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A review of bycatch of bluenose *Hyperoglyphe antarctica* in the target alfonsino (BYX 2) and gemfish (SKI 2) fisheries 1989–90 to 1996–97

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1. EXECUTIVE SUMMARY

The largest fishery for bluenose in New Zealand occurs in QMA 2. Most of the catch is taken as bycatch of the major midwater trawl fisheries for alfonsino (BYX 2) and gemfish (SKI 2), although bluenose also supports a small target line fishery in BNS 2. The BNS 2 TACC (currently 873 t) has been substantially over-caught since catch limits of 440 t were introduced for these species in 1984. This over-catch was reduced in 1994–95 and 1995–96, due in part to the TAC increase and to active avoidance of bluenose bycatch in the alfonsino and gemfish fisheries. Bluenose landings however, increased again during 1996–97.

Bluenose is a major bycatch of the midwater trawl fisheries for alfonsino, and to a lesser extent, a bycatch in the midwater trawl fisheries for gemfish and hoki. It also forms a minor bycatch of a wide range of other deeper inshore and middle depth trawl fisheries in QMA 2. Whilst 25–30% of landings are taken by line fishing, these landings are mostly associated with the target line fishery.

This report reviews bluenose bycatch in the target alfonsino and gemfish trawl fisheries, during 1988–89 to 1996–97. It examines the effects of fishing year, ground, season and fishing method on the ratio of bluenose, using loglinear regression models.

The analysis determined that the relationship between target and bycatch of bluenose differs between these two target fisheries. In the alfonsino target trawl fishery (which accounts for half of the 1996–97 bluenose trawl fishery landings), annual indices of bluenose bycatch increased from 1988–89 to a peak in 1993–94. The decline in the bycatch indices from 1994–95 to 1996–97 is generally consistent with previous research, and may be attributed to changes in fishing practices during this period.

The fishing ground and fishing year interaction entered the regression model, which indicates that bycatch varies in a complex fashion between fishing grounds and fishing years. The relatively low overall R^2 value of the regression model indicates that more variability may possibly be explained by other factors such as vessel and gear parameters that were not included in this analysis of the alfonsino fishery data.

The gemfish target fishery in QMA 2 (which accounts for only 6.5% of the 1996–97 bluenose trawl fishery landings) developed more recently than the alfonsino fishery. Target fishing occurs in shallow waters outside the normal range of bluenose. Annual bycatch indices continued to rise from 1992–92 to 1995–96, with a major spike occurring in 1992–93, although a slight decrease is indicated by the most recent data. Whilst the fishing ground plus fishing year interaction term also entered this model, caution is suggested in the interpretation of models of the gemfish target trawl fishery. The data are highly skewed and bimodal and may depart from the assumptions of the loglinear model. This is due in part to the high number of zero catch records present.

The use of a loglinear modelling approach using the bycatch ratio was found to be a relatively unsuccessful method for determining the effect of factors ground, season and method on the occurrence of bluenose bycatch. The method performed poorly, particularly in the target gemfish fishery. It is apparent that factors other than fishing ground, season and method may influence bluenose bycatch in these target fisheries. Accordingly, the objectives of INS9801 have been extended to include the analysis of these variables. The use of a ratio index as a basis for comparison of bluenose bycatch has some undesirable statistical properties, and the proportion of bycatch is suggested as a more appropriate unit. Under project INS9801, the weight of bycatch in each target fishery is modelled using a loglinear modelling approach. This project also evaluates the use of the proportion of bycatch and subsequent analysis using the logistic distribution. Project INS9801 also evaluates the use of an alternative multivariate approach for the analysis of bycatch occurrence data.

2. INTRODUCTION

2.1 Overview

This report fulfils the requirements of Objective 4 of the Ministry of Fisheries project BNS 9801: To estimate bluenose landings and bycatch ratios from historical landings data.

The report describes the analysis of the ratio of bluenose bycatch in the target alfonsino and gemfish fisheries, from the CELR (Catch, effort and landing return) and TCEPR (Trawl catch effort and processing return) databases held by the Ministry of Fisheries for the 1988–89 to 1996–97 fishing years. A stepwise multiple regression approach (Doonan

1991, Vignaux 1992, Vignaux 1994) was used to examine the relative effects of the variables fishing ground, season and method, on the ratio of bluenose by-catch.

2.2 Description of the fishery

Bluenose occur widely throughout New Zealand fisheries waters and are commonly taken as bycatch of line and trawl fishing on the deeper areas of the inner shelf (Annala & Sullivan 1997). The BNS 2 fisheries in QMA 2 (Figure 1) represent 41% of the 1995–96 national bluenose landings of 2 314 t.

