Longline bycatch of birds and mammals in New Zealand fisheries, 1990/91–1995/96, and observer coverage

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ABSTRACT

The official observer data that are available on the bycatch of seabirds and mammals during longline fishing operations in New Zealand waters are analysed, for the fishing years 1990/91 to 1995/96. Estimates of the amount of bycatch in five categories (fur seals, great albatrosses, mollymawks, petrels, and other seabirds) are presented for Fisheries Management Areas within fishing years. These are based on reports from official observers on fishing vessels, using ratio estimation with the number of hooks as the measure of fishing effort. The effects of factors that may influence bycatch rates are analysed. Diagrams are provided showing likely levels for the coefficient of variation (CV) of bycatch estimates as a function of the total effort in a fishery, in terms of the number of hooks used and the level of cover by official observers. One diagram is for a best-case scenario (the bycatch category with the minimum CV), the other for a worst-case scenario (highest CV). It is found that to obtain a CV of 20% requires about 25% observer cover for a fishery with three million hooks in a best-case scenario, but increases to 70% observer cover for some types of bycatch.

Manly et al. 2002. Longline bycatch of birds and mammals in New Zealand fisheries, 1990/91–1995/96, and observer coverage. *DOC Science Internal Series 43*. Department of Conservation, Wellington. 51 p.

1. Introduction

There are two tuna longline fisheries in the New Zealand exclusive economic zone (EEZ). The northern fishery is north of latitude 40°S, and the southern fishery is south of this line (Fig. 1). Within these fisheries there is accidental bycatch of fur seals (*Arctocephalus forsteri*) and approximately 20 bird species (Table 1). One sperm whale (*Physeter macrocephalus*) is also recorded in the database, but this record has not been included in any analyses.

Fur seals are usually released alive, with this occurring 96% of the time in the records (102 out of 106 cases where the status is known). However, birds are

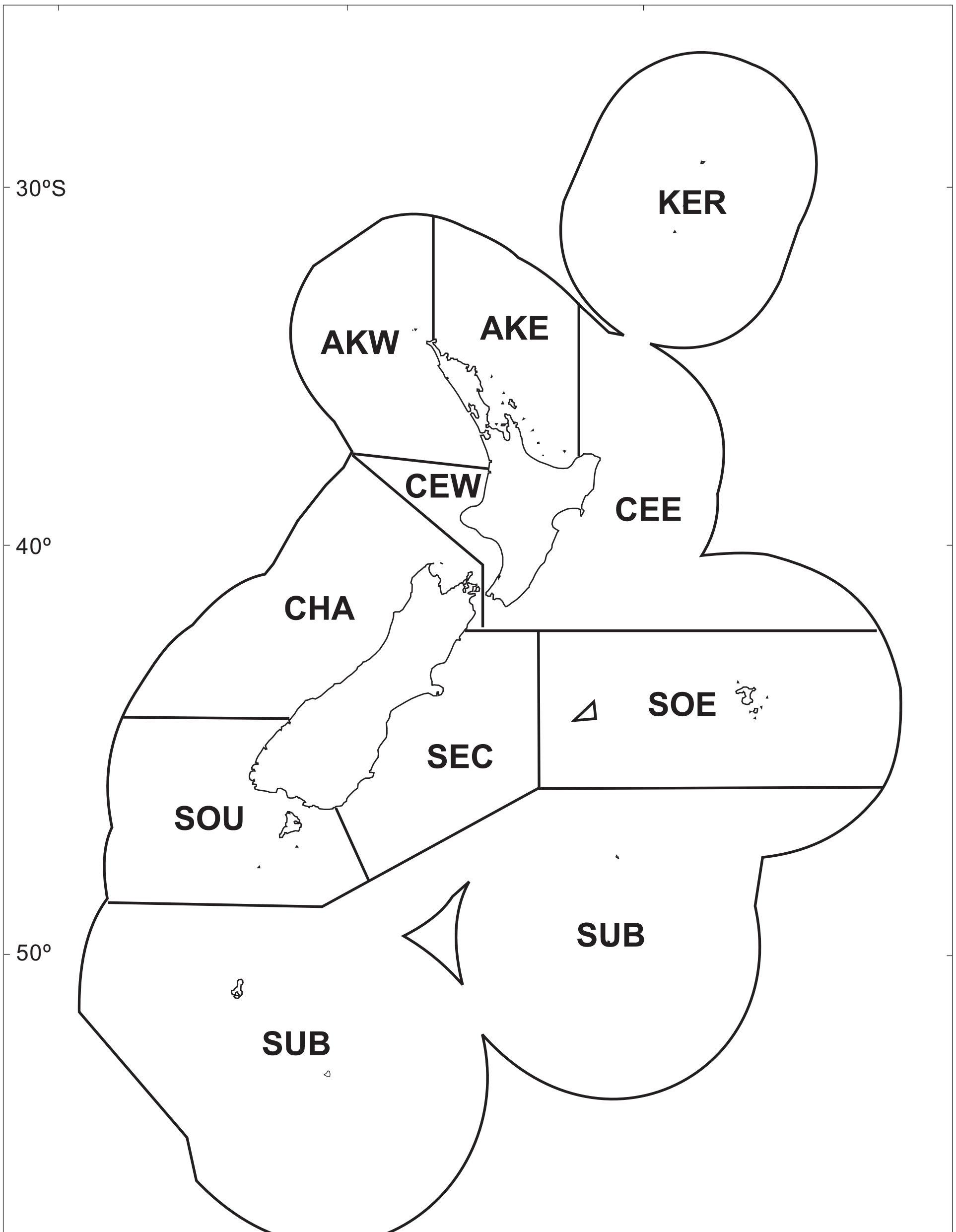

Figure 1. Fisheries Management Areas (FMAs) in the New Zealand Exclusive Economic Zone (EEC). The FMAs are: KER (Kermadec), AKE (Auckland East), AKW (Auckland West), CEE (Central East), CEW (Central West), CHA (Challenger), SEC (Southeast Coast), SOE (Southeast), SOU (Southland), and SUB (Sub-Antarctic).

usually found dead, with this occurring 88% of the time (417 out of 475 cases where the status is known). Dead seabirds have been returned where possible to the Museum of New Zealand for species identification since 1989. Otherwise identification has been based on photographs and descriptions of captured birds.

From 1987 to 1994 the northern fishery was used by foreign-licensed Japanese vessels, with a few foreign-licensed Korean vessels as well before 1989. However, this fishery was closed to foreign-licensed vessels from 1995 onwards because of increasing domestic capacity for longline fishing. Domestic owned and operated vessels have used the area since 1991. There have also been some chartered Japanese vessels in the area. Foreign-licensed and chartered Japanese vessels use kuralon for the mainline and monofilament for the snoods, whereas domestic vessels usually use monofilament for the mainline and always use this for the snoods. From 1987 to 1995 almost all of the observer cover in the northern fishery was on vessels with Japanese crews (either foreign-licensed or chartered).

TABLE 1. LIST OF SEABIRDS RECORDED AS BYCATCH FOR FISHING YEARS 1990/91 TO 1995/96, WITH SPECIES NAMES FROM ROBERTSON & NUNN (1998).

TYPE	COMMON NAME	SPECIES		COUNT
Great albatrosses	Antipodes Island wandering albatross	*Diomedea exulans antipodensis*		7
	Auckland Islands wandering albatross	*Diomedea exulans gibsoni*		22
	Light-mantled sooty albatross	*Phoebetria palpebrata*		3
	Salvin's albatross	*Diomedea salvini*		3
	Southern royal albatross	*Diomedea epomophora epomophora*		8
	Unidentified albatross			10
	Wandering albatross unidentified	*Diomedea exulans* ssp.		1
			Total	54
Mollymawks	New Zealand black-browed mollymawk	*Diomedea melanophrys impavida*		26
	New Zealand white-capped mollymawk	*Diomedea cauta steadi*		85
	Southern black-browed mollymawk	*Diomedea melanophrys melanophrys*		8
	Southern Buller's mollymawk	*Diomedea bulleri bulleri*		37
	Unidentified mollymawk			6
			Total	162
Petrels	Black petrel	*Procellaria parkinsoni*		2
	Grey petrel	*Procellaria cinerea*		99
	Northern giant petrel	*Macronectes halli*		1
	Southern giant petrel	*Macronectes giganteus*		2
	Unidentified petrel	Procellariidae (order)		83
	White-chinned petrel	*Procellaria aequinoctialis steadi*		33
			Total	220
Other seabirds	Cape pigeon	*Daption capensis*		1
	Large seabird			11
	Small seabird			1
	Sooty shearwater	*Puffinus griseus*		3
	Unidentified seabird			63
			Total	79

Foreign-licensed Japanese vessels still use the southern fishery, while domestic vessels have been making increasing use of this fishery since 1994. Chartered Japanese vessels have also mainly been active in this fishery rather than the northern one. As for the northern fishery, almost all observer cover was on Japanese crewed vessels until the 1995/96 fishing year (October to September); from then on all cover was on domestic vessels.

An earlier report by Baird (1996) provides information on the observer cover and estimated bycatch numbers rates for seabirds for the calendar years 1987 to 1995, for foreign licensed and chartered Japanese vessels (Table 2). In the northern fishery the observer cover in terms of line sets observed has ranged from 0.8% in 1987 to 100% in 1994. In the southern fishery the level of cover in terms of line sets on Japanese vessels varied from none in 1987 and 1988 to 53.5% in 1995.

TABLE 2. OBSERVER COVER AND ESTIMATED BYCATCH OF SEABIRDS (ALBATROSS, PETRELS AND BULLER'S MOLLYMAWK) IN THE NORTHERN AND SOUTHERN TUNA FISHERIES FROM BAIRD (1996).

	NORTHERN FISHERY			SOUTHERN FISHERY		
YEAR	TOTAL SETS	COVER (% OF SETS)	ESTIMATED BYCATCH	TOTAL SETS	COVER (% OF SETS)	ESTIMATED BYCATCH
1987	3127	0.8	751	2578	0.0	-
1988	2231	1.8	820	2221	0.0	-
1989	1175	4.0	2309	2135	1.9	1670
1990	1292	6.0	1270	1626	4.7	1126
1991	1762	6.9	533	2690	1.0	96
1992	1376	6.0	113	1772	9.8	72
1993	286	44.0	186	1213	24.2	542
1994	32	100.0	35	288	7.3	97
1995	18	72.2	1	445	53.5	166

2. Methods for estimation of bycatch from observer reports

The methods used to estimate bycatch for this report are fully described by Manly et al. (1997, 2002). In summary, the data available are the number of hooks used, $u_1, u_2, \ldots, u_n$ (in thousands), with corresponding bycatch numbers $x_1, x_2, \ldots, x_n$, for n sample units, where each unit consists of one or more sets made under similar conditions. From these data the bycatch rate (the number of individuals caught per thousand hooks) is estimated for a particular category of bycatch by

$$r = t_x/t_u \qquad (1)$$

where $t_x = \sum x_i$ is the number of individuals captured with $t_u = \sum u_i$ the number (in thousands) of observed hooks. The total number of individuals caught in the sampled fishery is then estimated by

$$\hat{T} = r(t_u + t'_u) \qquad (2)$$

Where t'_u is the number of unobserved hooks in the fishery, in thousands. This is essentially just a straightforward application of ratio estimation (Manly 1992, p. 35), and the variance of the estimated bycatch can be approximated by

$$\hat{\mathrm{Var}}(\hat{T}) = \frac{N^2 \sum_{i=1}^{n} (x_i - ru_i)^2}{(n-1)n} \left(1 - \frac{n}{N}\right) \qquad (3)$$

where N is the total number of possible sample units for the fishery.

Hooks are used here as the unit of effort because this seems more reasonable than the number of line sets. There are other measures of effort that could have been used, including the total set time and the total haul time.

With stratified sampling, the above equations can be applied separately for several different time periods or several different fishing areas. The estimated bycatch for all periods or all areas is then the sum of the separate estimates, and the estimated variance is the sum of the separate variances.

In using these equations, an important assumption is that the observed sample units (n) are effectively a random sample from the possible sample units (N). For the estimates calculated for this report a sample unit consists of the hooks on a series of up to five consecutive sets by one vessel with the same target, in the same fisheries management area, with sets starting at about the same time each day. This unit was used in preference to the hooks on single sets because inspection of the data suggests that there is at times a tendency for a series of consecutive sets by one vessel to involve bycatch incidents, and therefore not to represent the equivalent of a random sample. The maximum limit of five sets was chosen to ensure that the moon phase (one of the variables that was investigated for a relationship with bycatch) was relatively constant for each sample unit.

3. Bycatch estimates and observer cover

Bycatch estimates are based on data provided by the Ministry of Fisheries and the Department of Conservation. A database for observed sets was constructed from several primary sources giving information on the time, location and characteristics of the sets, vessel details, and bycatch, for observed sets in the fishing years 1990/91 to 1995/96. This database provided information on 1576 individual observed sets. From this database a second database of sample units was constructed, where a sample unit was defined to be up to five consecutive sets on the same vessel in the same Fisheries Management Area (FMA) with the same target, for the reasons explained in the previous section (to provide more independent data but without too much variation in the moon phase for the sets within one sample unit). The second database then consisted of a total of 502 sample units. These databases are contained in an Excel file called LONGLINE.XLS[1].

The sample units were classified in terms of the fishing year (October to September) and FMA, and estimates of bycatch were computed separately for each combination of these two factors for which there was some observer cover, using the equations presented in the previous section. The locations of FMAs are shown in Fig. 1. Roughly, the northern tuna longline fishery is in areas AKE, CEE and KER, and the southern fishery is in areas SOU and CHA.

Estimation of the total bycatch within FMAs and fishing years required estimates of the total effort in terms of hooks for each fishing year and FMA. For this purpose a file of total effort in terms of hooks, on a monthly basis, for Fisheries Statistical Areas (FSAs) for fishing years 1990/91 to 1995/96 was used. This file, R2688.CSV, was provided by the Ministry of Fisheries. FSAs are smaller areas than FMAs, and in a few instances there are boundaries where the FSAs are included in two or three FMAs. The total effort within the FSAs was then allocated to the FMAs in proportion to the geographical areas of overlap.

Tables 3 to 8 summarise the observer coverage and the estimated bycatch of fur seal and seabirds as derived from the 502 sample units, for the fishing years 1990/91 to 1995/96, for all FMAs. Most of the observed *fur seal* bycatch has been recorded in SOU and CHA, with some in CEE in fishing year 1993/94 only (Table 3). There was no observed bycatch in 1990/91 or 1991/92, and estimates for the other years range from 19 in 1995/96 to 162 in 1994/95.

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[1] The data on bycatch used in this study are held by the Department of Conservation in the file LONGLINE.XLS. This is a Microsoft Excel file containing the information on the sample units used to produce the estimates of total bycatch provided in Section 3, and also used for the log-linear model analysis described in Section 4. The file contains 502 rows of data, where each row relates to a series of up to five consecutive sets made by one vessel under similar conditions.
In the interests of confidentiality, the information in the file does not allow individual vessels to be identified and latitudes and longitudes for the position of vessels at the time of the first tow are rounded to the nearest 0.1 of a degree.

TABLE 3. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *FUR SEAL* BYCATCH FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, SEE FIG. 1) OF NEW ZEALAND.

FMA		FISHING YEAR 90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.000	0.000	0.000		0.000	0.000
	Estimated total bycatch	0	0	0		0	0
	Standard error	0	0	0		0	0
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.000	0.000	0.000	0.019	0.000	0.000
	Estimated total bycatch	0	0	0	6	0	0
	Standard error	0	0	0	5	0	0
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.000	0.000		
	Estimated total bycatch			0	0		
	Standard error			0	0		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.000	0.003	0.057	0.095	0.024
	Estimated total bycatch		0	9	30	113	3
	Standard error		0	5	4	13	3
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.000	0.000	0.019	0.034	0.038	0.071
	Estimated total bycatch	0	0	15	22	49	16
	Standard error	0	0	6	7	13	6
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.000		0.000		0.000	
	Estimated total bycatch	0		0		0	
	Standard error	0		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.000	0.000	0.004	0.021	0.037	0.007
	Estimated total bycatch	0	0	24	57	162	19
	Standard error	0	0	8	10	18	7
	Coefficient of variation (%)	–	–	35	17	11	36
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

TABLE 4. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *ALBATROSS* BYCATCH FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, FIG. 1) OF NEW ZEALAND.

		FISHING YEAR					
FMA		90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.010	0.000	0.065		0.000	0.000
	Estimated total bycatch	13	0	51		0	0
	Standard error	13	0	54		0	0
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.040	0.000	0.047	0.019	0.000	0.000
	Estimated total bycatch	141	0	44	6	0	0
	Standard error	107	0	11	4	0	0
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.048	0.000		
	Estimated total bycatch			2	0		
	Standard error			1	0		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.003	0.009	0.012	0.007	0.144
	Estimated total bycatch		11	27	7	9	20
	Standard error		10	12	2	4	11
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.000	0.000	0.014	0.000	0.000	0.000
	Estimated total bycatch	0	0	11	0	0	0
	Standard error	0	0	5	0	0	0
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.000		0.000		0.000	
	Estimated total bycatch	0		0		0	
	Standard error	0		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.011	0.001	0.024	0.004	0.002	0.008
	Estimated total bycatch	154	11	135	12	9	20
	Standard error	108	10	57	4	4	11
	Coefficient of variation (%)	70	94	42	36	43	52
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

TABLE 5. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *MOLLYMAWK* BYCATCH FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, FIG. 1) OF NEW ZEALAND.

		FISHING YEAR					
FMA		90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.058	0.043	0.097		0.000	0.000
	Estimated total bycatch	81	58	76		0	0
	Standard error	41	46	60		0	0
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.031	0.005	0.022	0.057	0.000	0.000
	Estimated total bycatch	109	13	21	17	0	0
	Standard error	57	12	6	13	0	0
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.335	1.634		
	Estimated total bycatch			14	20		
	Standard error			9	-		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.019	0.010	0.114	0.101	0.048
	Estimated total bycatch		64	31	60	119	7
	Standard error		37	11	16	38	4
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.000	0.000	0.000	0.004	0.010	0.018
	Estimated total bycatch	0	0	0	3	13	4
	Standard error	0	0	0	2	9	3
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.000		0.000		0.000	
	Estimated total bycatch	0		0		0	
	Standard error	0		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.014	0.014	0.025	0.036	0.030	0.004
	Estimated total bycatch	190	134	141	99	132	11
	Standard error	70	60	62	20	39	5
	Coefficient of variation (%)	37	45	44	21	29	48
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

TABLE 6. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *PETREL* BYCATCH FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, FIG. 1) OF NEW ZEALAND.

