light conditions at time of capture



Grey Petrel - Capture profile (96 birds)

Fig 68. Capture location

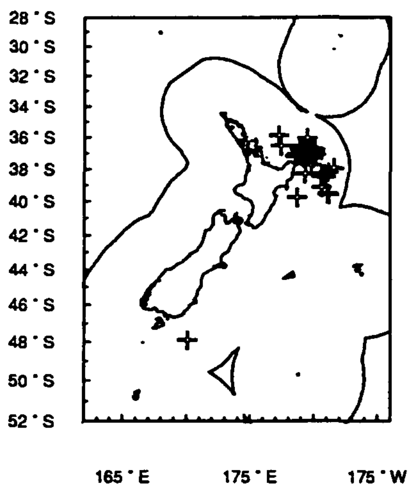


Fig 69. Day of capture

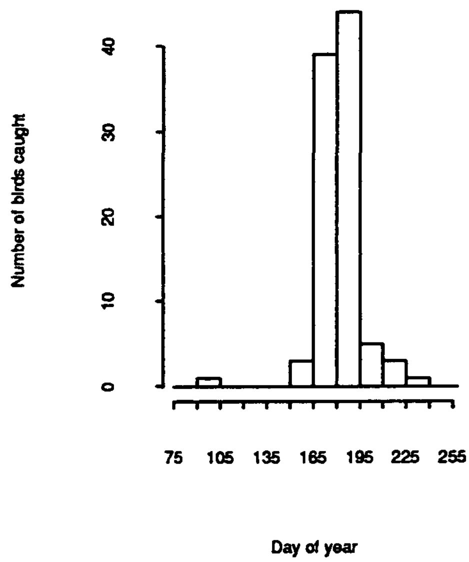


Fig 70. Time of capture

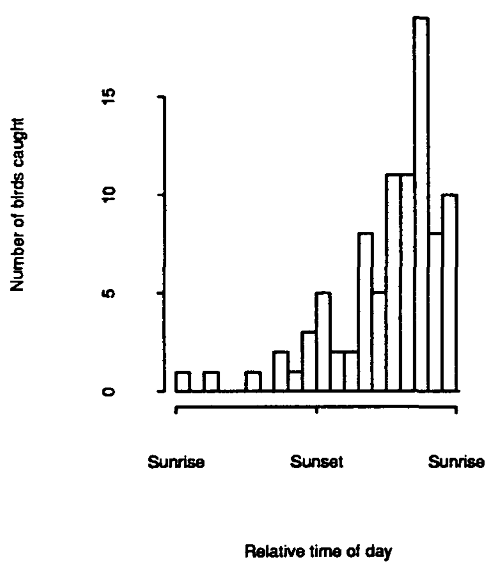
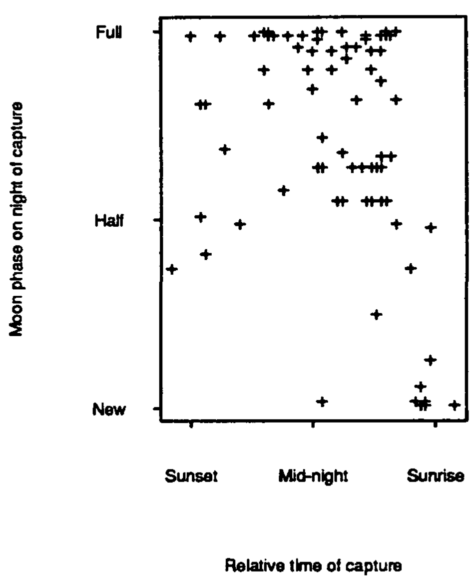


Fig 71. Light conditions at time of capture



Southern Bullers Albatross - Capture profile (24 birds)