Bluenose was originally taken as bycatch in the target groper line fishery (V. Basile, commercial fisher, *pers. comm.*). A target bluenose line fishery developed during the 1960's and 1970's around Cook Strait and Cape Campbell and this subsequently spread to East Coast of the North Island. With the introduction of midwater trawl fishing in the late 1980's (Ryan & Stocker 1991), target line fishing declined to less than 5% of landings. In more recent years, this line fishery has become re-established and now comprises 30% of the 1997–98 landings data (Blackwell 1998). Bluenose is taken as a by-catch in the line fisheries for ling and groper, and forms a minor by-catch of other line fisheries in QMA 2.

Historical landings in BNS 2 have slowly increased from 1981 to 1996–97 (Table 1), with an initial peak in 1986–87 and a second larger peak in 1993–94 (Figure 2). These landings have continued to increase despite the introduction of a catch limit of 440 t in 1984 (Table 1), and the establishment of a TACC of 660 t in 1986–87 (Annala & Sullivan 1997). Over-catch has fallen from a peak of 50% of the TACC in 1993–94 (Figure 2) to a 26% over-run of the 1996–97 TACC. Most of this over-catch is associated with the midwater trawl fisheries for alfonsino and gemfish, although bluenose forms a minor by-catch of most middle-depth trawl fisheries in QMA 2 (Langley 1995). Whilst the matching of quota to landings in these fisheries has also improved since 1995–96 (M. Claudatos, Fish Processor, Napier. *pers. comm.* 1997), the most recent landings (1996–97) continue to exceed the TACC.

2.3 Previous research

The close relationship between alfonsino and bluenose was recognised early in the development of the target alfonsino fishery (Cade *et al.* 1984, Horn & Massey 1989). Bluenose appeared to be an unavoidable bycatch in this fishery and concerns were raised that it may be susceptible to over-fishing (Horn 1988a, Ryan & Stocker 1991, Baedle 1995). Active efforts by fishers after 1994–95 to avoid bluenose bycatch have had some effect in reducing this level of over-catch. When bluenose quota is scarce, fishers avoid dusk and dawn fishing and target alfonsino mainly during the night. (Langley 1995). Fishers also avoid fishing grounds where bluenose by-catch is known to be high (Langley 1995, Blackwell 1998).

Horn (1988a) and Ryan & Stocker (1991) found that bluenose CPUE bycatch in the target alfonsino fishery had declined from 1984–85 to 1987–88, but bluenose bycatch had increased. Langley (1995) found that both bluenose CPUE and landings of the target species (alfonsino and gemfish) remained stable from 1988–89 to 1993–94, but bluenose over-catch in these fisheries had increased since 1990–91. He attributed this to a shift in effort to new fishing grounds for alfonsino which were characterised by higher catch rates of bluenose.

3. METHODS

3.1 Data used in the analysis

The preliminary analysis of estimated catch data from the bluenose fishery presented to the 1998 Inshore Working Group (IWG) determined that the major trawl fisheries associated with bluenose were gemfish and alfonsino. Although a substantial amount of bluenose is taken by in target line fishing, bluenose bycatch in other target line fisheries in QMA 2 is relatively unimportant. The IWG agreed that subsequent analysis be confined to bluenose bycatch associated with the trawl fisheries for alfonsino and gemfish.

3.2 Preparation of data

All bluenose landings data from the midwater and bottom trawl fisheries that identified target species as either gemfish or alfonsino in QMA 2 (Statistical areas 011–016, 201–206) were extracted from the CELR and TCEPR databases. These data were summarised by fishing day (24 hrs of target fishing activity, *see* Horn 1988a). Range and edit checks were completed as described in Blackwell (1997). The data were allocated to fishing grounds as defined by Ryan & Stocker (1991), by the explicit position data provided on the TCEPR records. For the CELR data where statistical area only is reported, data were allocated to the most common fishing ground within each statistical area, as described in Ryan & Stocker 1991).

The data set was reduced from 6443 to 6092 daily records after "grooming". The data contained large numbers of zero catches (representing 40% of data in the BYX 2 target fishery and up to 60% of data in the target SKI 2 fishery).

3.3 Review of landings data

Bluenose landings prior to 1981 are considered inaccurate (Horn & Massey 1989), as considerable quantities were misreported as other species including "bonita" or groper.

Although the target line fishery declined after the introduction of midwater trawling in 1983–84 (Table 2), this target fishery subsequently recovered and now represents 30% of the 1995–96 landings. Analysis of landings by fishing method and target species (Table 3) indicates that 67% of line caught bluenose is taken in this target fishery. Bluenose represents a minor bycatch of other line fisheries in QMA 2 (Table 3).