		FISHING YEAR					
FMA		90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.019	0.000	0.065		0.119	0.581
	Estimated total bycatch	27	0	51		171	690
	Standard error	17	0	38		75	179
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.040	0.028	0.149	0.532	0.115	0.067
	Estimated total bycatch	141	76	139	155	40	59
	Standard error	49	61	41	59	27	37
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.096	0.000		
	Estimated total bycatch			4	0		
	Standard error			1	0		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.000	0.087	0.022	0.044	0.000
	Estimated total bycatch		0	262	12	52	0
	Standard error		0	192	2	20	0
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.000	0.000	0.000	0.000	0.000	0.000
	Estimated total bycatch	0	0	0	0	0	0
	Standard error	0	0	0	0	0	0
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.044		0.000		0.000	
	Estimated total bycatch	10		0		0	
	Standard error	7		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.013	0.008	0.081	0.060	0.060	0.292
	Estimated total bycatch	178	76	456	167	263	749
	Standard error	52	61	200	59	82	183
	Coefficient of variation (%)	29	80	44	35	31	24
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

TABLE 7. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *OTHER SEABIRD* BYCATCH FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, FIG. 1) OF NEW ZEALAND.

		FISHING YEAR					
FMA		90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.019	0.022	0.000		0.000	0.000
	Estimated total bycatch	27	29	0		0	0
	Standard error	17	31	0		0	0
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.000	0.000	0.019	0.019	0.000	0.033
	Estimated total bycatch	0	0	18	6	0	30
	Standard error	0	0	5	5	0	30
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.000	0.000		
	Estimated total bycatch			0	0		
	Standard error			0	0		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.000	0.067	0.012	0.031	0.000
	Estimated total bycatch		0	200	7	37	0
	Standard error		0	92	2	11	0
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.012	0.000	0.000	0.000	0.000	0.000
	Estimated total bycatch	8	0	0	0	0	0
	Standard error	8	0	0	0	0	0
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.000		0.000		0.000	
	Estimated total bycatch	0		0		0	
	Standard error	0		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.003	0.003	0.039	0.004	0.008	0.012
	Estimated total bycatch	35	29	218	12	37	30
	Standard error	18	31	92	6	11	30
	Coefficient of variation (%)	52	107	42	48	30	102
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

TABLE 8. TOTAL EFFORT IN TERMS OF HOOKS USED (THOUSANDS), OBSERVED NUMBER OF HOOKS (THOUSANDS), AND ESTIMATED *TOTAL SEABIRD* BYCATCH (THE SUM OF THE VALUES IN TABLES 4 TO 7) FOR THE FISHING YEARS 1990/91 TO 1995/96 IN DIFFERENT FISHERIES MANAGEMENT AREAS (FMA, FIG. 1) OF NEW ZEALAND.

FMA		FISHING YEAR					
		90/91	91/92	92/93	93/94	94/95	95/96
AKE	Total hooks (,000)	1387	1341	782	1172	1442	1188
	Observed hooks (,000)	103	47	31	0	34	35
	Estimated bycatch/1000 hooks	0.107	0.064	0.226		0.119	0.581
	Estimated total bycatch	148	86	177		171	690
	Standard error	49	55	89		75	179
CEE	Total hooks (,000)	3553	2739	932	291	347	890
	Observed hooks (,000)	227	215	316	53	44	30
	Estimated bycatch/1000 hooks	0.110	0.033	0.238	0.628	0.114	0.100
	Estimated total bycatch	391	89	222	183	40	89
	Standard error	131	63	43	60	27	47
SEC	Total hooks (,000)	2569	102	41	12	6	3
	Observed hooks (,000)	0	0	21	3	0	0
	Estimated bycatch/1000 hooks			0.478	1.633		
	Estimated total bycatch			20	20		
	Standard error			9	0		
SOE	Total hooks (,000)	64	0	3	15	4	18
	Observed hooks (,000)			No observer cover			
SOU	Total hooks (,000)	4642	3461	2998	529	1182	141
	Observed hooks (,000)	0	324	676	405	545	42
	Estimated bycatch/1000 hooks		0.022	0.173	0.161	0.183	0.191
	Estimated total bycatch		75	520	85	217	27
	Standard error		39	213	16	44	11
SUB	Total hooks (,000)	87	32	22	3	7	0
	Observed hooks (,000)			No observer cover			
CHA	Total hooks (,000)	721	1642	777	642	1292	223
	Observed hooks (,000)	86	191	208	237	293	57
	Estimated bycatch/1000 hooks	0.012	0.000	0.014	0.004	0.010	0.018
	Estimated total bycatch	8	0	11	3	13	4
	Standard error	8	0	5	2	9	3
CEW	Total hooks (,000)	1	3	0	3	10	4
	Observed hooks (,000)			No observer cover			
AKW	Total hooks (,000)	229	4	40	72	49	78
	Observed hooks (,000)	0	4	0	45	0	0
	Estimated bycatch/1000 hooks		0.000		0.000		
	Estimated total bycatch		0		0		
	Standard error		0		0		
KER	Total hooks (,000)	234	53	3	36	38	22
	Observed hooks (,000)	23	0	3	0	18	0
	Estimated bycatch/1000 hooks	0.044		0.000		0.000	
	Estimated total bycatch	10		0		0	
	Standard error	7		0		0	
Total	Total hooks (,000)	13487	9377	5598	2775	4377	2567
	Observed hooks (,000)	439	781	1255	742	933	163
	Estimated bycatch/1000 hooks	0.041	0.027	0.170	0.105	0.101	0.315
	Estimated total bycatch	558	250	949	290	441	810
	Standard error	140	92	235	63	91	186
	Coefficient of variation (%)	25	37	25	22	21	23
	Observer cover (% of hooks)	3.3	8.3	22.4	26.8	21.3	6.3

For *seabirds* the estimates are presented separately for great albatrosses (referred to simply as albatrosses for the remainder of this report), the smaller mollymawks, petrels, other seabirds species, and total birds (Tables 4–8). The species involved are shown in Table 1. Estimates of the total bycatch for all bird species range from 250 in 1991/92 to 949 in 1992/93 (Table 8).

There has been no observer cover in SOE, SUB and CEW, and the missing cover in some FMAs in some years means that the estimated bycatch numbers will tend to be underestimates of the true numbers. For example, there were no observers in AKE for fishing year 1993/94. Therefore there is no estimated bycatch of seabirds even though the results in other fishing years suggest that the actual bycatch could have been quite high.

4. Factors affecting bycatch

Our analysis of the factors affecting the bycatch of fur seals and seabirds is based on the information from the 502 sample units that have been defined in Section 3, and used to estimate the amount of bycatch. Five dependent variables were analysed: the number of fur seals caught, the number of albatrosses caught, the number of mollymawks caught, the number of petrels caught, and the number of other seabirds caught on a sample unit, where the composition of the bird categories is as defined in Table 1.

The variables that were considered as being possibly related to bycatch were as follows:

Sets: the number of line sets in the sample unit;

VSize: an index of the size of the vessel, derived from a principal components analysis, as described by Manly et al. (2002);

Nationality: the nationality of the vessel, treated as a factor with the levels (1) for Japan, and (2) for New Zealand;

Status: the ownership status of the vessel, treated as a factor with the levels (1) for chartered, (2) for New Zealand, and (3) for foreign owned;

Target: the target species, treated as a factor with the levels (1) for bigeye tuna (*Thunnus obesus*), and (2) for southern bluefin tuna (*Thunnus maccoyii*);

FMA: the Fisheries Management Area (Fig. 1), treated as a factor and coded (1) for AKE, (2) for CEE, (3) for SEC, (4) for SOE, (5) for SOU, (6) for SUB, (7) for CHA, (8) for CEW, (9) for AKW, and (10) for KER;

Phase: the average moon phase for the sample unit, calculated using Dings' (1999) Ephemeris Tool program;

Year: the fishing year, treated as a factor with levels from (1) for 1990/91 to (6) for 1995/96;

Month: the month in the fishing year for the first set in a sample unit, treated as a factor with levels from (1) for October to (12) for September;

SCode: a code for the time when fishing began each day, with the levels (1) 9 pm to 3 am, (2) for 3 am to 9 am, (3) for 9 am to 3 pm, and (4) for 3 pm to 9 pm;

SetT: the total time for all sets in hours;

HaulT: the total time for all hauls in hours;

Hooks: the total number of hooks used on all sets in thousands;

Length: the total length of the line used on all sets;

Tori: the fraction of sets for which a tori pole was used;

Ccamlr: the fraction of sets for which a tori line with CCAMLR specifications was used;

Thrower:	the fraction of sets for which a mechanical bait thrower was used; and
Wind:	the average Beaufort wind force at the start of setting.

These variables were not all used for model fitting, or were modified before use. For example, Sets, SetT, HaulT, Hooks and Length are all measures of fishing effort that are highly related. It is therefore not appropriate to use all of these together in a model.

4.1 INITIAL DATA EXPLORATION

For an initial exploration of the data the dependent variables were plotted against all of the variables just defined, as shown in Fig. 2. For simplicity these plots have no horizontal scale markings. However, they can be interpreted easily enough because for variables the low values are on the left and the high

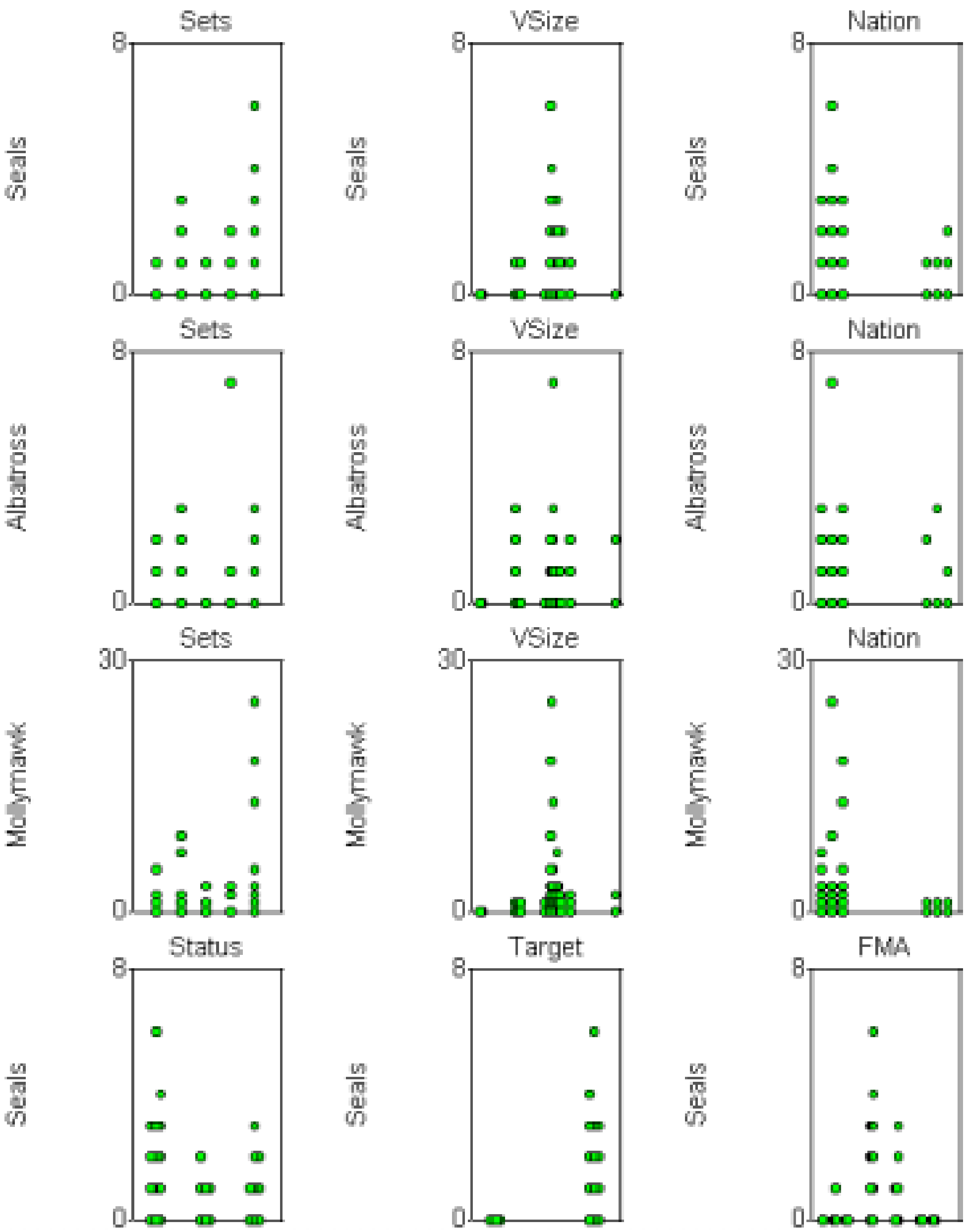
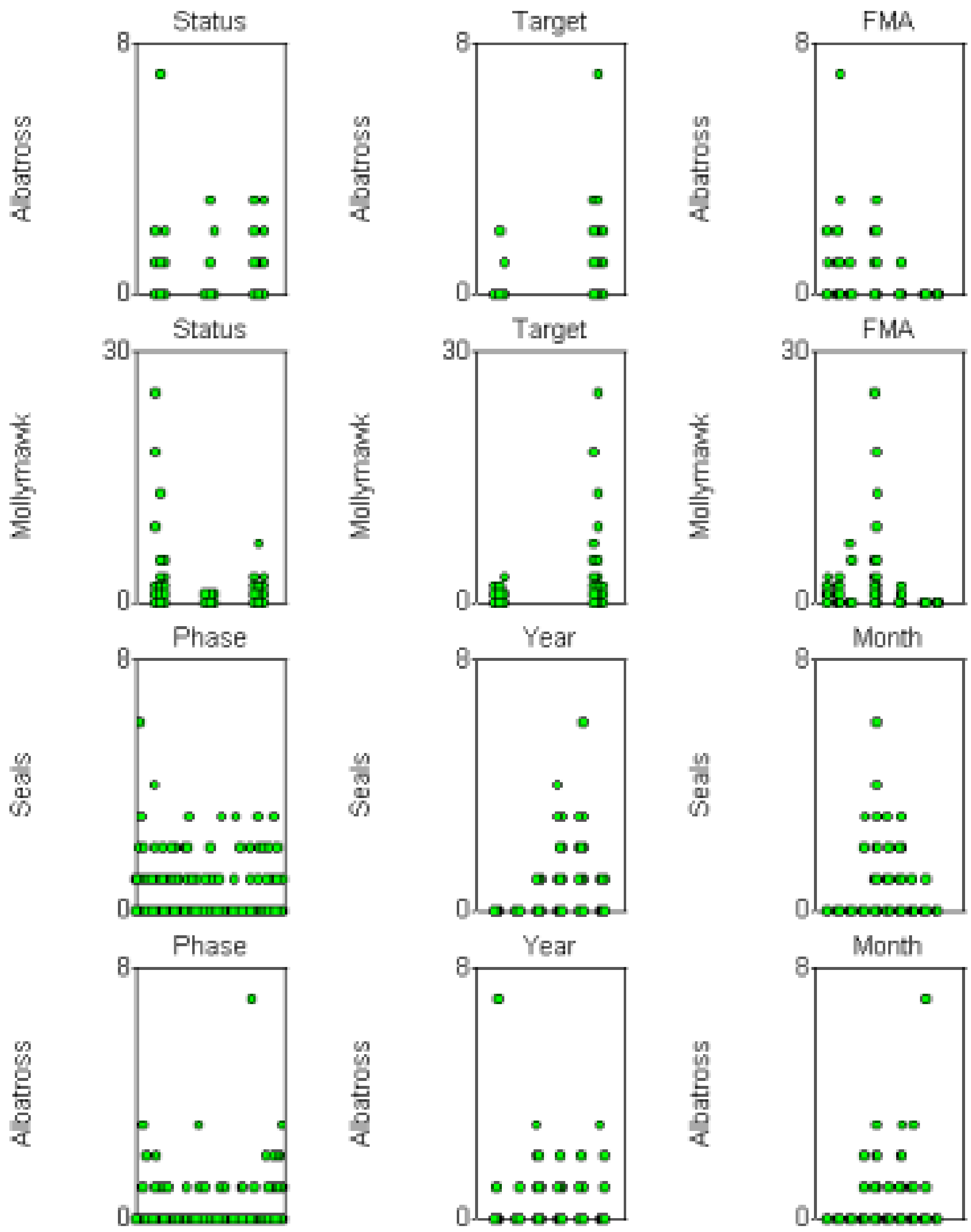


Figure 2. Plots of the bycatch of fur seals, albatross, mollymawks, petrels and other birds in sample units, against the characteristics of the units. See the main text for definitions of variables. Points have been jittered for cases where the horizontal variable has few possible values to avoid many points being hidden. The scales are not provided for the horizontal variables but in all cases low values are on the left and high values on the right.

values on the right, and factor levels also increase from left to right. From the plots the following points can be noted:

- For *fur seals* high bycatch for individual sample units has occurred with sample units containing five sets, intermediate-sized vessels, Japanese vessels, chartered vessels, targeting southern bluefin tuna, in Fisheries Management Areas SOU and CHA, at all moon phases, in fishing years 1993/94 and 1994/95, from January to April, for sets starting in the middle of the night, with high set and haul times, many hooks, a moderately long total line length, with a tori pole used, with a CCAMLR tori line, without a bait thrower, and with moderate wind speeds.
- For *albatross*, high bycatch with individual sample units has occurred with two or more sets, intermediate-sized vessels, Japanese vessels, chartered, domestic and foreign vessels, targeting southern bluefin tuna, in Fisheries Management Areas CEE and SOU, at all moon phases, in fishing years 1990/91, 1992/93 and 1995/96, from February to June, for sets starting in the middle of

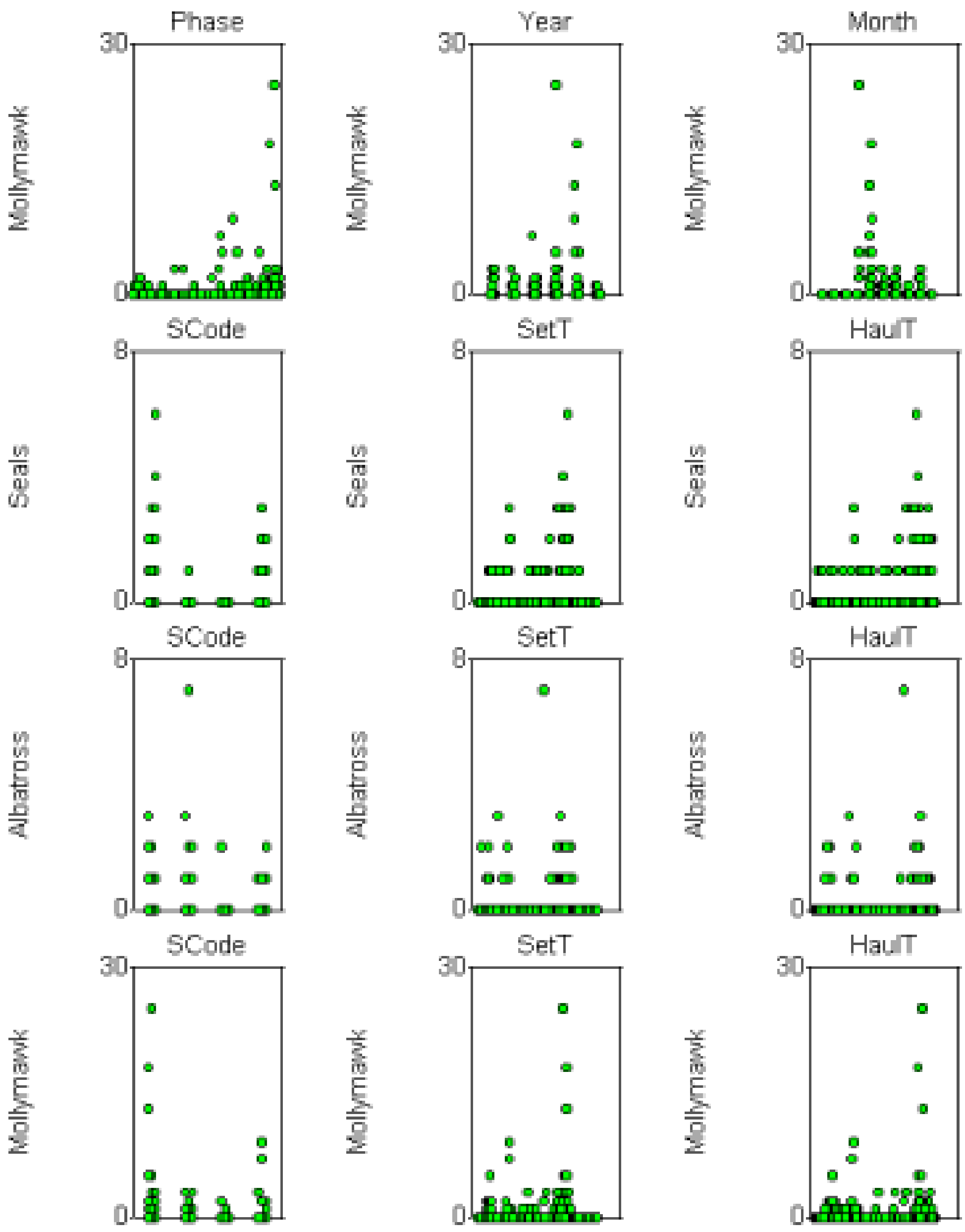
Figure 2. *continued*



the night, with all set and haul times, with all hook numbers, with short to medium line lengths, with the use of a tori pole, without a CCAML tori line, without a bait thrower, and with moderate to high wind speeds.