Fig 72. Capture location

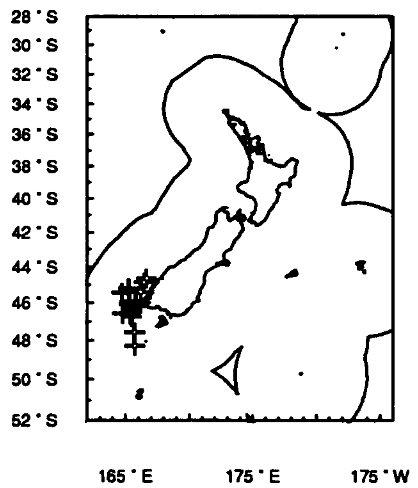


Fig 73. Day of capture

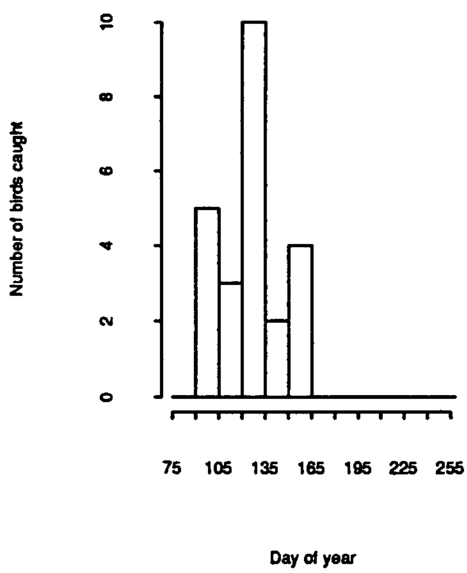


Fig 74. Time of capture

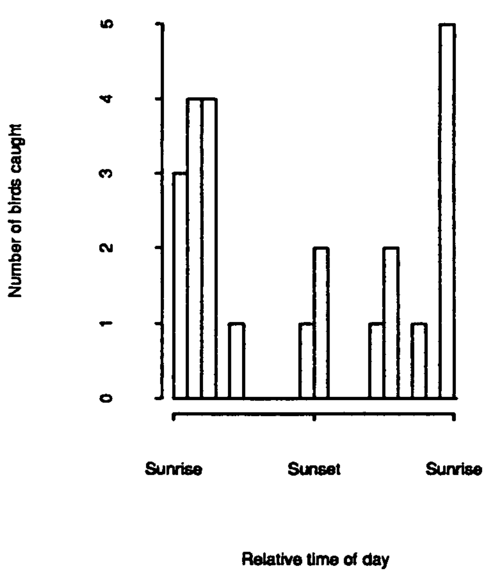
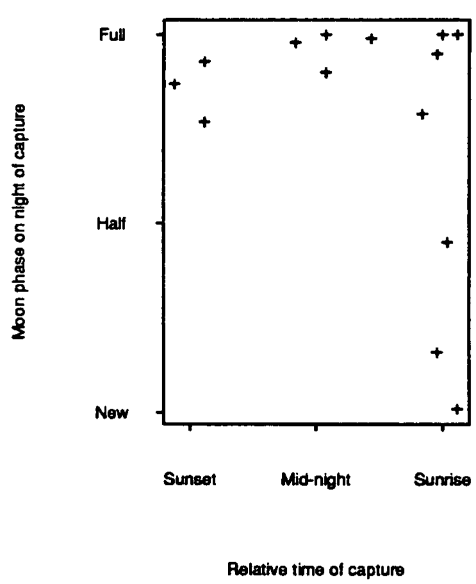


Fig 75. Light conditions at time of capture



Wandering Albatross - Capture profile (37 birds)

Fig 76. Capture location

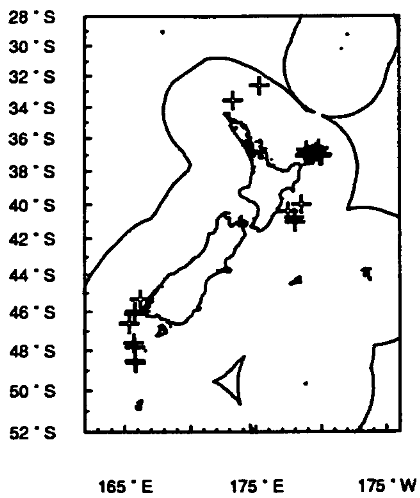


Fig 77. Day of capture

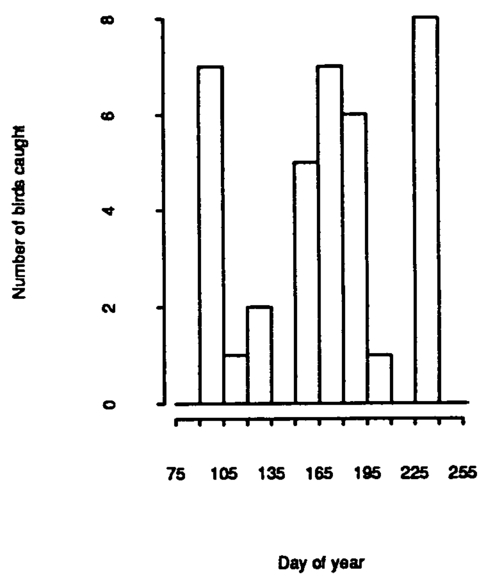


Fig 78. Time of capture

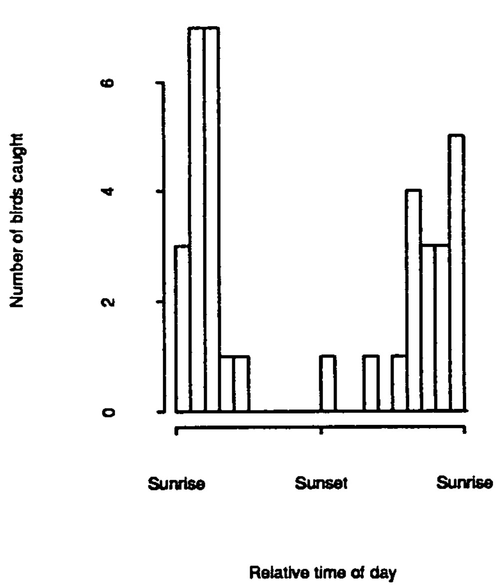


Fig 79. Light conditions at time of capture