Target bluenose trawl catch declined after 1990–91 (Table 3) and almost all trawl bluenose is now taken as bycatch. By 1995–96, of the 683 t of bluenose taken by trawling, 73% was taken as bycatch of the alfonsino target fishery. A further 12% of bluenose trawl landings was taken in hoki target fishing, 10% in gemfish target fishing and 4% in cardinal fish target fishing. Whilst most bluenose is caught in the first and second quarters of the fishing year (Table 4), this apparent seasonality may relate to shifts in effort in the target fisheries for alfonsino and hoki.

These data were presented to the 1998 Inshore Working Group and it was agreed that subsequent analysis should be confined to the midwater trawl fisheries for BYX 2 and SKI 2. The variables to be analysed were to be confined to fishing year, ground, season, target species and fishing method (Table 5).

3.4 Models

A range of data transformations were applied to the data, including the arcsine transformation, generally considered appropriate for the analysis of data in the form of proportions (Green 1979). Examination of residual plots and quartile-quartile plots determined that the log (x+1) transformation as specified in the contract appeared to be the most suitable for this analysis.

The lognormal linear (LNL) regression model (Doonan 1991, Vignaux 1992, Vignaux 1994) has been variously used to identify sources of variation in standardised CPUE in the alfonsino and bluenose fisheries (Langley 1995, Blackwell 1997). In this application, the effects of fishing year, ground, season, target species and fishing method on bluenose bycatch in the alfonsino and gemfish trawl fisheries were analysed separately using the stepwise log linear modelling procedure (Proc GLM) of the SAS statistical software package (SAS 1989).

It is usual to apply a log transformation to landed catch data, to stabilise the variance (Doonan 1991). To avoid problems of trying to calculate the log of zero, or to divide by zero when determining the by-catch ratio, a nominal weight of 1 kg was added to both the bycatch weight (numerator), and to the target species weight (denominator). A log transformation was then applied to this bycatch ratio. A sensitivity analysis was carried out to determine the effect of variation in the level of the constant term on subsequent analysis.

A stepwise multiple regression approach was used to calculate the log linear model. Analysis was continued until less than 1% improvement was seen in the R^2 with the inclusion of an additional variable. Analysis of the data examined both the main effects and first order interactions between these variables. Residual plots were examined for evidence of significant departures from model assumptions.

To aid in the interpretation of the trends between fishing years, seasons, grounds and methods, the median and interquartile range of the bycatch ratio was determined. Data are presented for the median bycatch ratio as the mean was highly variable (Appendix 1), particularly between fishing years and fishing grounds. The median bycatch ratio is less influenced by extreme values in the data.

4. RESULTS

4.1 BYX 2 target fishery

LNL regression analysis. Examination of the residual plots showed no evidence of departure from model assumptions. The variables fishing ground, fishing year, and the fishing year plus fishing ground interaction term entered the model. Addition of the remaining variables and interactions explained less than 1% of the variation in the data. The R^2 values for the fitted model (Table 6) explain only 11% of variability in the bycatch ratio, and other variables not included in this analysis may explain additional amounts of variation. Analysis of these variables is however, outside of the objectives of the current project.

The median and interquartile bycatch ratio data (log scale) have been examined for the variables included in the analysis. From Figures 3–6, little contrast occurs in the median and interquartile ranges of the bycatch ratio between fishing years, fishing grounds, quarter and method, although the years of highest overcatch appear to correspond to the years of widest interquartile range. The regression coefficients for the fitted variables are given in Table 7. Whilst the relative fishing year indices (Figure 7) are generally consistent with the overall level of overcatch (Figure 2), the existence of a significant fishing year and fishing ground interaction term indicates that changes in bycatch ratio differ between fishing grounds. Whilst bycatch indices (relative to 1996–97) appear to have increased for all grounds except Madden between 1988–89 and 1996–97, this is complicated by the spread of effort from the Madden, and later the Palliser and Ritchie grounds, to other areas, later in the development of the fishery. The bycatch ratio has remained relatively high on the Madden ground, except for 1992–93 and 1995–96.

A sensitivity analysis was completed to review the effect of variation in the constant (c) on the regression model. For values of c=0.01 kg, 1.0 kg and 10.00 kg (Table 8), the values of R^2 from the regression model varied by less than 1%. The parameter estimates from the model fits were found to be similar, suggesting that the model was not sensitive to changes of this magnitude in the constant term.