- For *mollymawks*, high bycatch with individual sample units has occurred with five sets, intermediate sized vessels, Japanese vessels, chartered vessels, targeting southern bluefin tuna, in Fisheries Management Area SOU, close to a full moon, in 1993/94 and 1994/95, in January and February, with sets starting in the middle of the night, with long set and haul times, with large numbers of hooks, with a long line, with the use of a tori pole, with the use of a CCAMLR tori line, without a bait thrower, and with moderately high wind speeds.
- For *petrels*, high bycatch with individual sample units has occurred with five sets, large vessels, Japanese vessels, chartered and foreign vessels, targeting southern bluefin tuna, in Fisheries Management Areas CEE and SOU, near to a full moon, in 1992/93, 1993/94 and 1994/95, from February to May, with sets starting from 3 pm to 3 am, with moderately long set times and long haul times,

Figure 2. *continued*

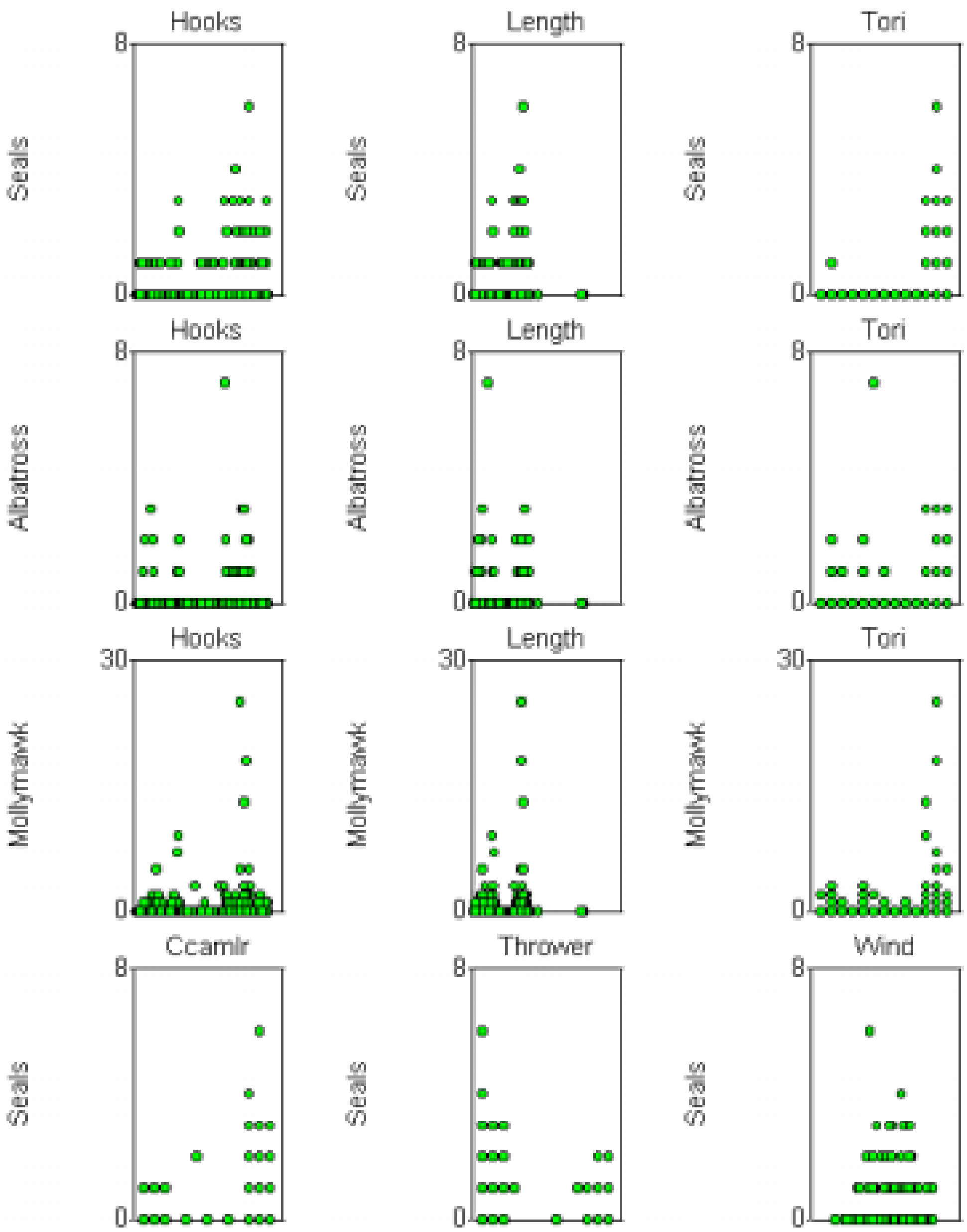


with many hooks, a moderately long line, with or without a tori pole, with and without a CCAMLR tori line, without a bait thrower, and with moderate to high wind speeds.

- For *other seabirds*, high bycatch with individual sample units has occurred with sample units consisting of three sets, large vessels, Japanese vessels, domestic and foreign vessels, targeting southern bluefin tuna, in Fisheries Management Area SOU, at close to a full moon, in 1992/93, in February, with sets starting in the night, with moderate set and haul times, with moderate numbers of hooks, with a moderately short line length, using a tori pole, without a CCAMLR tori line, without a bait thrower, and with low wind speeds.

These results should be treated with caution because the incidents of high bycatch may not be a good indication of general trends, and because of relationships between the variables being considered to account for bycatch. They are, however, a useful starting point for a fuller analysis of the data.

Figure 2. *continued*



4.2 LOG-LINEAR MODEL FITTING

Log-linear modelling was used in an attempt to better understand the relationship between the bycatch numbers and the other variables. Thus if X_1 to X_p represent variables describing the characteristics of a sample unit, then it was assumed that the expected amount of bycatch of a certain type is given by an equation of the form

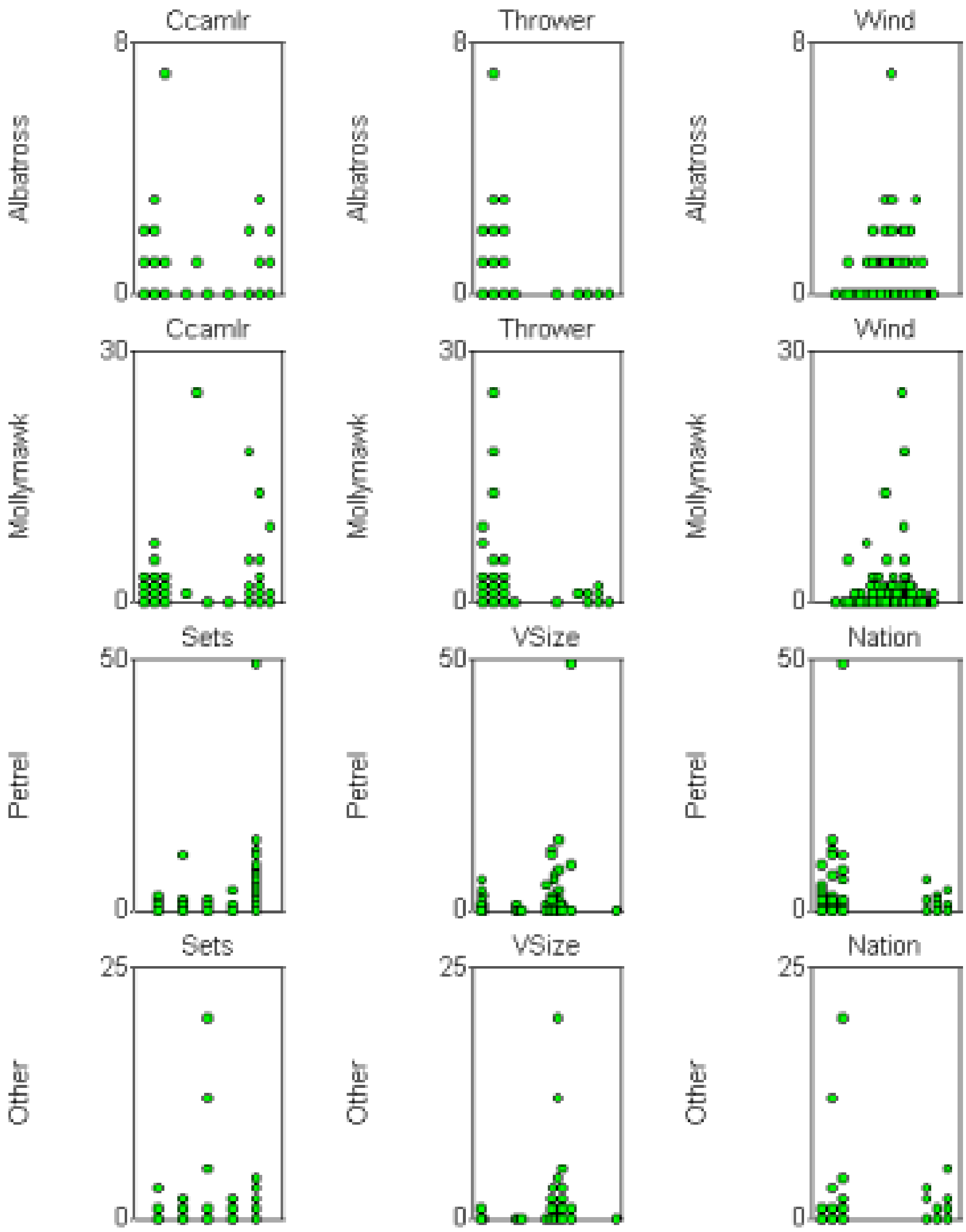
$$\mu = \text{Hooks}.\exp(\beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p) \quad (4)$$

with the observed bycatch having a Poisson distribution. The expected bycatch is then proportional to the number of hooks (in thousands), which can be allowed for by using an offset in the model, i.e. writing equation 4 as

$$\mu = \exp\{\log_c(\text{Hooks}) + \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p\} \quad (5)$$

with $\log_c$(Hooks) as a known part of the exponential argument called an offset. Model fitting was done using the SAS GENMOD procedure (SAS Institute 1999)

Figure 2. *continued*



and the generalized linear model facility in GENSTAT (Lawes Agricultural Trust 1999). Both of these programs allow for variables and factors in models.

The procedure used for fitting the model was the same for each of the dependent variables, and proceeded as follows:

a. Some of the variables described above were modified before use. In particular, the Month variable was reduced to four levels by making up a new variable Quarters, with levels (1) October to December, (2) January to March, (3), April to June, and (4) July to September, and the effort variables HaulT and Length were transformed to logarithms to produce LogHT = $\log_e$(HaulT), and LogLth = $\log_e$(Length). The logarithmic transformations were made on the assumption that any effects of the effort variables would be multiplicative on the expected bycatch, thus requiring the logarithm of effort in the linear part of the log-linear model.

b. For each category of bycatch, sample units were excluded from the fitting process if they were in FMAs or years where no bycatch had ever been recorded. The estimated bycatch for these cases was then just set at zero.

Figure 2. *continued*

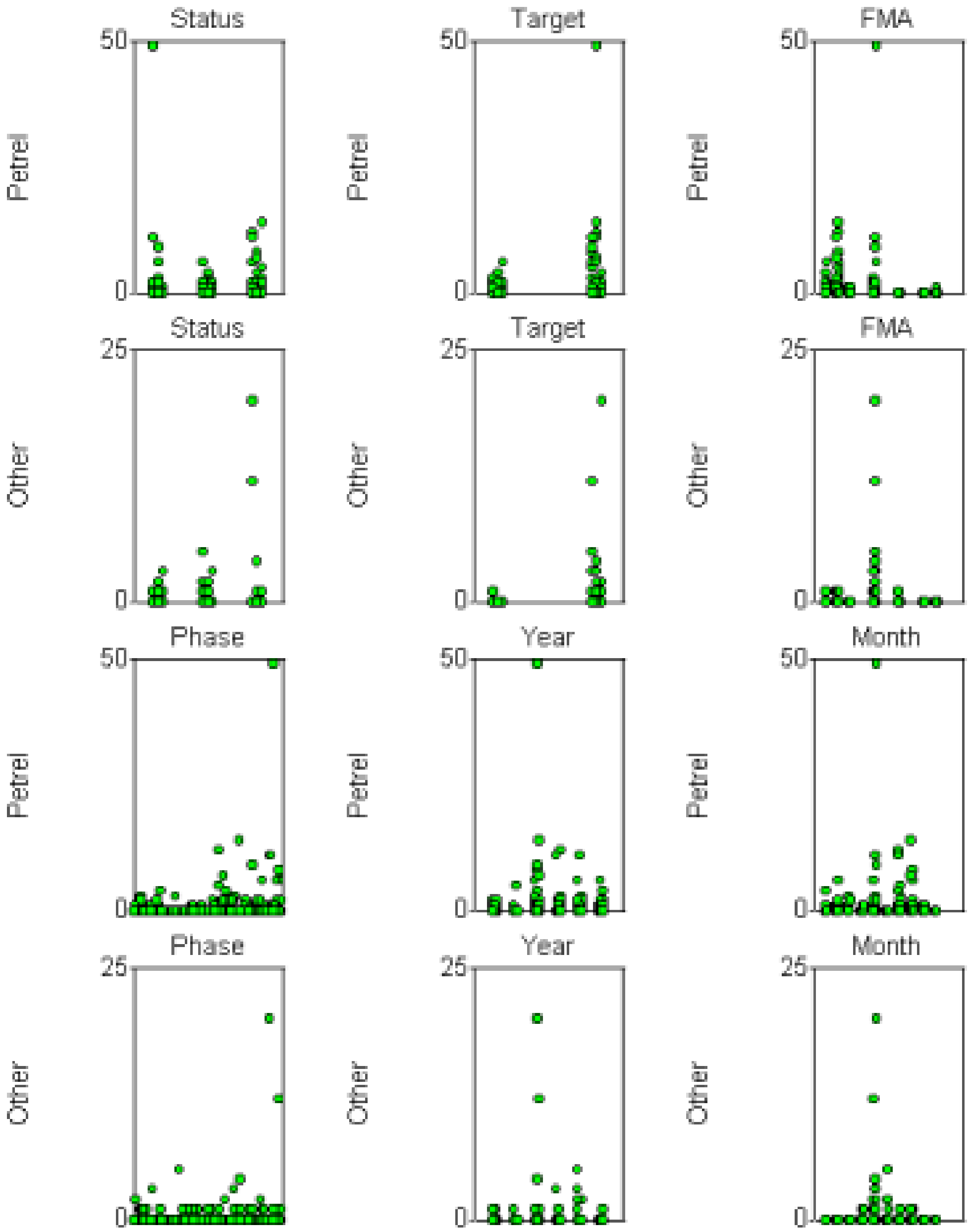
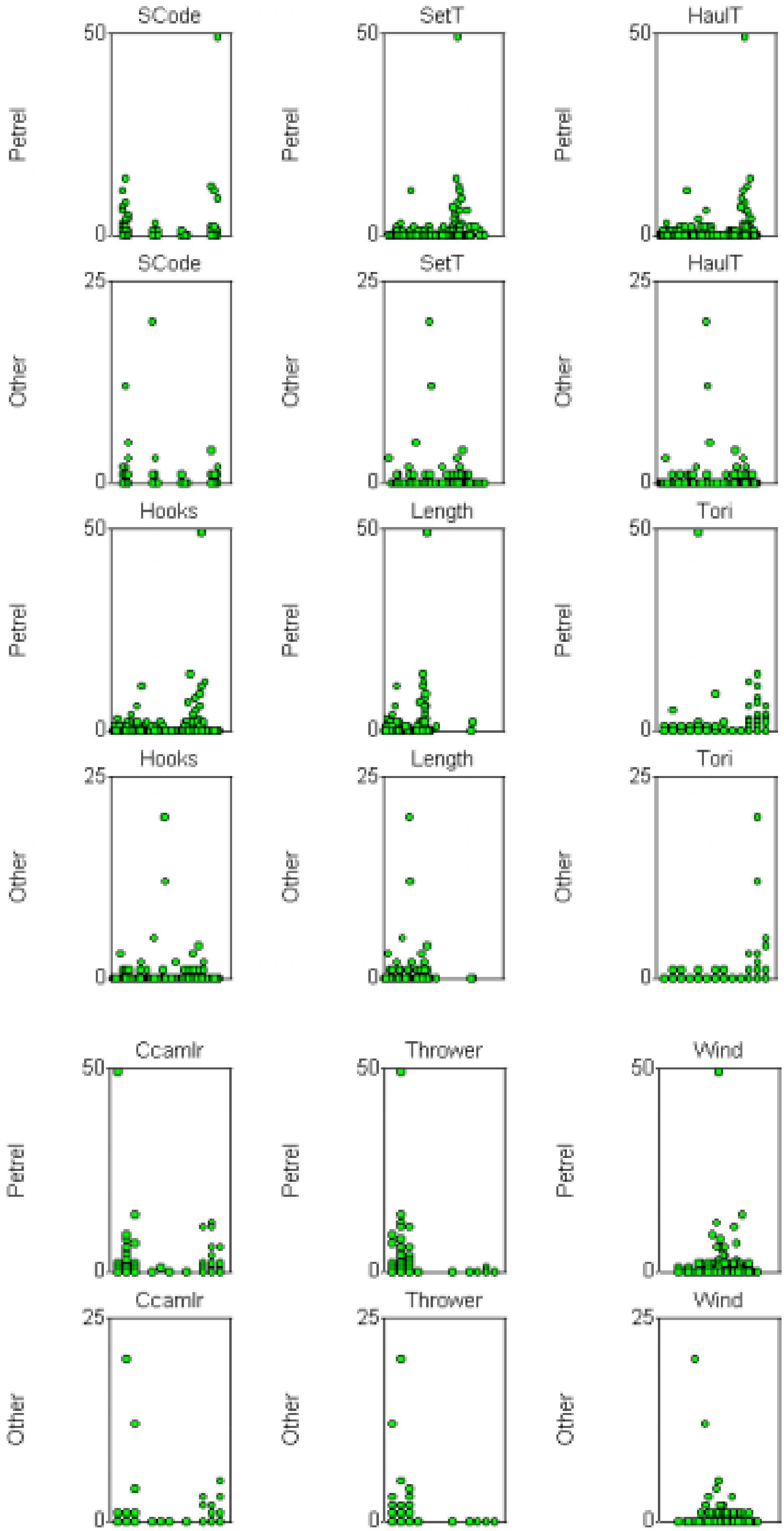