These patterns of bycatch ratio are complex and may be influenced by changes in the pattern of target fishing between fishing years, and to other variables outside the scope of the current analysis.

4.2 SKI target fishery

LNL regression analysis. Examination of the residual plots indicated that the data are skewed and bimodal. These departures from the model assumptions suggest caution in the interpretation of the SKI 2 target fishery data. The variables fishing year, ground and the fishing year plus ground interaction term entered the model, followed by quarter, then the ground plus quarter, and the fishing year plus quarter interaction term. The R^2 values (Table 9) indicate that the fitted model explains only 19% of the variation in the data. Other variables not examined in this project may explain significant amounts of variation.

The median and interquartile ranges of the bycatch ratio (log scale) have been examined to aid in interpretation of the data. From Figure 8 the median bycatch ratio increases from 1991–92, peaks in 1993–94 and then declines, which is generally consistent with the overall pattern of bluenose overcatch (Figure 2).

The median bycatch ratio (Figure 9) is high and relatively variable between the central fishing grounds (Ritchie, Motukura, Madden), and low, for both the northern grounds (East Cape, Tuaheni Tolaga) and southern grounds (Cook strait, Palliser). The value for the Kaiwhata ground indicates a low level of fishing activity. Little contrast is indicated between seasons (Figure 10), whilst a higher level of bycatch appears associated with midwater trawling (Figure 11).

The significant interaction terms (Table 9) suggest that complex relationships exist between these variables and the indices are given in Table 10. As noted in the analysis of the BYX 2 fishery, interpretations of the fishing year and fishing ground interaction is complicated by the spread of effort from the Madden, and Palliser grounds to other areas, later in the development of the fishery. However, the high number of zero records and concerns over the model assumptions precluded a detailed interpretation of these data.

A sensitivity analysis was completed to review the effect of variation in the constant (c) on the regression model (Table 11). For values of c 0.01 kg, 1.0 kg and 10.00 kg, the values of R^2 from the regression model varied by less than 1%. However, the parameter estimates varied between the three levels of R^2, which suggests that the fitted model is sensitive to changes in the value of the constant term.

The standardised annual indices of bycatch in the SKI 2 target fishery (Figure 12) may only be indicative of changes in bycatch ratio in this fishery and should be interpreted with caution. The ratio appears to have remained low from 1988–89 to 1991–92, then sharply increased to peak in 1992–93. The ratio declined sharply in 1993–94, then slowly increased from 1993–94 to 1995–96. The most recent data (1996–97) indicates a slight decrease in bycatch has occurred.

5. DISCUSSION

Bluenose in BNS 2 is a major bycatch of the midwater trawl fisheries for alfonsino and a minor bycatch in the gemfish fishery. It forms a minor, but increasing bycatch in the hoki and cardinal fish target fisheries. Although a small target line fishery exists, the bycatch of bluenose in other line fisheries is minimal.

Examination of the landings data reveals that the overall level of bluenose over-catch has increased from 1981 to peak in 1993–94 at 50% of the TACC. Whilst efforts by the fleet to reduce this level of bluenose bycatch have been partially successful at reducing bycatch between 1994–95 and 1995–96, the 1996–97 landings indicate a further increase in bluenose bycatch has occurred.

This project examined the effect of variables of fishing year, fishing ground, season and fishing method, on the bycatch ratio (weight of bluenose/weight of target species) in the BYX 2 and SKI 2 fisheries. The use of ratio data has several statistical disadvantages (Green 1979, Snedecor & Cochran 1980) and appears to be highly sensitive to the number of observations in the data. The bycatch ratio is difficult to interpret when bycatch is low but target catch is high, and is undefined when bycatch is high, but target catch is low.

Statistical advice (A. Dunn, NIWA, Greta Point *pers. comm.* 1998) suggests that the proportion of bluenose bycatch in the total catch, may have been a more suitable estimator of the relative level of bycatch. This appears to be less influenced by extreme values and does not require an arbitrary constant term. It is recommended that subsequent analyses consider the use of this estimator.

Initial examination of the data revealed a high proportion of zero catch records, particularly in the SKI 2 target trawl fishery, which exceeded 60% for some fishing years. From a range of data transformations including the arcsine transformation (Green 1979), the log (x+1) transformation (as specified in the contract) was found to be the most appropriate. However, the apparent bimodality and possible skewness of the data suggests that this transformation was insufficient to fully comply with the model assumptions especially in the SKI 2 target fishery.

For the target alfonsino trawl fishery, trends in the standardised annual indices of bluenose bycatch are generally consistent with the overall trends in bluenose landings. Whilst bycatch appears to have been reduced from the peak in 1993–94, due in part to the introduction of measures designed to decrease bycatch in this fishery (Langley 1995, Annala & Sullivan 1997), the indices have decreased for 1996–97 although overall bluenose landings have increased. Within the BYX 2 trawl fishery, the bycatch ratio differs between fishing years and fishing grounds in a complex manner generally consistent with (Langley 1995). The indices for the fishing year and fishing ground interaction are low for the Palliser ground and higher for the Tuaheni, Ritchie and Madden grounds, as suggested by Langley (1995). However, the indices for the Kaiwhata, Nth. Madden and Motukura grounds are also higher than the Palliser ground. The low overall R^2 values in the regression model suggests that other variables (such as vessel parameters of size, horsepower and gear parameters) should be investigated determining the relative level of bluenose bycatch between season, grounds and fishing year.

The target gemfish trawl fishery developed during 1991–92 and bluenose became a bycatch issue (Langley 1995). As the fishery expanded into new fishing grounds during 1992–93, some of these new areas include waters more shallow than the normal depth range of bluenose (M. Claudatos, Fish Processor, Napier, *pers. comm.* 1998). This has increased number of zero catch records of bluenose bycatch in this fishery to 60% for some fishing years (Blackwell 1998). These zero catch records and the variability in the bycatch ratio data may have confounded trends in the bycatch ratio. Although these data should be interpreted with caution, the annual indices appear generally consistent with the landings data and suggest that bycatch has been substantially reduced from the initial 1992–93 level. In subsequent years, annual bycatch indices have continued to rise, with a slight reduction in bycatch suggested for 1996–97. A detailed interpretation of the interaction terms in the target SKI 2 fishery was not been completed, due to a lack of data for many fishing ground-fishing year combinations, and for concerns about accuracy of the data.

The level of bluenose bycatch varies in a complex manner between target fisheries, fishing grounds and fishing years. Major changes appear to have occurred in fishing patterns in these target fisheries during the review period 1988–89 to 1996–97, which may have influenced the ratio of bluenose bycatch. In both the target SKI 2 and BYX 2 fisheries, the relative scarcity of bluenose quota after 1993–94 has encouraged fishers to attempt to reduce their bluenose bycatch. Fishers advise that from 1994–95, they have actively avoided grounds where bluenose are abundant, and now move away from areas where bluenose bycatch is high (Ryan & Stocker 1991, Langley 1995). However, the nature and scope of these changes probably varies in a complex pattern between vessels, vessel crews, fishing grounds and fishing years.

Whilst analysis of changes in the target alfonsino and gemfish fisheries indicates the level of bycatch appears to have decreased in these fisheries, the overall level of bluenose over-catch has again increased for 1996–97. The reasons for this increase are probably complex and may involve changes in other target fisheries (such as the recently developed fishery for hoki in QMA 2) that are not modelled in this project.

The changes in bluenose bycatch ratio may also relate to changes in relative abundance of alfonsino, gemfish and bluenose in the different fishing grounds. Bluenose are considered relatively fast growing (Horn 1988b) and may exhibit age-specific migration between fishing grounds (Horn & Massey 1989). Analysis of commercial catch landings data (Horn & Massey 1989, Blackwell 1998) indicates that the fishery appears to be dominated by 2–5 yr old fish which appear to be sexually immature (Horn & Massey 1989). Although bluenose recruit into the trawl fishery at ages 2–3 yrs (Blackwell 1998), the level of movement between fishing grounds is currently unknown.

A stepwise loglinear regression approach (Doonan 1991, Vignaux 1992, 1994, Ballara 1997), has not previously been used to model the bycatch ratio. The technique appears to have serious limitations where the data depart from the model assumptions of normalcy and constant variance, such as in the target SKI 2 fishery.

It is suggested that subsequent research into target-bycatch relationships consider the use of alternative approaches such as logistic analysis (A. Dunn, NIWA, Wellington, *pers. comm.* 1998) and review the use of the proportion of bycatch instead of the ratio of bycatch.

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Table 1: Reported landings (t) of bluenose by fishstock to 1996–97 and annual TACs (t) from 1985–86 to 1996–97.