Figure 2. *continued*



c. A log-linear model was fitted with $\log_e$(Hooks) as an offset and an allowance for the effects of the factors FMA and Year, plus their interaction. This model is denoted as FMA + Year + FMA.Year. A check was made that each of the terms FMA, Year and FMA.Year is significantly related to the bycatch variable, which was always the case.

d. The variables and factors VSize, Nation, Status Target, Phase, Year, Quarter, SCode, LogST, LogHT, LogLth, Tori, Ccamlr, Thrower and Wind were added into the model one at a time, with the variable added being the one that reduced the mean deviance (minus twice the maximised log-likelihood, a measure of goodness of fit) as much as possible. However, this process was stopped when none of the unentered terms produced a significant reduction in the deviance, using a 5% level of significance.

e. The final model obtained at the last step was accepted, and expected bycatch levels calculated using this model. Standardised deviance residuals were also computed to check the fit of the model, as recommended by McCullagh & Nelder (1989).

Tables 9–13 show a summary of the final models that were determined by this procedure. Apart from the effects of the FMA and year, the variables and factors included in the models (in the order of their entry in the selection procedure) are: Thrower and Quarter for fur seal bycatch; SCode, Status, Phase, Thrower, LogHT, LogST and VSize for albatross bycatch; Phase, Quarter, Status, Thrower, Target, Ccamlr and Tori for mollymawks; Phase, Status, SCode, Thrower, Quarter, Wind, LogST and VSize for petrels; and Wind, Status, Phase and Thrower for other seabirds.

There are two important points to note about the fitted models. First, zero bycatch for some factor combinations and confounding between the terms that are included in models means that some of the estimates and standard errors that are shown in Tables 9–13 are very large, with many examples of situations where the estimated coefficients are not significantly different from zero. Nevertheless, the fitting process ensured that all terms included in the final models are significantly related to bycatch.

Second, the correlation between terms means that the individual estimates of parameters should be treated with caution. For example, the model for albatross bycatch has an estimated coefficient of –3.26 for LogST (the logarithm of the total set time), implying that the expected bycatch decreases with increasing set times. This seems unlikely. However, LogHT (the logarithm of the total haul time) is also in the model, where this is highly related to LogST. It is well known that in situations like this the estimated coefficients may have the wrong sign while still giving reasonable estimates for expected values of the dependent variable.

Because of the difficulty in interpreting estimated coefficients, it is better to interpret the fitted models in terms of the expected bycatch that they produce in different situations. The expected bycatch per 1000 hooks is shown in Fig. 3, plotted against all of the variables found to be significant in at least one of the fitted log-linear models. Inspection of this figure shows that apart from the FMA and year, which are obviously important, the following can be said about the other variables and factors included in the final models:

- For fur seals the expected bycatch is sometimes high for quarters 2 and 3 (January–March and April–June), is low at other times of the year, and is higher without the bait thrower than it is with the bait thrower.
- For albatross the expected bycatch is always low for SCode 4 (sets starting between 3 p.m. and 9 p.m.), is always low with Status 3 (foreign vessels), has no very clear relationship with the phases of the moon, occurs only in the absence of a bait thrower, has no clear relationship with the logarithms of set times and haul times, and is only high for small and medium vessel sizes.
- For mollymawks the expected bycatch is only high close to a full moon, tends to be high in quarter 2 (January–March), and is absent in quarter 1 (October–

TABLE 9. SUMMARY OF THE CHOSEN LOG-LINEAR MODEL FOR DESCRIBING THE BYCATCH OF *FUR SEALS*, SHOWING THE PARAMETER ESTIMATES AND A SUMMARY ANALYSIS OF DEVIANCE TABLE.

		ESTIMATES OF MODEL PARAMETERS		
VARIABLE[a]	ESTIMATE	STD ERROR[b]	RATIO	P-VALUE[c]
Constant	-3.70	0.88		
FMA 2	-7.90	25.60	-0.31	0.757
FMA 5	-1.17	1.12	-1.04	0.297
Year 3	-1.18	0.71	-1.66	0.097
Year 4	-0.15	0.62	-0.23	0.815
Year 5	0.02	0.59	0.04	0.970
FMA 2 . Year 3	0.10	28.90	0.00	0.998
FMA 2 . Year 4	6.70	25.60	0.26	0.794
FMA 3 . Year 5	1.20	40.70	0.03	0.976
FMA 5 . Year 3	-1.02	1.42	-0.72	0.474
FMA 5 . Year 4	1.09	1.20	0.91	0.364
FMA 5 . Year 5	1.62	1.17	1.39	0.166
Thrower	-1.59	0.37	-4.35	0.000
Quarter 2	2.09	0.90	2.32	0.021
Quarter 3	1.13	0.75	1.51	0.131

			SUMMARY ANALYSIS OF DEVIANCE		
MODEL TERM	DEVIANCE[d]	D.F.	CHANGE[e]	D.F.	P-VALUE
Constant	325.1	332			
FMA+Year+FMA.Year	219.2	321	105.9	11	0.000
+ Other variables[f]	183.8	318	35.4	3	0.000

[a] Some of the variables (e.g. FMA 2) have been made up by the computer program to allow for factor effects. Combinations are missing if they cannot be estimated because of lack of data, or because they have to be set to zero to estimate the model.

[b] Standard errors are as shown in the computer output.

[c] P-values are significance levels obtained by comparing the ratio, Estimate/(Standard error), with the standard normal distribution.

[d] A goodness of fit statistic equal to twice the maximised log-likelihood.

[e] The reduction in deviance obtained by adding the terms in the line below to the model. This can be compared with the chi-squared distribution with the stated degrees of freedom (d.f.) to assess the significance of the added terms (McCullagh & Nelder 1989). The P-value shown is the significance level obtained.

[f] The other variables are those in addition to those for FMA, Year and FMA.Year.

TABLE 10. SUMMARY OF THE CHOSEN LOG-LINEAR MODEL FOR DESCRIBING THE BYCATCH OF *ALBATROSSES*, SHOWING THE PARAMETER ESTIMATES AND A SUMMARY ANALYSIS OF DEVIANCE TABLE. FOR NOTES, SEE TABLE 9.

	ESTIMATES OF MODEL PARAMETERS			
VARIABLE[a]	ESTIMATE	STD. ERROR[b]	RATIO	P-VALUE[c]
Constant	18.69	6.45		
FMA 2	2.78	1.08	2.57	0.010
FMA 3	-8.62	373.75	-0.02	0.982
FMA 5	8.76	77.42	0.11	0.910
FMA 7	-9.33	126.89	-0.07	0.941
Year 2	-4.45	65.70	-0.07	0.946
Year 3	0.52	2.78	0.19	0.852
Year 4	1.51	141.20	0.01	0.991
Year 5	2.04	92.37	0.02	0.982
Year 6	7.27	90.04	0.08	0.936
FMA 2 . Year 2	-6.08	106.98	-0.06	0.955
FMA 2 . Year 3	0.90	2.85	0.32	0.752
FMA 2 . Year 4	-0.83	141.20	-0.01	0.995
FMA 2 . Year 5	-6.43	112.53	-0.06	0.954
FMA 2 . Year 6	-4.71	125.97	-0.04	0.970
FMA 3 . Year 3	11.91	373.75	0.03	0.975
FMA 5 . Year 2	-4.14	101.55	-0.04	0.967
FMA 5 . Year 3	-8.63	77.46	-0.11	0.911
FMA 5 . Year 4	-8.46	161.03	-0.05	0.958
FMA 5 . Year 5	-9.00	120.52	-0.07	0.940
FMA 7 . Year 2	3.43	158.67	0.02	0.983
FMA 7 . Year 3	9.75	126.91	0.08	0.939
FMA 7 . Year 5	-0.39	163.2	0.00	0.998
FMA 7 . Year 6	8.22	160.89	0.05	0.959
SCode 2	1.92	0.48	4.00	0.000
SCode 3	4.48	1.12	3.98	0.000
SCode 4	0.63	0.54	1.15	0.248
Status 2	-9.71	45.92	-0.21	0.832
Status 3	-1.54	0.53	-2.91	0.004
Phase	1.14	0.48	2.39	0.017
Thrower	-15.35	58.53	-0.26	0.793
LogHT	3.92	1.57	2.48	0.013
LogST	-3.26	1.56	-2.09	0.037
VSize	1.86	1.16	1.59	0.111

	SUMMARY ANALYSIS OF DEVIANCE				
MODEL TERM	DEVIANCE[d]	D.F.	CHANGE[e]	D.F.	P-VALUE
Constant	295.6	482			
FMA+Year+FMA.Year	208.9	459	86.7	23	0.000
+ Other variables	124.8	449	84.1	10	0.000

December), tends to be high for Status 1 (chartered vessels), is high only in the absence of a bait thrower, is only high for target 2 (southern bluefin tuna), tends to be high without a CCAMLR tori line, and tends to be high with a tori pole.

TABLE 11. SUMMARY OF THE CHOSEN LOG-LINEAR MODEL FOR DESCRIBING THE BYCATCH OF *MOLLYMAWKS*, SHOWING THE PARAMETER ESTIMATES AND A SUMMARY ANALYSIS OF DEVIANCE TABLE. FOR NOTES, SEE TABLE 9.

	ESTIMATES OF MODEL PARAMETERS			
VARIABLE[a]	ESTIMATE	STD. ERROR[b]	RATIO	P-VALUE[c]
Constant	-3.17	56.32		
FMA 2	8.14	16.78	0.49	0.628
FMA 3	0.43	43.87	0.01	0.992
FMA 5	17.42	30.06	0.58	0.562
FMA 7	-2.10	43.86	-0.05	0.962
Year 2	2.61	1.31	1.99	0.047
Year 3	-0.28	0.83	-0.33	0.738
Year 4	8.33	40.54	0.21	0.837
Year 5	-8.47	38.73	-0.22	0.827
Year 6	-7.87	24.97	-0.32	0.753
FMA 2 . Year 2	-4.06	1.69	-2.40	0.016
FMA 2 . Year 3	-0.04	0.99	-0.04	0.967
FMA 2 . Year 4	-6.92	40.54	-0.17	0.865
FMA 2 . Year 5	-7.99	47.35	-0.17	0.866
FMA 2 . Year 6	-6.51	41.93	-0.16	0.877
FMA 3 . Year 3	10.03	40.55	0.25	0.805
FMA 5 . Year 2	-13.04	24.98	-0.52	0.602
FMA 5 . Year 3	-11.31	24.96	-0.45	0.651
FMA 5 . Year 4	-17.31	47.60	-0.36	0.716
FMA 5 . Year 5	0.42	44.75	0.01	0.992
FMA 7 . Year 2	-3.23	46.99	-0.07	0.945
FMA 7 . Year 3	-0.39	46.68	-0.01	0.993
FMA 7 . Year 5	17.90	56.06	0.32	0.750
FMA 7 . Year 6	19.13	47.59	0.40	0.688
Phase	3.08	0.36	8.61	0.000
Quarter 2	0.50	56.31	0.01	0.993
Quarter 3	-0.71	56.31	-0.01	0.990
Quarter 4	-1.62	56.31	-0.03	0.977
Status 2	-2.23	1.01	-2.21	0.027
Status 3	-1.52	0.30	-5.02	0.000
Thrower	-1.31	0.39	-3.34	0.000
Target 2	-8.77	16.78	-0.52	0.601
Ccamlr	-1.38	0.47	-2.93	0.003
Tori	1.02	0.40	2.58	0.010

	SUMMARY ANALYSIS OF DEVIANCE				
MODEL TERM	DEVIANCE[d]	D.F.	CHANGE[e]	D.F.	P-VALUE
Constant	821.9	482			
FMA+Year+FMA.Year	589.5	459	232.4	23	0.000
+ Other variables	302.3	449	287.2	10	0.000

- For petrels the expected bycatch tends to be high near a full moon, has no clear relationship with the vessel status (chartered, domestic or foreign), tends to be high for SCodes 1 and 4 (sets starting from 3 pm to 3 am), is high only in the absence of a bait thrower, tends to be highest in quarters 2 and 3

TABLE 12. SUMMARY OF THE CHOSEN LOG-LINEAR MODEL FOR DESCRIBING THE BYCATCH OF *PETRELS*, SHOWING THE PARAMETER ESTIMATES AND A SUMMARY ANALYSIS OF DEVIANCE TABLE. FOR NOTES, SEE TABLE 9.

	ESTIMATES OF MODEL PARAMETERS			
VARIABLE[a]	ESTIMATE	STD. ERROR[b]	RATIO	P-VALUE[c]
Constant	-13.17	2.10		
FMA 2	2.65	0.87	3.04	0.002
FMA 3	-8.77	134.65	-0.06	0.949
FMA 5	-9.77	23.72	-0.41	0.680
FMA 7	-9.13	39.09	-0.23	0.815
Year 2	-4.46	28.93	-0.15	0.877
Year 3	3.37	1.15	2.93	0.003
Year 4	2.19	43.86	0.05	0.960
Year 5	4.96	1.73	2.87	0.004
Year 6	7.98	1.59	5.02	0.000
FMA 2 . Year 2	5.70	28.93	0.20	0.844
FMA 2 . Year 3	-1.11	1.20	-0.93	0.353
FMA 2 . Year 4	1.17	43.86	0.03	0.979
FMA 2 . Year 5	-0.81	1.39	-0.59	0.558
FMA 2 . Year 6	-3.96	1.20	-3.30	0.000
FMA 3 . Year 3	10.01	134.65	0.07	0.941
FMA 5 . Year 2	7.77	42.24	0.18	0.854
FMA 5 . Year 3	8.26	23.74	0.35	0.728
FMA 5 . Year 4	7.97	49.87	0.16	0.873
FMA 5 . Year 5	6.75	23.77	0.28	0.776
FMA 7 . Year 2	5.96	54.67	0.11	0.913
FMA 7 . Year 3	-2.31	45.32	-0.05	0.959
FMA 7 . Year 5	-3.59	41.47	-0.09	0.931
FMA 7 . Year 6	-1.36	44.18	-0.03	0.975
Phase	2.09	0.30	7.08	0.000
Status 2	-3.11	1.35	-2.31	0.021
Status 3	-2.79	0.45	-6.17	0.000
SCode 2	-0.78	0.48	-1.62	0.104
SCode 3	1.98	1.14	1.74	0.082
SCode 4	1.61	0.23	7.01	0.000
Thrower	-5.82	1.61	-3.60	0.000
Quarter 2	0.34	0.64	0.53	0.593
Quarter 3	-1.34	0.73	-1.85	0.065
Quarter 4	-0.42	0.78	-0.54	0.586
Wind	0.34	0.09	3.96	0.000
LogST	0.85	0.21	3.99	0.000
VSize	0.79	0.28	2.78	0.005

	SUMMARY ANALYSIS OF DEVIANCE				
MODEL TERM	DEVIANCE[d]	D.F.	CHANGE[e]	D.F.	P-VALUE
Constant	1150.9	482			
FMA+Year+FMA.Year	784.2	459	366.7	23	0.000
+ Other variables	411.2	446	373.0	13	0.000

TABLE 13. SUMMARY OF THE CHOSEN LOG-LINEAR MODEL FOR DESCRIBING THE BYCATCH OF *OTHER SEABIRDS*, SHOWING THE PARAMETER ESTIMATES AND A SUMMARY ANALYSIS OF DEVIANCE TABLE. FOR NOTES, SEE TABLE 9.

ESTIMATES OF MODEL PARAMETERS				
VARIABLE[a]	ESTIMATE	STD. ERROR[b]	RATIO	P-VALUE[c]
Constant	-3.05	0.82		
FMA 2	-11.13	69.13	-0.16	0.872
FMA 5	0.50	96.17	0.01	0.996
FMA 7	-0.04	1.23	-0.03	0.973
Year 2	-1.36	1.30	-1.04	0.296
Year 3	-10.68	166.57	-0.06	0.949
Year 4	-9.28	58.59	-0.16	0.874
Year 5	-12.81	83.55	-0.15	0.878
Year 6	-11.97	67.32	-0.18	0.859
FMA 2 . Year 2	1.04	106.20	0.01	0.992
FMA 2 . Year 3	21.41	180.34	0.12	0.906
FMA 2 . Year 4	20.21	90.62	0.22	0.824
FMA 2 . Year 5	12.27	126.18	0.10	0.923
FMA 2 . Year 6	21.02	96.49	0.22	0.828
FMA 5 . Year 2	-11.35	113.52	-0.10	0.920
FMA 5 . Year 3	11.35	192.33	0.06	0.953
FMA 5 . Year 4	9.39	112.61	0.08	0.934
FMA 5 . Year 5	12.49	127.39	0.10	0.922
FMA 7 . Year 2	-9.57	64.91	-0.15	0.883
FMA 7 . Year 3	0.77	178.38	0.00	0.997
FMA 7 . Year 5	3.31	91.54	0.04	0.971
FMA 7 . Year 6	-0.50	84.87	-0.01	0.995
Wind	-0.77	0.10	-7.88	0.000
Status 2	2.97	0.60	4.95	0.000
Status 3	1.07	0.34	3.15	0.002
Phase	2.34	0.40	5.83	0.000
Thrower	-16.32	52.61	-0.31	0.756

SUMMARY ANALYSIS OF DEVIANCE					
MODEL TERM	DEVIANCE[d]	D.F.	CHANGE[e]	D.F.	P-VALUE
Constant	507.1	477			
FMA+Year+FMA.Year	379.8	456	127.3	21	0.000
+ Other variables	219.3	451	160.5	5	0.000

(January–March and April–June), is highest with a moderate amount of wind, and has no clear relationship with the logarithm of the set time or with the vessel size.

- For other seabirds the expected bycatch tends to be high with low amounts of wind, tends to be low with chartered vessels, tends to be high near a full moon, and only occurs in the absence of a bait thrower.

Figure 4 shows the locations of the sample units, with an indication of whether the expected bycatch of fur seals per 1000 hooks is zero, less than 0.08 (some), or 0.08 or more (high). High expected bycatch only occurs off the west coast of the south island of New Zealand.

Figure 5 is similar, but is for the total of all seabird bycatch. In this case the indicated levels of expected bycatch per 1000 hooks is zero, less than 0.4 (some), or more than 0.4 (high). High expected bycatch occurs in the southwest, and to the east generally.

4.3 CHECKING THE ASSUMPTIONS OF THE MODELS

To assess the general fit of the log-linear models to the data, the standardised deviance residuals were plotted against the same variables as used for the expected bycatch. The results obtained are shown in Fig. 5. Because of the nature of the data, with many instances of zero bycatch, it is unreasonable to expect these residuals to be normally distributed. Nevertheless, for a perfect model it is anticipated that most of the residuals should be within the range

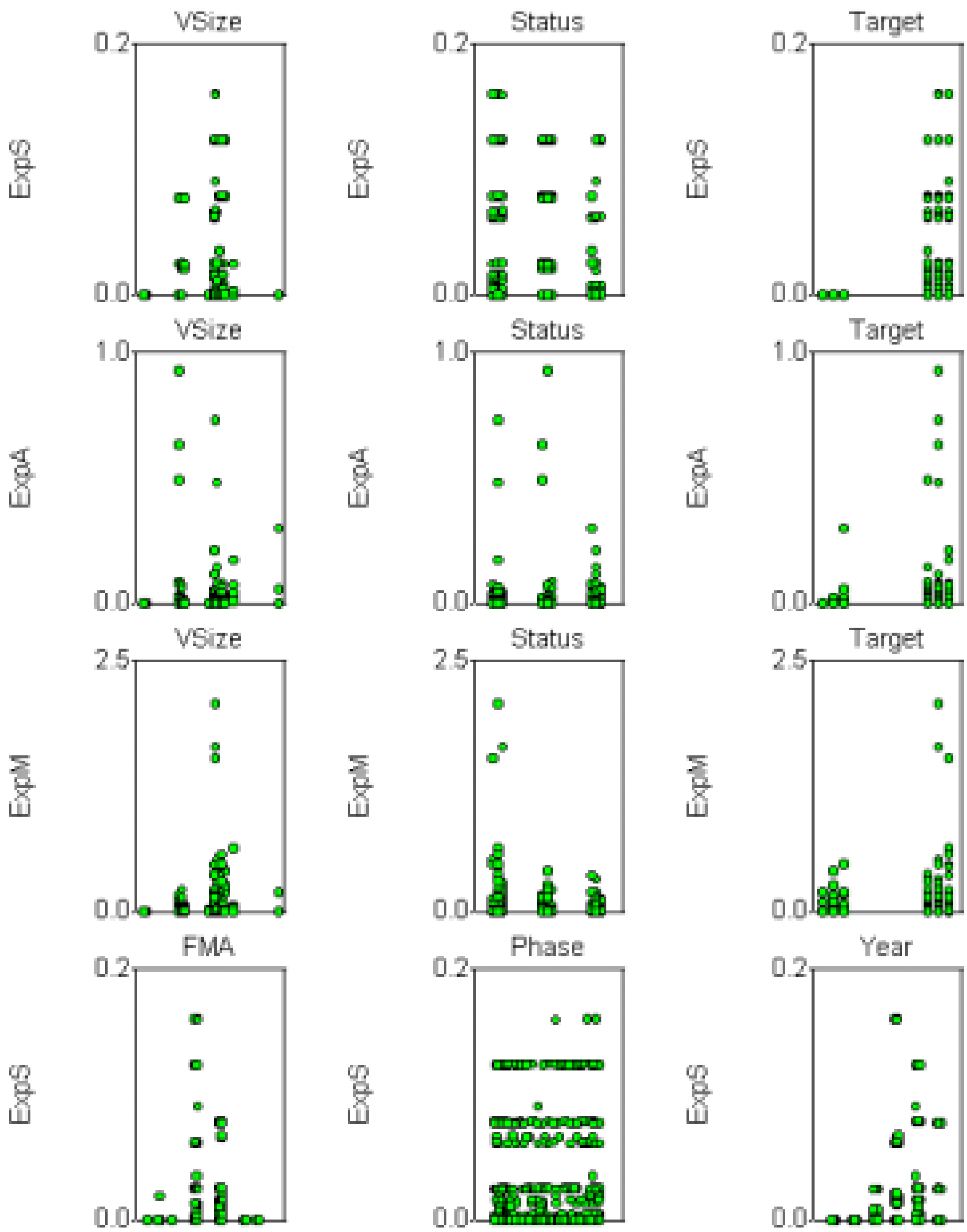


Figure 3. The expected bycatch per 1000 hooks according to fitted log-linear models (ExpS for fur seals, ExpA for albatross, ExpM for mollymawks, ExpP for petrels, and ExpO for other seabirds). Points have been jittered for cases where the horizontal variable has few possible values to avoid many points being hidden. The scales are not provided for the horizontal variables but in all cases low values are on the left and high values on the right.

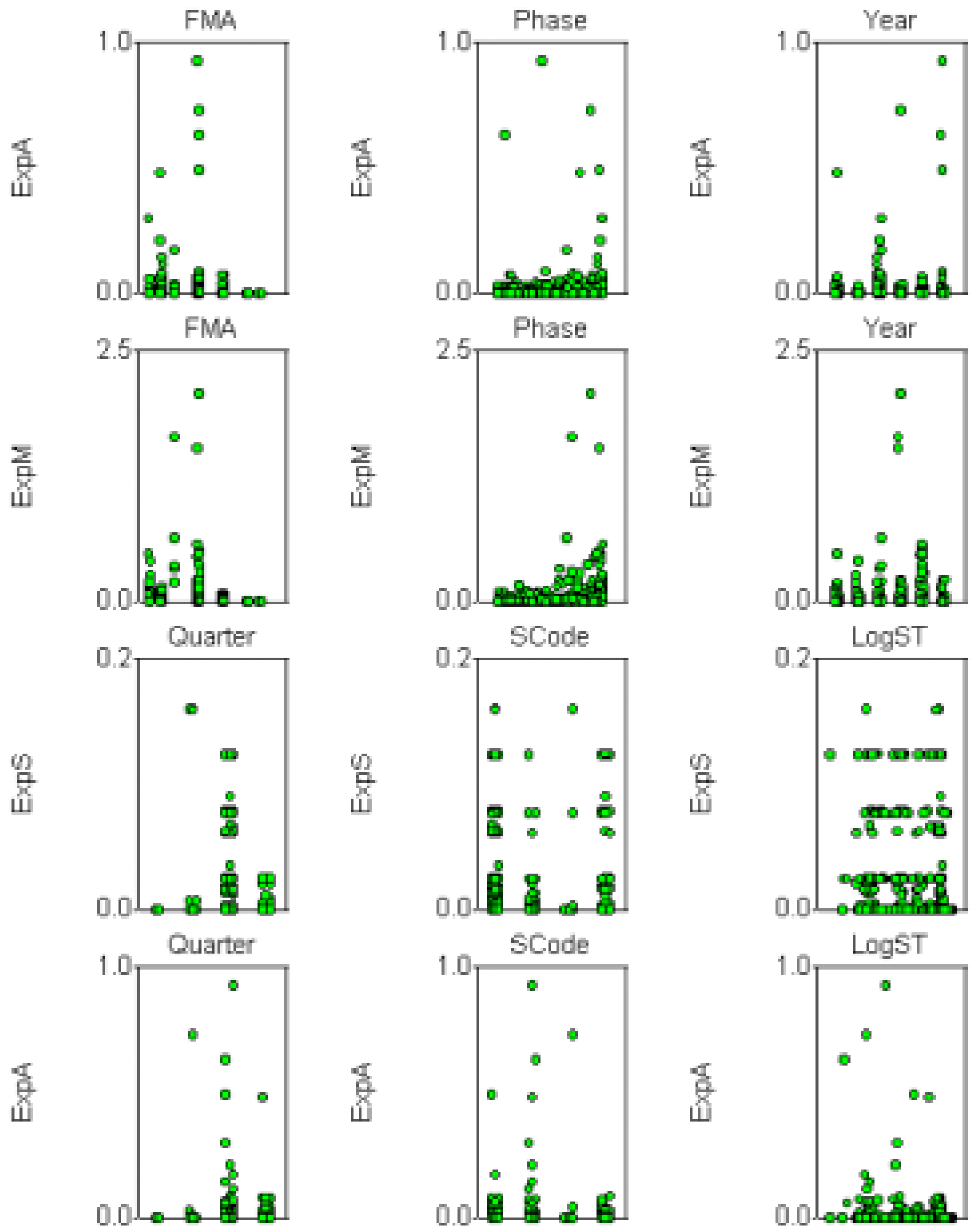
from about –3 to +3, and not show any obvious relationships with the variables that they are plotted against.

For the residuals from the fur seal model (DevRS) and the albatross model (DevRA), the residuals are generally within the anticipated range, and have fairly reasonable distributions. The models for these categories of bycatch therefore seem satisfactory.

For the residuals from the mollymawk model (DevRM) the range of the residuals is wider, from –4.64 to +4.52. The residual of –4.64 occurred when the expected bycatch was 4.57, but only one mollymawk was captured, while the residual of +4.52 occurred when the expected bycatch was 1.26, but 9 mollymawks were captured.

For petrels the range of the residuals is even more extreme, from –5.07 to 9.09. However, in this case the residual of 9.09 is the result of what is clearly a very unusual incident, where the expected bycatch was 13.73 but 49 petrels were

Figure 3. *continued*

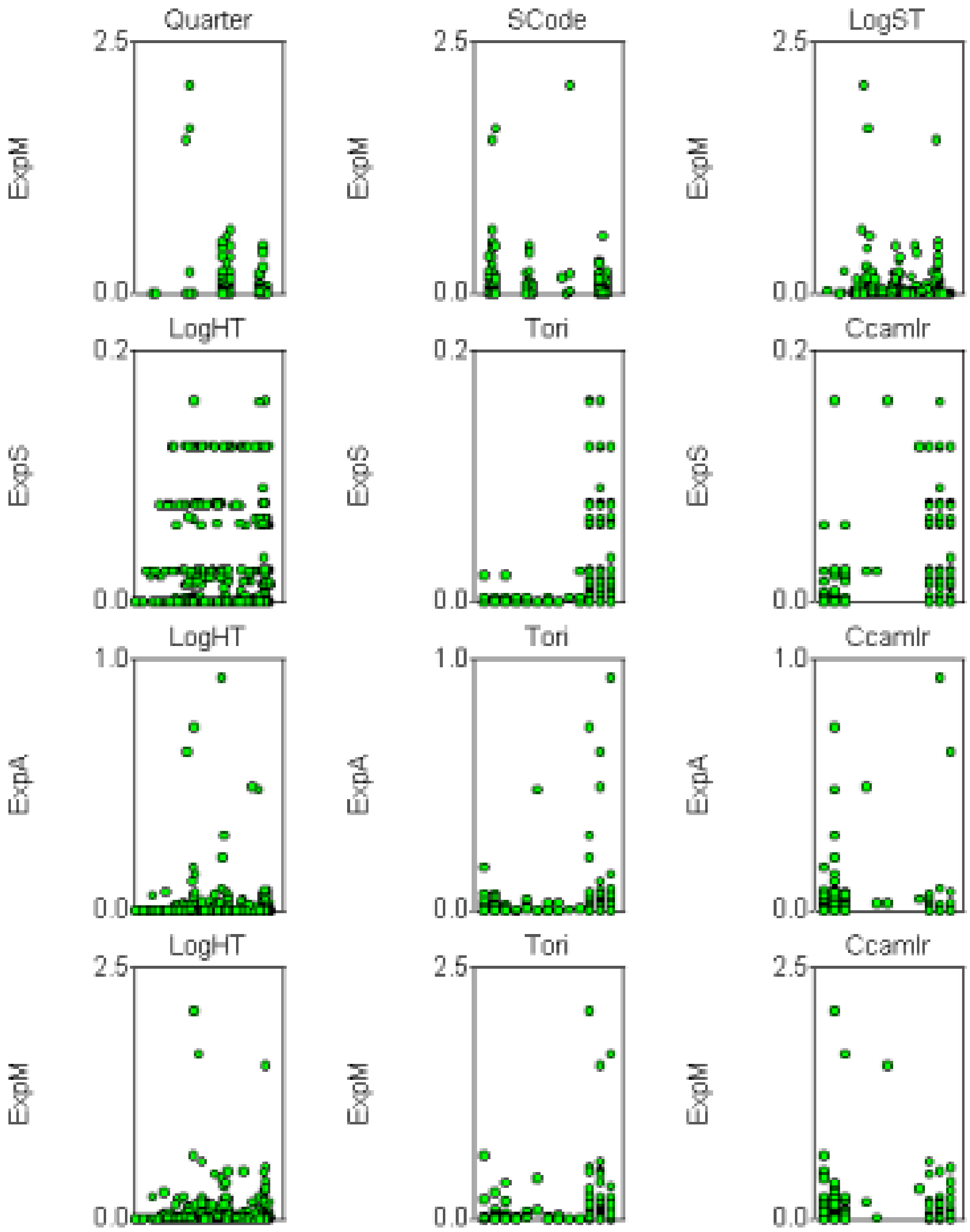


captured. By contrast, the residual of -5.07 occurred when the expected bycatch was 9.40, but no petrels were captured. Actually, the two sample units involved are for the same FMA, in the same fishing year, with other characteristics being rather similar. The very high observed bycatch of 49 petrels on one unit is therefore partly responsible for the high expected bycatch of 9.4 on the other one.

For other birds the situation is similar to that for the mollymawks. The residuals range from -3.45 to +4.81, with the minimum residual occurring when the expected bycatch was 3.89 but there was none, and the maximum residual occurring when the expected bycatch was 0.02 but 3 birds were captured.

Overall, the analysis of residuals suggests that, as could have been anticipated in advance, the assumptions of the log-linear model are only rather approximately correct. In particular, it seems that the distribution of bycatch is not always well approximated by the Poisson distribution. However, this is not a simple case of over-dispersion that can be allowed for by introducing a heterogeneity factor in

Figure 3. *continued*

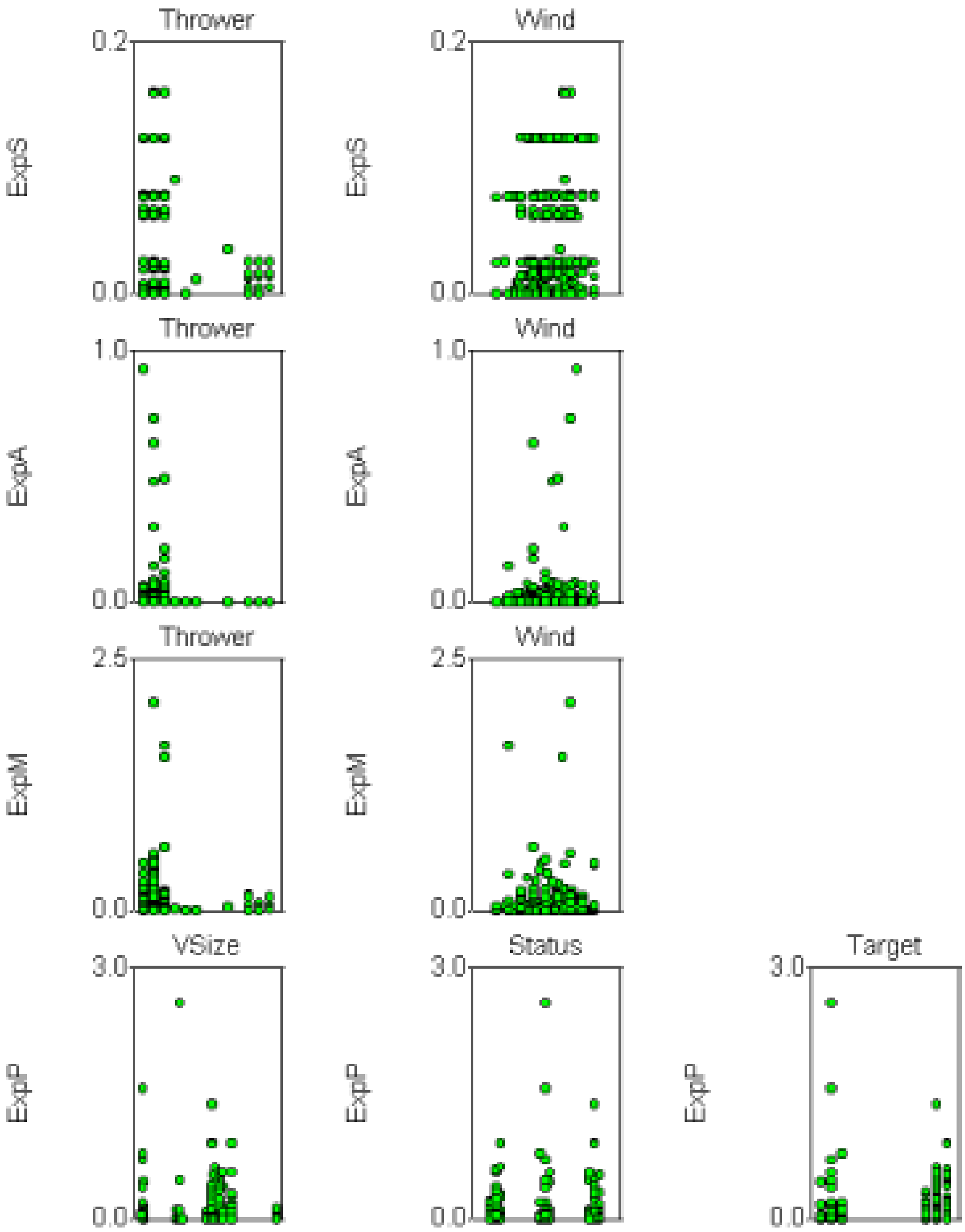


the model (i.e. assuming that the variance is larger than the mean, rather than equal to the mean, which is what happens with the Poisson distribution).