Fishstock	BNS 1		BNS 2		BNS 3		BNS 7		BNS 8		BNS 10			
QMA(s)	1 & 9		2		3, 4, 5 & 6		7		8		10		Total	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1981 *	146	–	101	–	36	–	12	–	–	–	0	–	295	–
1982 *	246	–	170	–	46	–	22	–	–	–	0	–	484	–
1983 +	250	–	352	–	51	–	47	–	1	–	0	–	726	–
1984 +	464	–	810	*440*	81	–	30	–	1	–	0	–	1411	–
1985 +	432	–	745	*440*	73	–	26	–	1	–	0	–	1326	–
1986 +	440	–	1009	*440*	33	–	53	–	1	–	0	–	1566	–
1986–87ϒ	286	450	953	660	93	150	71	60	1	20	7	10	1411	1350
1987–88ϒ	405	528	653	661	101	166	104	62	1	22	10	10	1274	1449
1988–89ϒ	480	530	692	768	90	167	135	69	13	22	10	10	1420	1566
1989–90ϒ	535	632	766	833	132	174	105	94	3	22	0	10	1541	1765
1990–91ϒ	696	705	812	833	184	175	72	96	5	22	12 #	10	1781	1841
1991–92ϒ	765	705	919	839	240	175	62	96	5	22	40 #	10	2031	1847
1992–93ϒ	787	705	1151	842	224	350	120	97	24	22	29 #	10	2335	2026
1993–94ϒ	615	705	1288	849	311	350	79	97	27	22	3 #	10	2323	2033
1994–95ϒ	706	705	1028	849	389	357	83	150	79	100	0	10	2286	2171
1995–96ϒ	675	705	953	849	513	357	140	150	70	100	10	10	2352	2171
1996–97ϒ	966	1000	1100	873	540	357	145	150	86	100	9 #	10	2846	2490

(*440* t) Competitive total catch 1 Oct–30 Sept 1985-86 and 1986-87 (Baird & McKoy (1988))
* MAF data
\+ FSU data.
ϒ QMS data.
χ Includes landings from unknown areas before 1986-87, but excludes catches outside the N.Z. EEZ
\# Includes exploratory catches in excess of the TACC

Table 2: Estimated bluenose landings in BNS 2 by method from 1982–83 to 1995–96. Source: TCEPR and CELR data

Fishing method	Fishing year													
	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96
BT	40	427	478	691	992	501	649	581	374	458	608	756	740	683
Line	192	344	262	69	43	52	28	84	349	458	424	446	329	307
Setnet	1	2	1	1	6	4	15	19	29	18	18	6	5	5
Total	233	773	741	761	1041	557	692	684	752	934	1050	1208	1074	995

Table 3: Reported bluenose landings (t) by fishing method in each target fishery from 1988–89 to 1995–96. Source: TCEPR and CELR data

		Fishing year						
Fishing method	Target fishery	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96
Line	Bluenose	36	301	371	325	331	267	208
	Alfonsino	0	0	0	0	0	0	0
	Gemfish	0	1	14	0	0	2	2
	Groper	9	22	5	12	16	12	23
	Ling	32	25	49	82	73	44	30
	Ribaldo	0	0	0	0	0	1	1
	School shark	0	1	1	0	0	3	2
	Other	6	0	18	5	26	0	41
	Total	83	350	458	424	446	329	307
Setnet	Total	19	29	18	18	6	6	5
Trawl	Bluenose	117	147	77	55	1	1	1
	Alfonsino	432	157	313	368	503	526	496
	Barracouta	1	0	0	0	0	0	0
	Cardinal	2	5	2	2	26	34	25
	Gemfish	16	12	25	112	166	84	65
	Hoki	4	27	17	16	30	41	83
	Ling	1	1	0	1	2	0	0
	Orange roughy	1	0	2	1	14	19	3
	Scampi	4	10	9	19	5	7	7
	Rubyfish	3	1	9	31	8	23	2
	Other	1	13	4	3	1	4	1
	Total	582	373	458	608	756	739	683
All mthods total		684	752	934	1050	1208	1074	995

Table 4: Reported monthly landings of BNS 2 1993–94 to 1996–97. Source: QMS data

	Fishing year			
Month	**1993–94**	**1994–95**	**1995–96**	**1996–97***
Oct	141.91	152.798	126.785	103.796
Nov	173.883	172.69	257.399	169.315
Dec	175.257	112.552	113.985	124.204
Jan	136.845	136.109	65.192	106.947
Feb	110.506	59.039	74.782	115.376
Mar	75.091	84.359	67.992	149.886
Apr	92.739	47.177	61.502	66.454
May	80.474	28.579	50.467	70.866
Jun	55.784	31.089	31.542	26.42
Jul	31.752	48.696	31.997	22.46
Aug	134.844	76.021	22.172	19.905
Sep	78.468	79.173	49.093	57.783

* 1996–97 estimated monthly totals pro-rated from 1995–96 data and 1996–97 QMS total