When over-dispersion is suspected, a common way to allow for it is to estimate the heterogeneity factor by the mean deviance (the deviance divided by its degrees of freedom) for the model that is assumed to be correct. This is, for example, the standard approach implemented in GENSTAT. On this basis, all of the models show under-dispersion, with estimated heterogeneity factors of 0.58 for fur seals, 0.28 for albatrosses, 0.67 for mollymawks, 0.92 for petrels, and 0.49 for other birds (Tables 2–6).

Alternatively, the heterogeneity factors can be estimated using the Pearson chi-squared statistics, as recommended by McCullagh & Nelder (1989, p. 200). This gives rather variable results, with the estimated heterogeneity factors being 1.01 for fur seals, 0.53 for albatross, 2.20 for mollymawks, 3.18 for petrels, and 1.79 for other birds. A concern with this approach is that the high estimated

Figure 3. *continued*

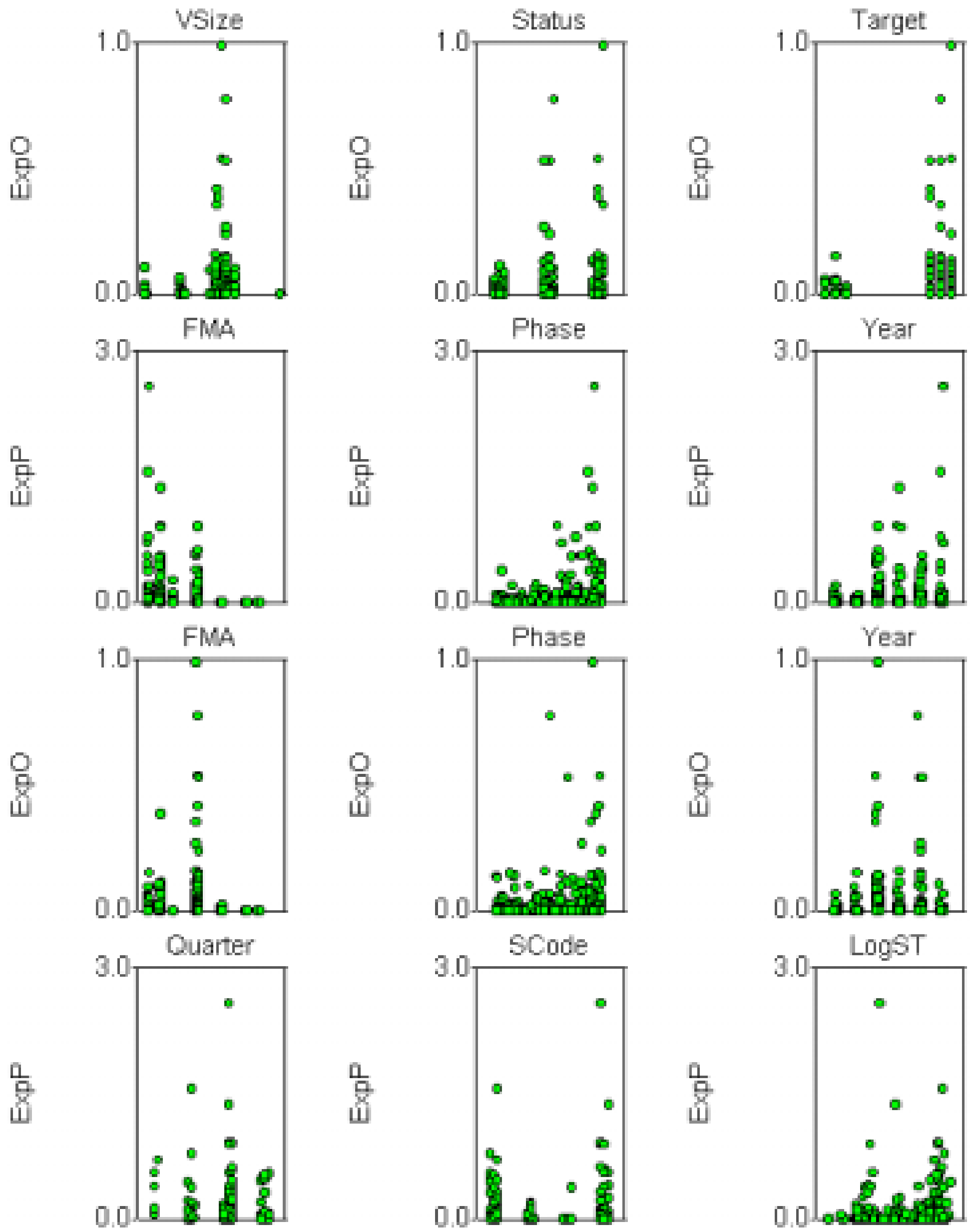


values are mainly due to a few individual observations where the expected bycatch was very low but a single individual was captured.

To understand the situation better, a small simulation study was carried out using the mollymawk model. Five hundred sets of data were generated using the Poisson means from the model, and the same model was fitted to each set of data. A heterogeneity factor was then estimated for each simulated set of data using the mean deviance and the Pearson chi-squared statistic. The estimates using the mean deviance ranged from 0.27 to 0.51, with a mean of 0.38. The estimates using the Pearson chi-squared statistic ranged from 0.36 to 2.18, with a mean of 0.72.

This simulation shows clearly that estimated heterogeneity factors will almost always be less than 1.00 for data of the type being considered, even when the model is perfectly correct. Furthermore, it seems clear that the real data (with estimated heterogeneity factors of 0.67 using the mean deviance and 2.20 using

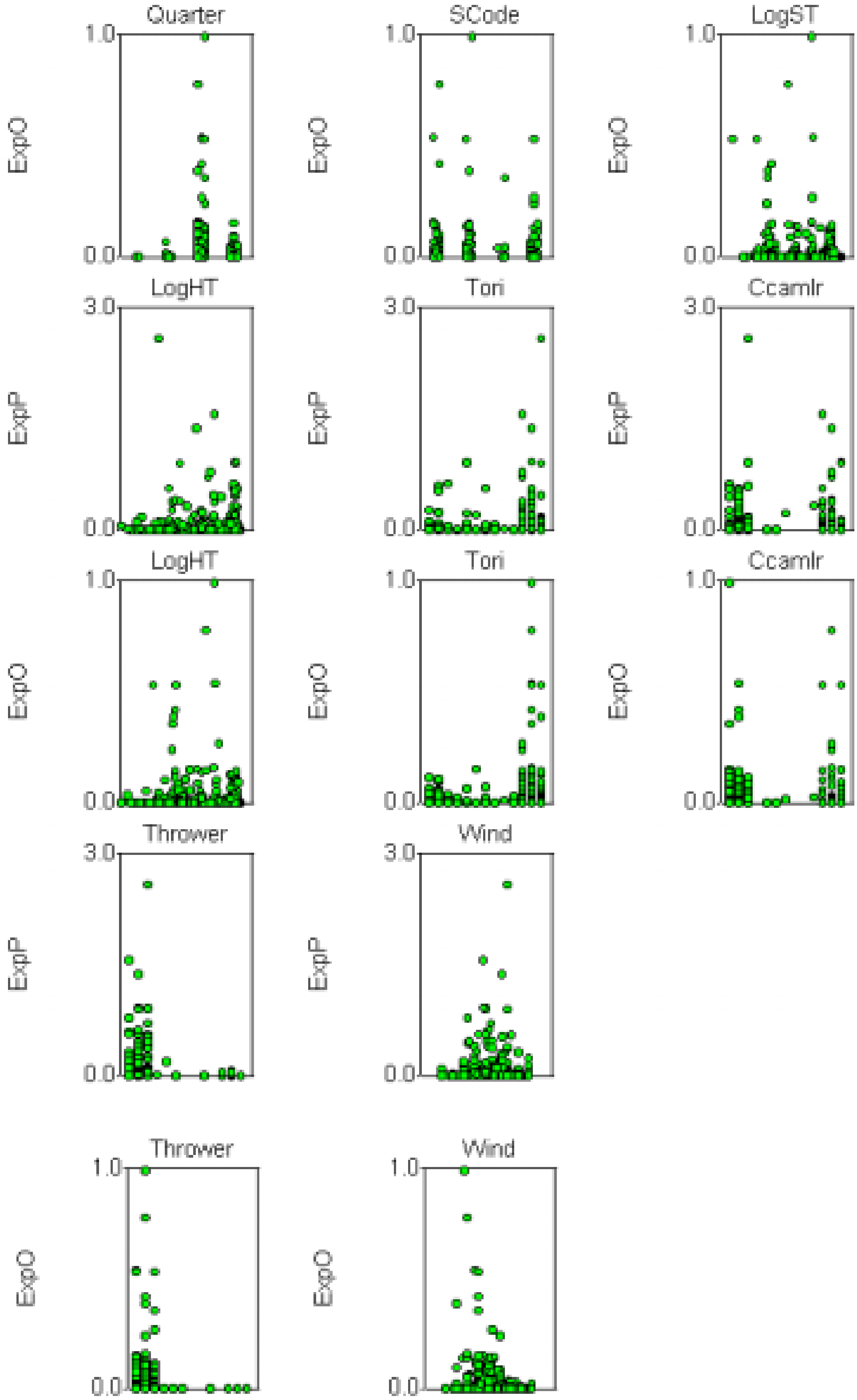
Figure 3. *continued*



the Pearson chi-squared statistic) shows more variation than should occur if the Poisson distribution is correct.

The effect of heterogeneity is to make the effects of factors appear to be more significant than they should be, and make the calculated standard errors of estimates too small. Correcting for heterogeneity is obviously not straight-forward for the analyses presented above, because the usual simple approaches

Figure 3. *continued*



do not apply, and the model selection procedure should also be taken into account. However, the overall effects of the variables in the final models are all very highly significant, and would presumably remain so if appropriate corrections for heterogeneity were made. Furthermore, as noted earlier, the confounding between variables means that estimates and their standard errors need to be interpreted with caution even in the absence of heterogeneity.

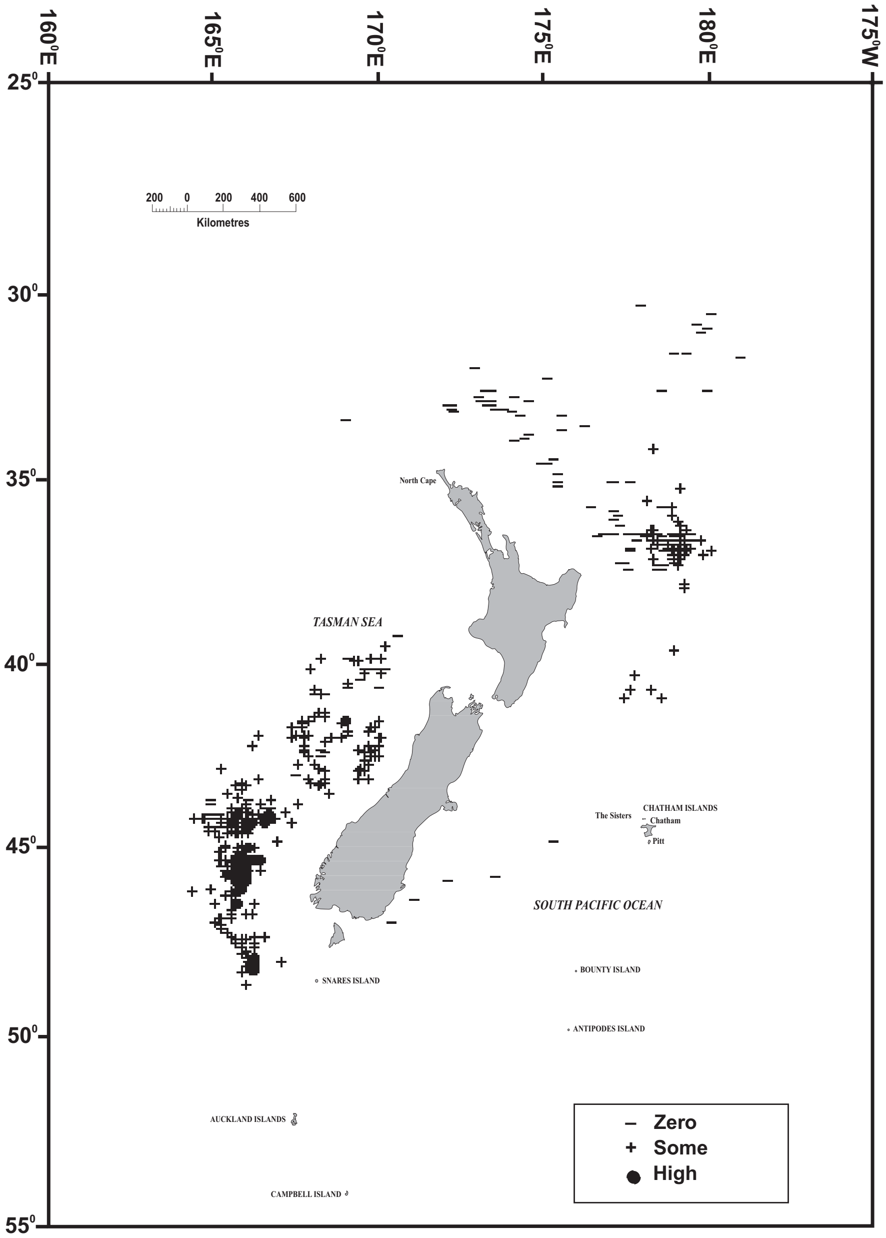


Figure 4. Locations of sample units, with an indication of whether the expected bycatch of *fur seals* is zero, some, or high.

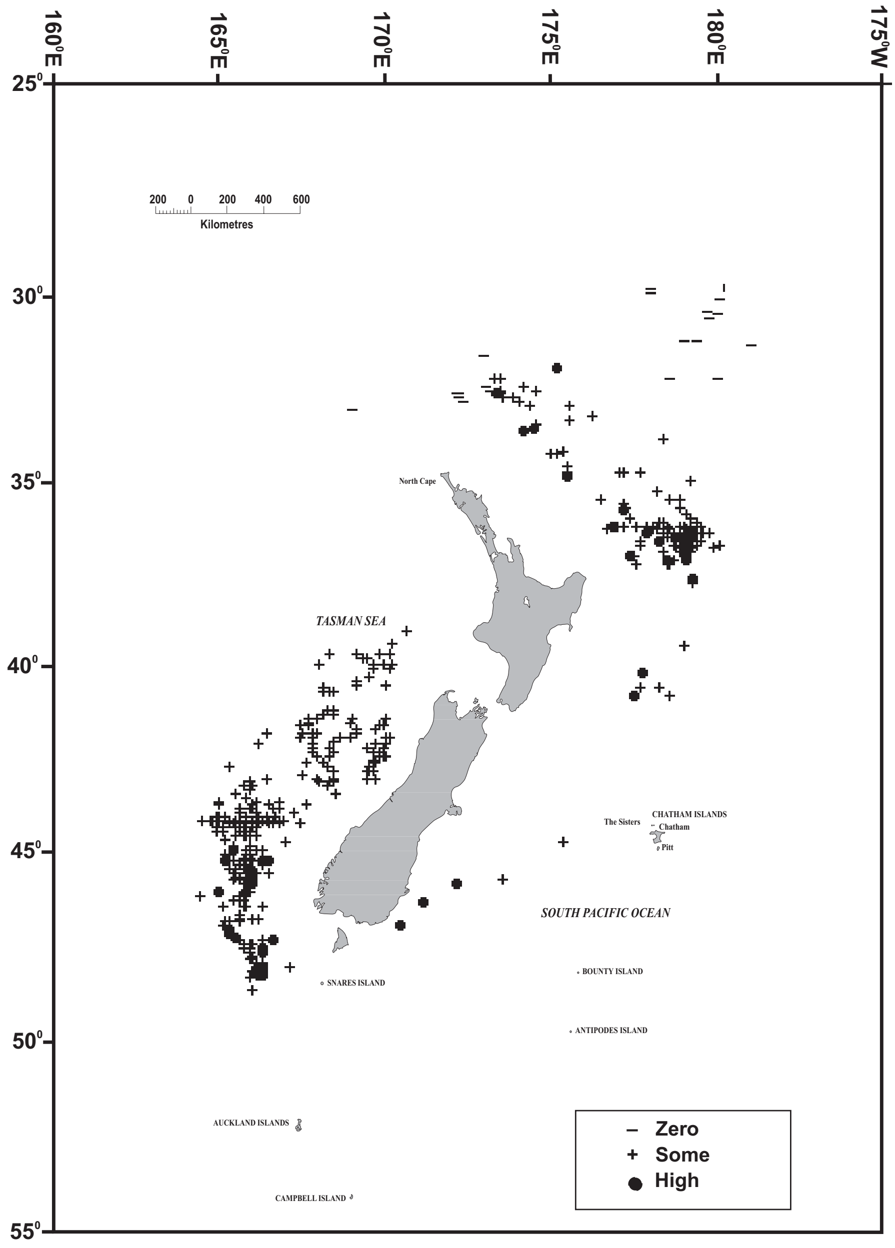
4.4 THE EFFECTS OF DIFFERENT FACTORS AND VARIABLES

In summary, the following can be said about the different variables that have been considered in this study:

VSize: This variable has been included in the final models for albatrosses, and petrels, indicating increased bycatch with increasing vessel size. For the other bycatch species the expected bycatch was particularly high for a group of moderately large vessels. These relationships could, of course, be due to some other characteristics of the particular vessels, and where and when they were fishing.

Nationality: This factor has not been included in any of the final models, but it is confounded with status.

Figure 5. Location of sample units with an indication of whether the expected bycatch of all types of *seabird* is zero, some, or high.



Status: This factor has been included in the final models for all of the seabirds. For chartered vessels the expected bycatch of albatrosses and mollymawks tends to be high, for New Zealand vessels the expected bycatch of albatrosses, petrels and other seabirds tends to be high, and for foreign vessels the expected bycatch of petrels and other seabirds tends to be high. This may of course be related to differences in status in terms the areas and times when fishing took place.

Target: This factor has only been included in the final model for mollymawks. However, in fact high expected bycatch of fur seals, albatrosses, mollymawks, and other seabirds only occurs when the target species is southern bluefin tuna.

FMA: This is an important factor for all types of bycatch.

Phase: This variable has been included in the final models for all of the birds categories. In all cases the expected bycatch increases with the moon phase.

Year: This is an important factor for all types of bycatch.

Quarter: This factor has been included in the final models for fur seals, mollymawks, and petrels. In fact, the expected bycatch varies considerably with this factor for all bycatch species.

SCode: This factor has been included in the final models for albatrosses and other seabirds. For albatrosses, high expected bycatch is usually from 3 a.m. to 3 p.m., while for petrels that is the time of low expected bycatch.

SetT: The logarithm of this variable (the total set time) has been included in the final models for albatrosses and petrels. However, for albatrosses the estimated coefficient is negative, presumably because the logarithm of the total haul time is also in the model. In fact, there is no clear relationship between the expected bycatch and the set time for any of the bycatch species.

HaulT: The logarithm of this variable (the total haul time) has been included in the final model for albatrosses, but there is in fact no clear relationship between the expected bycatch and the haul time for any species.

Length: The logarithm of this variable (the total length of the line used on all sets) is not included in any of the final models.

Tori: This variable has only been included in the final model for mollymawks. For all bycatch species, high expected bycatch only occurs when a tori pole is used. This seems strange as the use of a tori pole is supposed to reduce the bycatch of birds.

Ccamlr: This variable has only been included in the final model for mollymawks, where the highest expected bycatch only occurred in the absence of the CCAMLR tori line.

Thrower: This seems to be a very important variable. It has been included in the final models for all the bycatch species, and the expected bycatch is only ever high in the absence of a mechanical thrower.

Wind: This variable is included in the final models for petrels and other seabirds. For petrels there is no clear relationship between the expected bycatch and this variable, but the positive coefficient in the model implies increasing bycatch with increasing wind levels. For other seabirds the coefficient is negative and the highest expected bycatch occurs with low wind levels.

The apparent effects of the tori pole and the mechanical bait thrower need a further discussion. First, it can be noted that the use of the tori pole shows no very obvious associations with variables and factors other than the bait thrower, but the bait thrower tended to be used with medium to large vessels, Japanese vessels, targeting southern bluefish tuna, only in fishing years 1993/94 to 1995/96, with the CCAMLR line. Therefore, the apparent effect of the bait thrower in reducing bycatch may actually be related to one or more of these other characteristics, but the apparent increase in bycatch related to the use of the tori pole cannot be explained away so easily.

The nature of the association between the use of the tori pole and the bait thrower is that when the bait thrower was used, the tori pole was always used as well. However, the tori pole was sometimes used without the bait thrower. Table 14 shows how the average bycatch per 1000 hooks on observed vessels varied with three levels (not used, used less than half of the time, or used half of the time or more) of the use of the tori line and the bait thrower. For fur seals, bycatch rate was minimal unless the tori pole was used, in which case it was lowest with the thrower used more than half of the time. With seabirds, the bycatch rate was highest with the tori pole used less than half of the time, and lowest with both the tori pole and the bait thrower both used half of the time or more. It may be that these rates are related to the characteristics of individual vessels. However, if nothing else, it can be said that there is not much evidence that the use of a tori pole reduces bycatch.

TABLE 14. OBSERVED BYCATCH RATES PER THOUSAND HOOKS FOR *FUR SEALS* AND THE TOTAL OF *ALL CATEGORIES OF SEABIRDS*, GIVEN SEPARATELY FOR DIFFERENT LEVELS OF USE OF THE TORI POLE AND THE MECHANICAL BAIT THROWER (NOT USED, USED LESS THAN 50% OF THE TIME, OR USED 50% OR MORE OF THE TIME) FOR THE SETS IN A SAMPLE UNIT.

USE OF TORI POLE			USE OF BAIT THROWER			
			NONE	< 50%	50% OR MORE	OVERALL
None		Sample units	94	0	0	94
		Hooks (,000)	960			960
	Bycatch rate	Fur seals	0.001			0.001
		Seabirds	0.038			0.038
< 50%		Sample units	10	0	0	10
		Hooks (,000)	128			128
	Bycatch rate	Fur seals	0.000			0.000
		Seabirds	0.572			0.572
50% or more		Sample units	340	2	56	398
		Hooks (,000)	2641	20	566	3227
	Bycatch rate	Fur seals	0.036	0.051	0.016	0.033
		Seabirds	0.150	0.102	0.016	0.126
Overall		Sample units	444	2	56	502
		Hooks (,000)	3729	20	566	4315
	Bycatch rate	Fur seals	0.026	0.051	0.016	0.025
		Seabirds	0.135	0.102	0.016	0.119

5. Assessment of the observer coverage needed in the future

For determining the levels of observer coverage required in future seasons, the coefficient of variation (CV, the standard error/estimate expressed as a percentage) is used as the measure of precision. In general, a CV of 20% or less is desirable. Then, for example, if the estimated bycatch is 100 animals the standard error is about 20, and an approximate 95% confidence interval for the true bycatch is 100 ± 40 animals. Depending upon the decisions to be made, this may or may not provide sufficient precision.

The CV gives an indication of the variation expected from sampling errors. It is important to realise that it gives no information about bias in the sampling

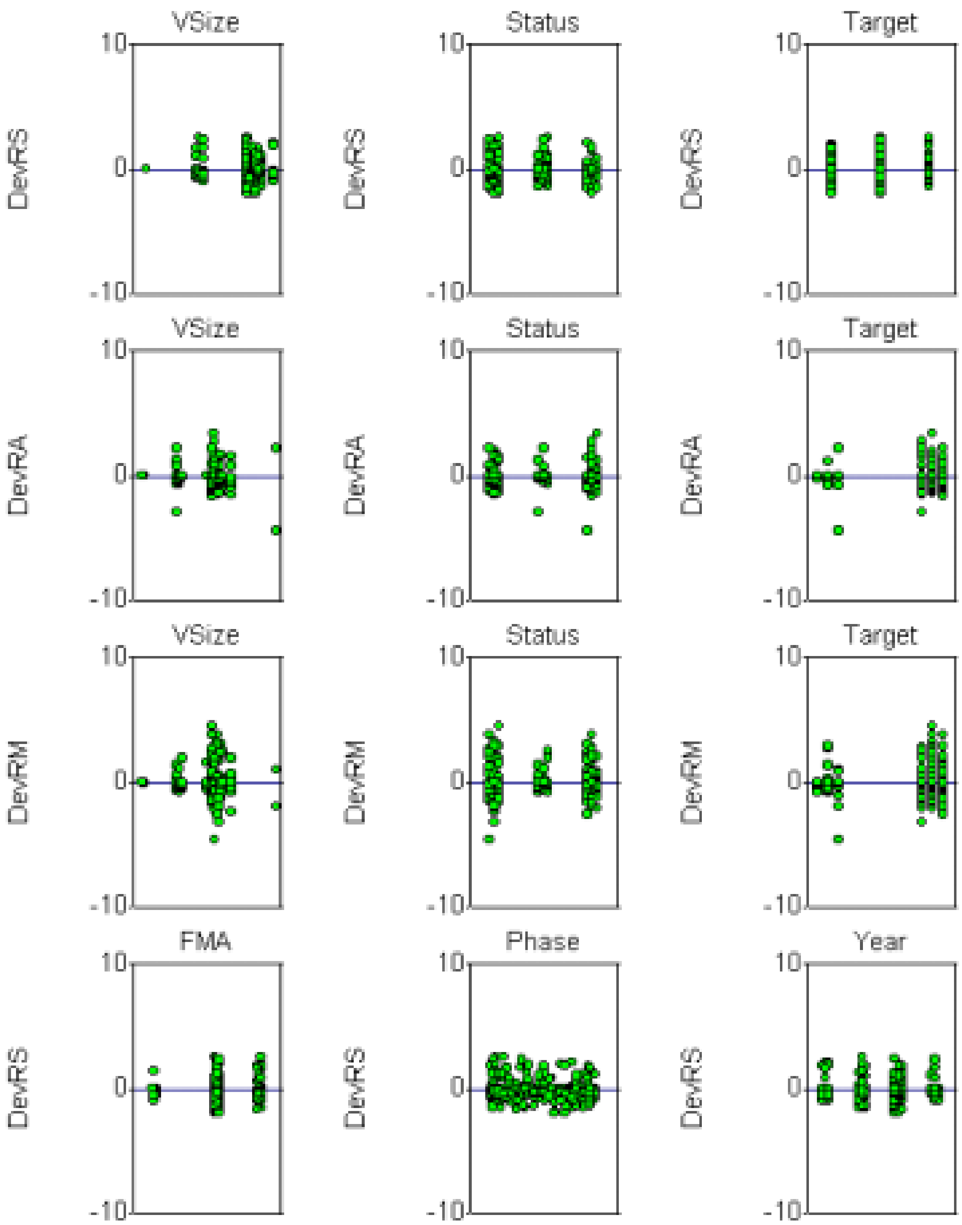


Figure 6. Standardised deviance residuals from the fitted log-linear models (DevRS for fur seals, DevRA for albatross, DevRM for mollymawks, DevRP for petrels, and DevRO for other birds) plotted against characteristics of the sample units. Points have been jittered for cases where the horizontal variable has few possible values to avoid many points being hidden. The scales are not provided for the horizontal variables but in all cases low values are on the left and high values on the right.

procedure. Thus there may be a high level of observer cover but poor estimates of bycatch if the sample units used for estimation are not selected in a manner that is as close to random as possible.

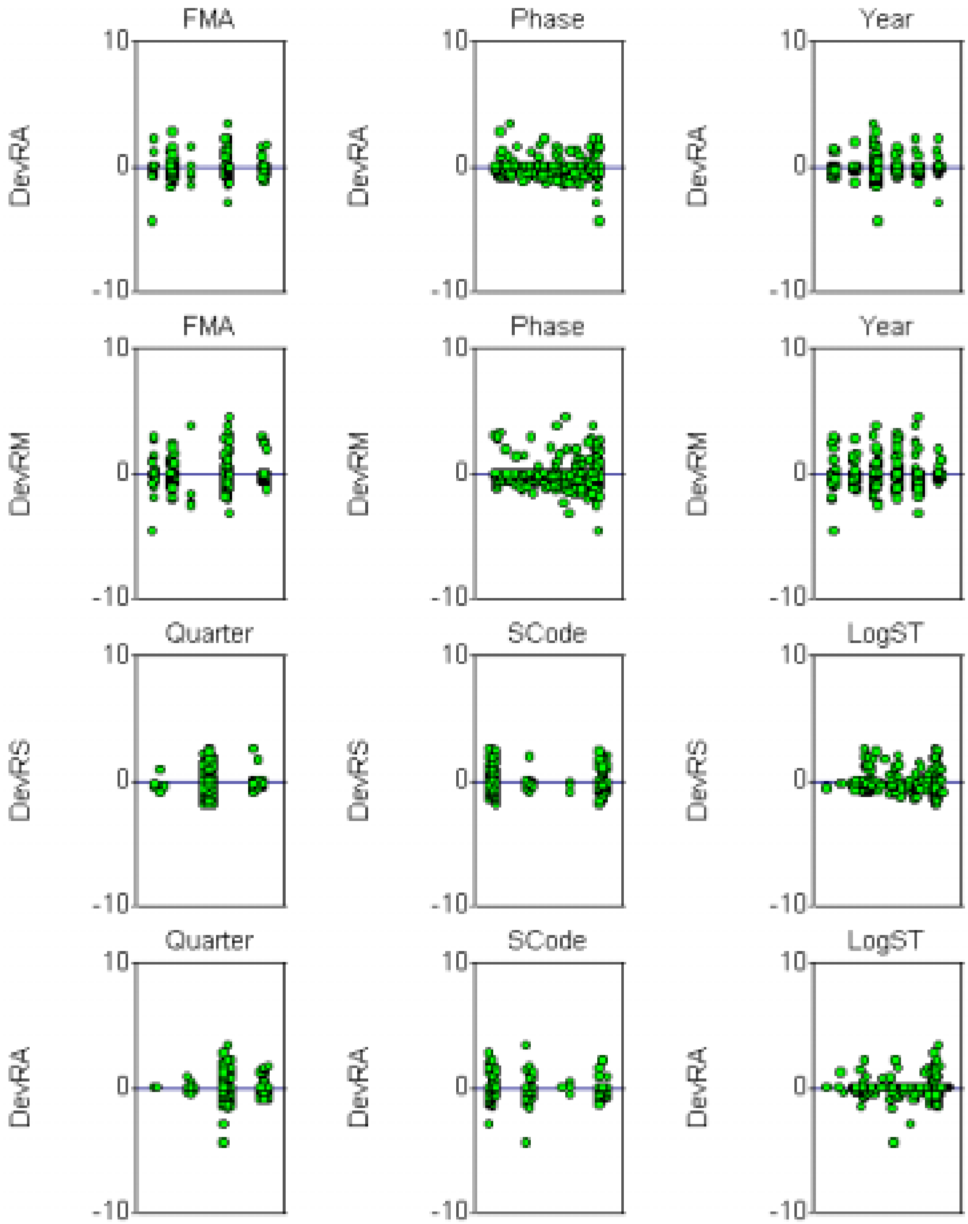
The CV is the standard error as a percentage of the mean, which is also the standard deviation of percentage relative errors, i.e., the standard deviation of

RE = 100(Estimate – True Value)/(True Value).

Thus when a series of bycatch estimates are obtained with a different true value for each one, it is reasonable to regard the achieved CV as the standard deviation of the relative errors.

Figure 6 shows the CVs that are expected with this definition, for various levels of observed cover, for a best-case and a worst-case scenario in terms of the five categories of bycatch that have been considered in this report (fur seals, albatross, mollymawks, petrels, and other seabirds). The best case is the CV for the estimated bycatch category with the smallest CV for a given level of

Figure 6. *continued*

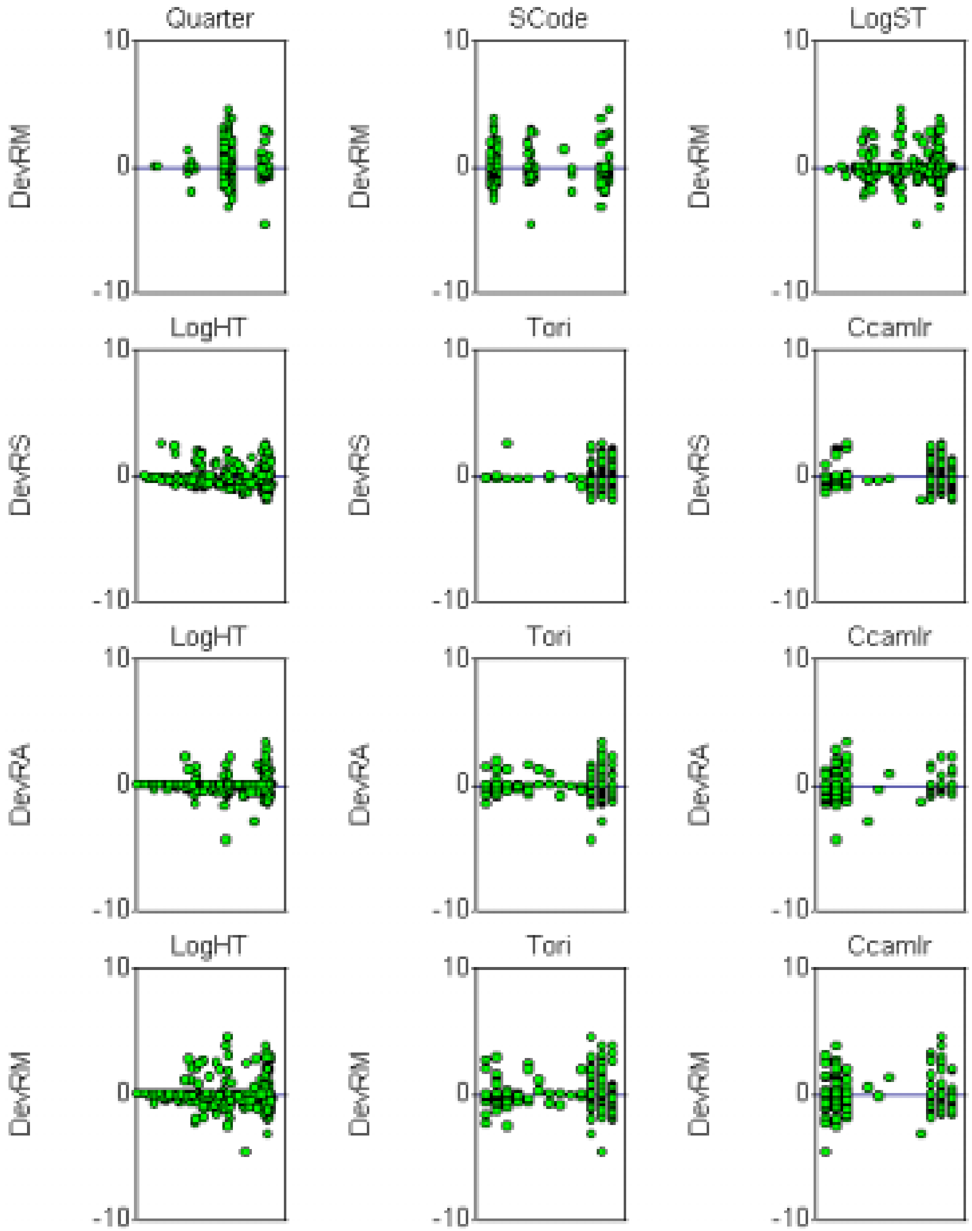


observer cover and total effort (in terms of thousands of hooks). The worst case is the CV for the estimated bycatch category with the largest CV. At the lowest levels of effort the best-case scenario is usually for albatrosses or other birds, and the worst-case scenario is for fur seals or petrels. At high levels of effort the best-case scenario is for fur seals and the worst-case scenario is for other birds.

In producing these figures it is assumed that ratio estimation will be used as described in Section 2, with the sample units being defined as in the analyses in Sections 3 and 4 of this report, i.e. a series of up to five consecutive sets carried out on one vessel, with the same target species, in the same FMA. It is also assumed that the future bycatch rates for each bycatch category will be similar to those experienced in the past.