Table 5: Summary of variables used in the analysis of BNS 2 bycatch Ratios

Variable	Description
Fishing year	Fishing years 1989–90 to 1996–97
Fishing ground	East Cape Tolaga Bay Tuaheni Ritchie/Paoanui Motukura Nth Madden Madden Sth Madden Kaiwhata Palliser Cook Strait
Target	Target species (BYX, SKI)
Season	Quarter of fishing year : 1 (Oct-Dec) 2 (Jan-Mar) 3 (Apr - Jun) 4 (Jul-Sep)
Method	Fishing method : Midwater trawl Bottom trawl

Table 6: Lognormal linear model (LNL). Choice of variables in order of importance in Regression analysis against log (bycatch ratio + 1) for BYX 2 target fishing from 1989–90 to 1996–97 (where values in bold represent significant variables)

	R^2 at iteration					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
Ground	**0.03**	*				
Fishing year	0.02	**0.06**	*			
Ground*Fishing year			**0.11**	*		
Quarter				0.11	*	
Ground*Fishing year					0.13	*
Ground*Quarter					0.12	
Method						0.13
Percentage increase in R^2		3.0	5.00	0.50	0.10	0.01

Table 7: Lognormal linear model (LNL). Standardised indices of bycatch ratio for significant variables in the regression analysis against log (bycatch ratio + 1) for BYX 2 target fishing from 1989–90 to 1996–97

Variable		
Fishing ground	**Ground**	**Index**
	(relative to Tuaheni)	
	EastCape	28.84
	Tolaga	9.26
	Tuaheni	1.00
	Ritchie	1.44
	CookStr	2.33
	N_Madden	8.57
	Madden	0.45
	S_Madden	2.52
	Motukura	5.25
	Kaiwhata	20.36
	Palliser	3.20
Fishing year	**Year**	**Index**
	(relative to 1996–97)	
	1988-89	0.84
	1989-90	4.85
	1990-91	2.10
	1991-92	8.55
	1992-93	5.72
	1993-94	9.85
	1994-95	3.74
	1995-96	4.30
	1996-97	1.00

Table 7: – *continued.*

Fishing year*Ground interaction

Ground (relative to Tuaheni, 1996–97)	**Index** **Fishing year** 1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97
East Cape							0.12	0.04	1.00
Tolaga Bay						0.13	0.20	0.16	1.00
Tuaheni	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ritchie/Paoanui	0.04	0.63	0.46	0.34	0.44	0.50	0.64	1.17	1.00
Motukura			0.56	0.33	0.28	0.84		0.38	1.00
Nth Madden					0.27	0.09	0.12	0.05	1.00
Madden	14.57	5.85	4.33	6.81	0.73	2.60	4.01	0.05	1.00
Sth Madden							0.30	1.65	1.00
Kaiwhata		0.06		0.01	0.20	0.03	0.04	0.01	1.00
Palliser	1.09	0.24	0.28	0.35	0.14	0.10	0.10	0.10	1.00
Cook Str		0.01		2.20	0.01		1.00		1.00

Table 8: BNS 2 sensitivity analysis. Comparison of three levels of the constant (c) for the fitted model of log (bycatch ratio + 1) in the BYX 2 target trawl fishery

Constant	R^2
0.01 kg	0.11
1.00 kg	0.11
10.00 kg	0.11

Table 9: Lognormal linear model (LNL). Choice of variables in order of importance in regression analysis against log (bycatch ratio + 1) for SKI 2 target fishing from 1989–90 to 1996–97 (where values in bold represent significant variables)

Variables	**Iteration** 1	2	3	4	5	6	**R2 at iteration** 7
Fishing year	**0.06**	*					
Ground	0.03	**0.10**	*				
Ground* Fishing year			**0.13**	*			
Quarter				**0.14**	*		
Quarter*Ground					**0.17**	*	
Quarter*Fishing year					0.17	**0.19**	*
Method							0.19
Percentage increase in R2		4.0	3.0	1.0	3.0	2.0	0.1

Table 10: Lognormal linear model (LNL). Standardised indices of bycatch ratio for significant variables in the regression analysis against log (bycatch ratio + 1) for SKI 2 target fishing from 1989–90 to 1996–97

Variables	Year	
Fishing year	(relative to 1996–97)	**Index**
	1988–89	0.01
	1989–90	0.05
	1990–91	0.02
	1991–92	0.25
	1992–93	2.67
	1993–94	0.43
	1994–95	0.87
	1995–96	1.18
	1996–97	1.00