The procedure used to obtain the best- and worst-case scenarios with an observer cover of 100% and an expected total effort of N thousand hooks was a type of bootstrap approach, as follows:

Figure 6. *continued*



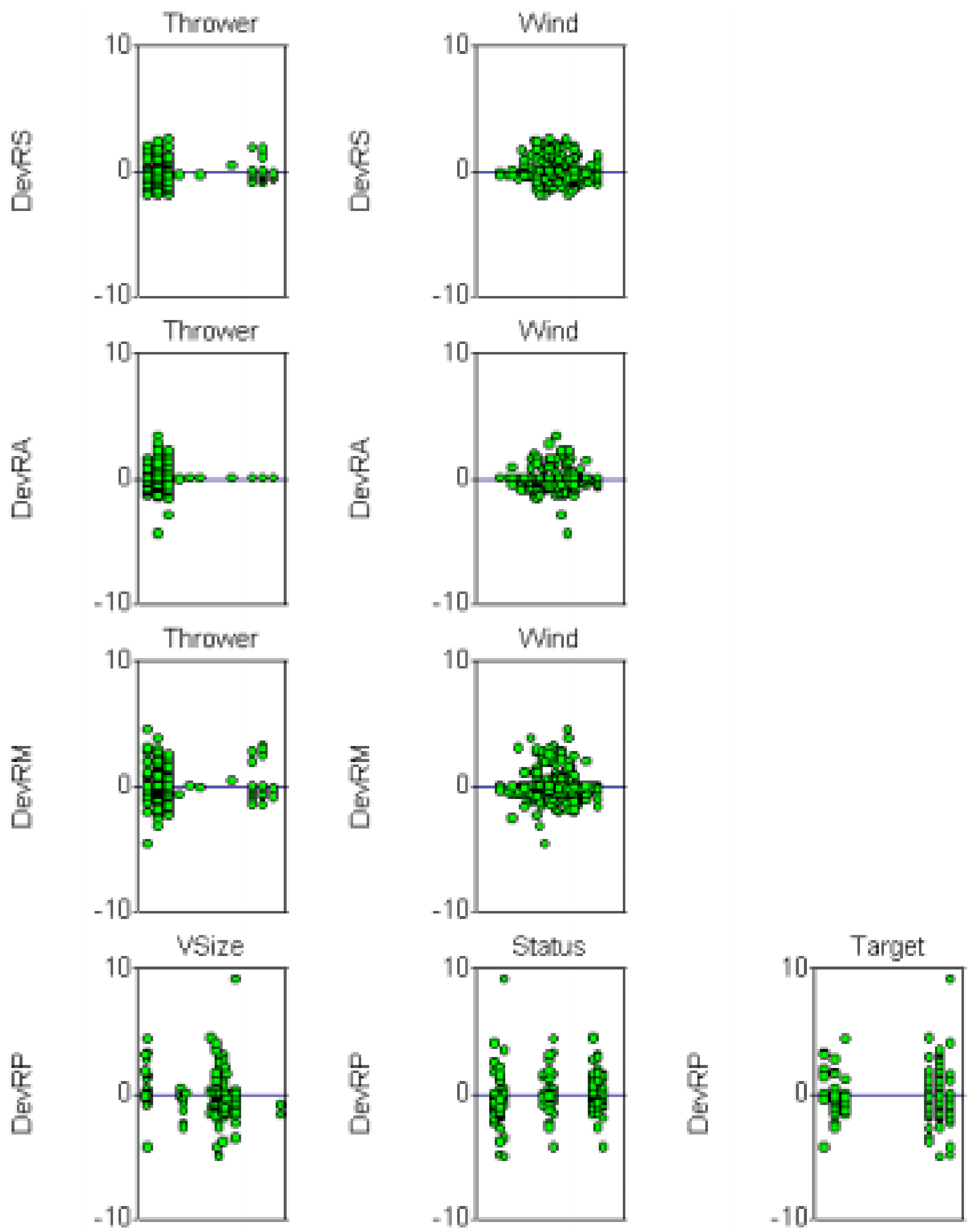
a. The 502 sample units that were used for the estimation of bycatch as described in Section 3 were used to represent a source population for future data.

b. For each bycatch category, units were removed for any FMA or fishing year where no bycatch was observed. Different units were removed for different bycatch categories, as necessary.

c. For each bycatch category, units were selected at random from the source population until the accumulated number of hooks exceeded 1000(N–5). Stopping before N thousand hooks in this way ensured that the expected total number of hooks in the chosen units is close to N thousand, taking into account the fact that the number of hooks in individual sample units varies from 340 to about 18 thousand. The set of selected units provides a simulated fishery, with total bycatch B.

d. Each unit in the simulated fishery was given a probability P of being observed.

Figure 6. *continued*



e. Equation 2 was used to obtain the estimate $\hat{T}$ of the total bycatch for all selected units, using the information from the observed units. This was done separately for each category of bycatch.

f. The percentage relative error in the estimate for each bycatch category was calculated as

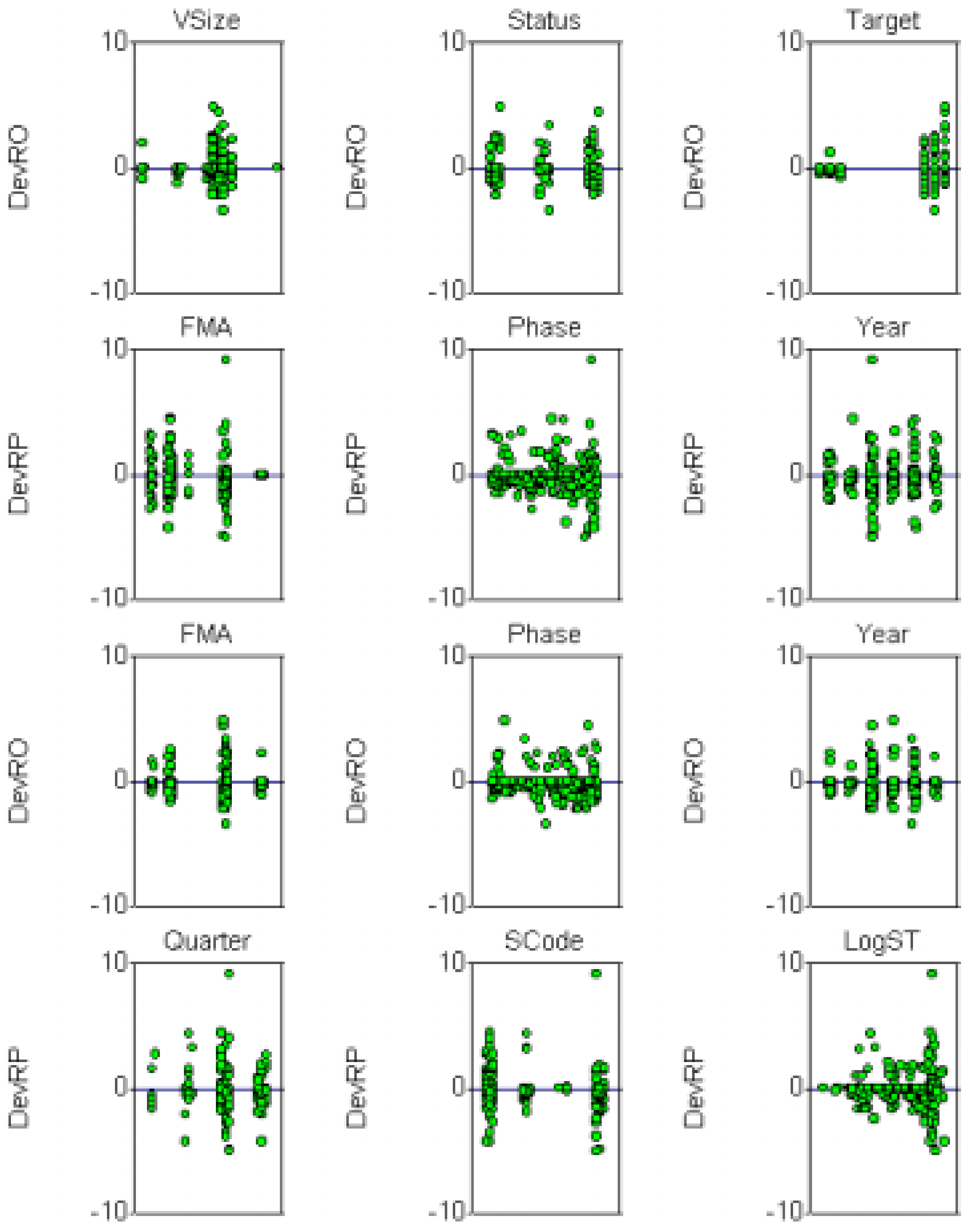
$$RE = 100(\hat{T} - B)/B.$$

g. Steps b to f were repeated 5000 times, and the standard deviation of RE was calculated for each bycatch category. The CV estimated from the simulation was taken as the standard deviation of RE.

h. The smallest CV was chosen from those for the different bycatch categories for the best-case scenario. The largest CV was chosen for the worst-case scenario.

Where stratification is desirable, the results shown in Fig. 7 can be applied separately for each stratum. The following calculation can then be used to determine the CV for the estimate of bycatch in the whole fishery:

Figure 6. *continued*

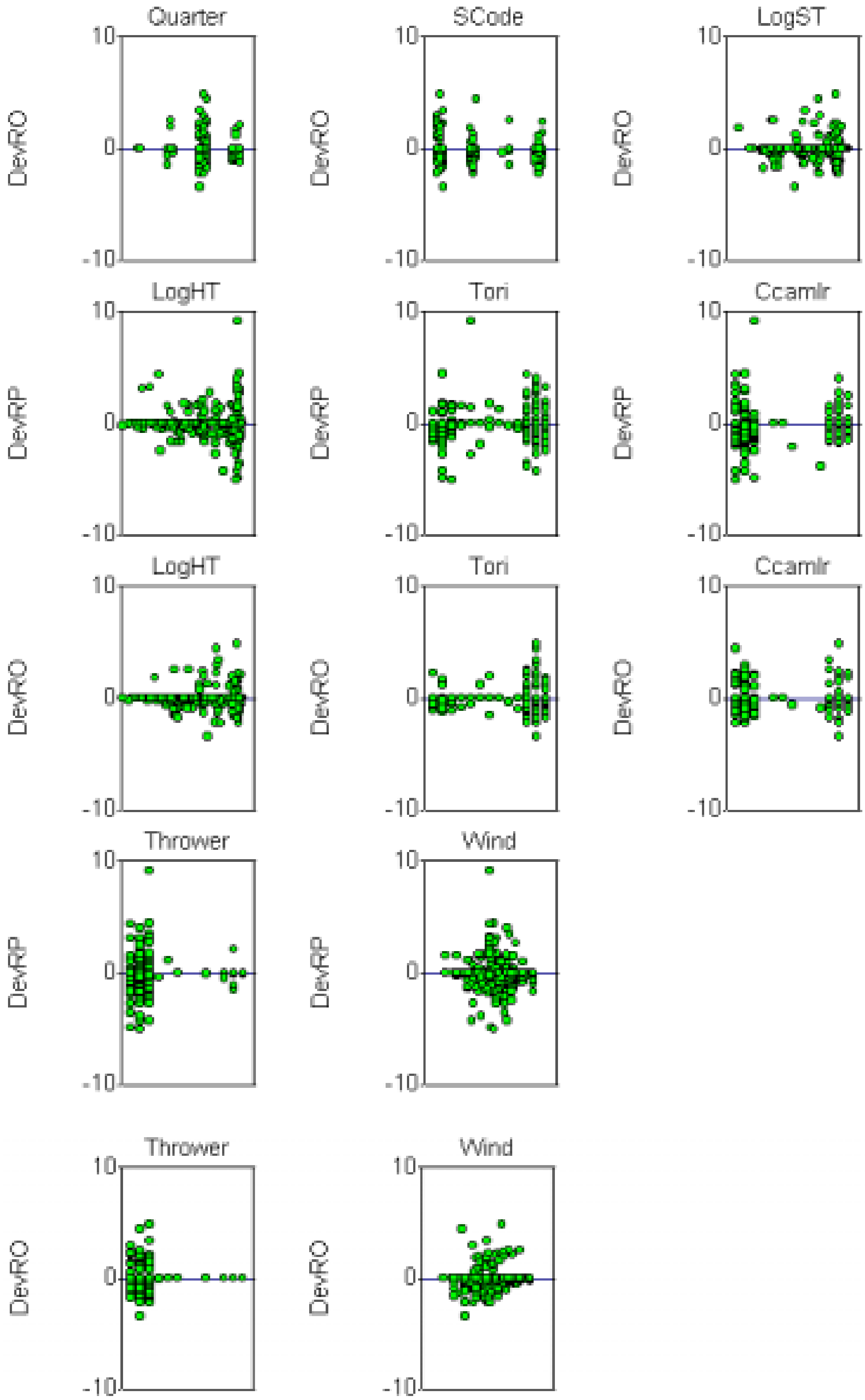


$$CV = 100\%[\sum (CV_i)^2 \ \hat{T}_i^2]/\hat{T}$$

where CV_i and $\hat{T}_i$ are CV and estimated bycatch in stratum i, $\hat{T} = \sum \hat{T}_i$ is the overall estimated bycatch, and the summation is over all strata.

Figure 7 shows that obtaining a CV of 20% requires at least 70% observer cover for a fishery with 500,000 hooks, at least 50% cover with one million hooks, at

Figure 6. *continued*



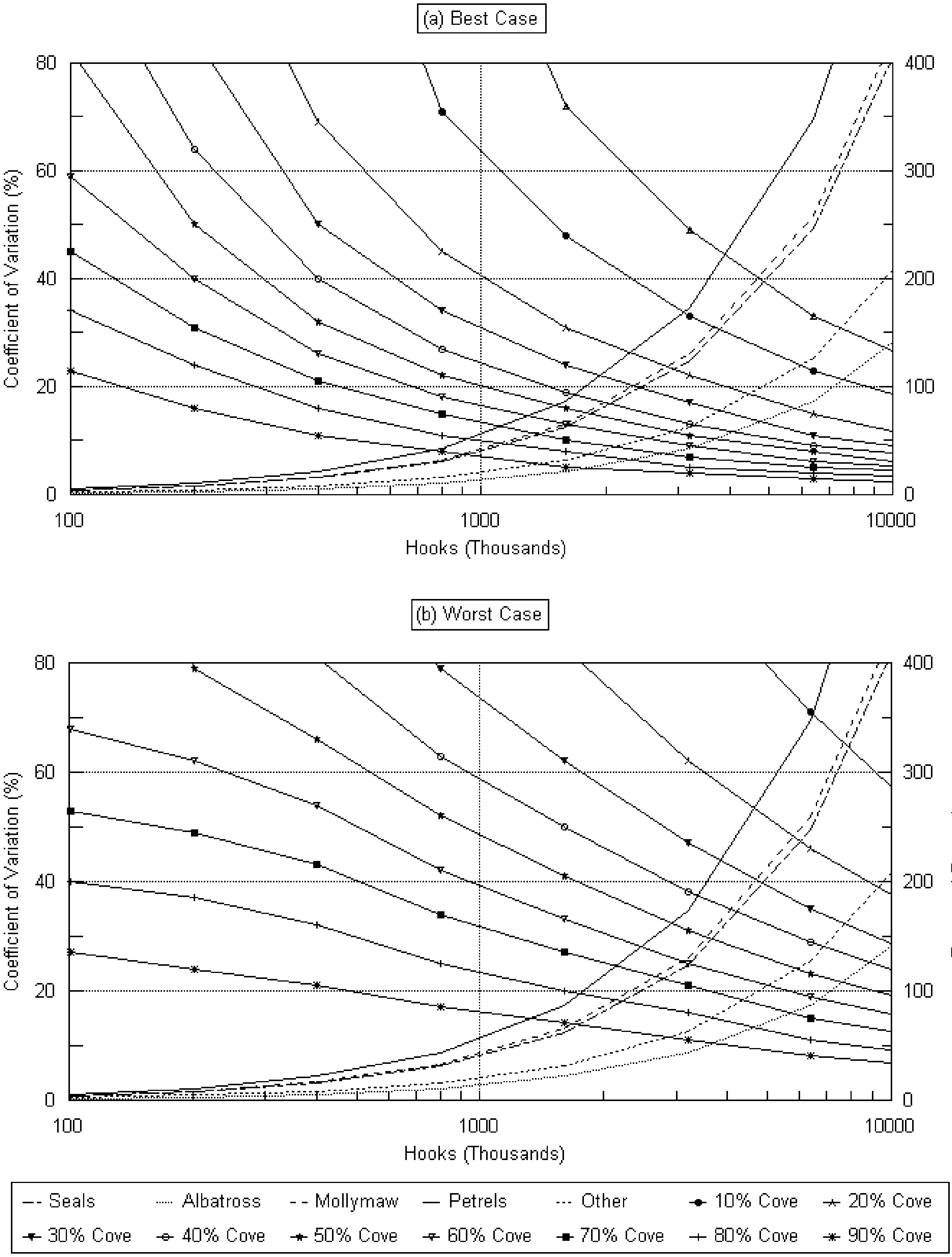


Figure 7. Coefficients of variation (CVs) for estimates of total bycatch as a function of the expected effort in a fishery and the level of observer cover for (a) the bycatch category with the smallest CV, the best-case scenario; and (b) the bycatch category with the highest CV, the worst-case scenario, assuming that historic bycatch rates on sample units will apply in the future. The expected amounts of bycatch are also shown for the bycatch categories.

least 25% cover with 3 million hooks, and at least 10% cover with 10 million hooks. This is the best-case scenario. For bycatch that is harder to estimate the percentage cover required for a 20% CV ranges from 90% for a fishery with 500,000 hooks to 50% cover for a fishery with 10 million hooks (Fig.7b).

To put effort into perspective, it can be noted that there have been between about 3 million and 13 million hooks used in the fishing years 1991/92 to 1995/96 in observed areas (Table 3).

6. Summary

- There is a northern and a southern fishery (divided by the 40° south latitude), with the northern fishery used by foreign vessels up to 1995, and New Zealand vessels since 1991. Foreign vessels still use the southern fishery, with domestic vessels in this area since 1994.
- There is accidental bycatch of fur seals, great albatrosses, mollymawks, petrels, and other seabirds in the fisheries, with most fur seals released alive and most birds killed.
- Ratio estimation is used for estimating bycatch numbers, using stratification based on fishing years and Fisheries Management Areas (FMAs). The sample units consist of up to five consecutive sets on the same vessel, in the same FMA, with the same target. There are 502 such units in the database where an official observer recorded the bycatch details.
- Most fur seal bycatch is in the SOU (Southland) and CHA (Challenger) FMAs. Estimates for the whole of the Exclusive Economic Zone (EEZ) range from 19 animals in fishing year 1995/96 to 162 in 1994/95.
- Seabird bycatch estimates are provided for great albatrosses, mollymawks, petrels, and other seabirds. Estimates of the total bycatch for the whole of the EEZ range from 250 in 1991/92 to 949 in 1992/93.
- Factors related to bycatch are investigated graphically, and by fitting log-linear models to the bycatch for observed sample units. Apart from the fishing year and the FMA, which are important factors for all categories of bycatch, significant relationships were found between some categories of bycatch and the vessel size, the status of the vessel (chartered, domestic or foreign), the target fish, the moon phase, the quarter of the fishing year, the time when sets are started, the total set and haul times, the use of a tori pole, the use of a CCAMLR tori line, and the wind force. However, relationships between these variables makes it difficult to separate their apparent effects.
- The residuals from the log-linear models are sometimes larger than might be expected, suggesting that the assumptions made are not entirely correct. This and other evidence suggests some over-dispersion in the data. However, standard methods for handling this do not seem to be appropriate. Therefore no adjustments have been made to the analysis to allow for possible over-dispersion.
- A bootstrap type of simulation is used to determine the coefficients of variation (CVs) that are likely to be obtained when estimating bycatch in the future, with different levels of observer cover. Because the CVs vary considerably with the bycatch category, results are presented for a worst-case and a best-case scenario. In practice the situation for a specific type of bycatch will be somewhere between these extremes.

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