Fishing ground	Ground	Index
	(relative to Tuaheni)	
	EastCape	3.72
	Tolaga	0.20
	Tuaheni	1.00
	Ritchie	3,317.61
	CookStr	0.76
	N_Madden	3,540.41
	Madden	5.82
	S_Madden	195.58
	Motukura	133.88
	Kaiwhata	1,438.13
	Palliser	581.48

Fishing year*Ground interaction

	Index								
	Fishing year								
Ground	**1988–89**	**1989–90**	**1990–91**	**1991–92**	**1992–93**	**1993–94**	**1994–95**	**1995–96**	**1996–97**
(relative to Tuaheni, 1996–97)					0.70	0.11	1.86	0.24	
East Cape		0.29	1.35	0.10					1.00
Tolaga Bay			1.06	2.27	1.15	1.43	9.34	2.73	1.00
Tuaheni		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ritchie/Paoanui				0.01	0.04	0.01		1.00	1.00
Motukura					0.24		4.82	0.54	1.00
Nth Madden			0.02	0.05	0.17	0.37	0.08	0.36	1.00
Madden	4.87	0.95	1.45	0.65	1.28	1.15	0.88	0.73	1.00
Sth Madden							1.36		1.00
Kaiwhata									1.00
Palliser	1.00	0.47	0.93	0.42	2.98	5.71	1.03	1.45	1.00
Cook Str		2.79	9.17	0.56	28.70	0.52	12.40	1.00	1.00

Quarter	Quarter	Index
	(relative to Qtr 4)	
	1	0.75
	2	0.26
	3	0.28
	4	1.00

Table 10: *(continued)*

Ground*Quarter interaction — Index

	Quarter 1	2	3	4
East Cape	0.39	0.08	1.00	1.00
Tolaga Bay	1.79	34.23	10.72	1.00
Tuaheni	1.00	1.00	1.00	1.00
Ritchie/Paoanui	1.00		1.00	
Motukura	1.92	0.47	17.40	0.00
Nth Madden	0.02	0.01	0.01	1.00
Madden	0.28	0.37	0.21	1.00
Sth Madden	1.23			1.00
Kaiwhata		1.00		
Palliser	0.01	0.01	0.01	1.00
Cook Str	0.46	1.34	7.71	1.00

Fishing year*Quarter interaction — Index

Fishing year (relative to 1996–97)	Quarter 1	2	3	4
1988–89			1,053.63	1.00
1989–90	4.87	7.28	5.07	1.00
1990–91	4.07	16.99	15.01	1.00
1991–92	0.42	2.01	5.28	1.00
1992–93	0.10	0.46	0.30	1.00
1993–94	3.34	12.35	2.95	1.00
1994–95	0.62	0.73	1.60	1.00
1995–96	0.46	0.59	1.00	1.00
1996–97	1.00	1.00	1.00	1.00

Table 11: BNS 2 sensitivity analysis. Comparison of three levels of the constant (c) for the fitted model of log (bycatch ratio + 1) in the SKI 2 target trawl fishery

Constant	R^2
0.01 kg	0.19
1.00 kg	0.19
10.00 kg	0.20

Appendix 1: Bluenose bycatch ratio (reported kg. per day fished) in the target BYX 2 and SKI 2 trawl fisheries 1988–89 to 1996–97

Bluenose ratio $\frac{\text{Wt. BNS 2 + 1}}{\text{Wt. target species +1)}}$

Bycatch ratio by ground in the target BYX 2 trawl fishery (where n≥ 5)

Ground	Mean ratio	Median ratio	Interquartile range
East Cape	0.89	1.00	0.76
Tolaga	8.61	0.30	0.93
Tuaheni	12.96	0.25	0.65
Ritchie	44.10	0.16	0.45
Nth Madden	54.28	0.18	0.58
Madden	42.60	0.38	0.88
Sth Madden	2.32	0.34	0.90
Motukura	123.61	0.48	1.40
Kaiwhata	7.04	0.16	0.96
Palliser	79.06	0.14	0.64
Cook Strait	73.14	0.25	0.99

Bycatch ratio by fishing year in the target BYX 2 trawl fishery

Fishing year	Mean ratio	Median ratio	Interquartile range
1988–89	0.55	0.22	0.98
1989–90	65.98	0.26	0.60
1990–91	1.05	0.12	0.28
1991–92	110.12	0.25	0.91
1992–93	66.85	0.19	0.77
1993–94	78.96	0.33	1.04
1994–95	12.26	0.21	0.84
1995–96	33.24	0.20	0.68
1996–97	1.93	0.20	0.95

Bycatch ratio by quarter in the target BYX 2 trawl fishery
(where 1=Oct–Dec, 2+Jan–Mar, 3=Apr–Jun, 4=Jul–Sep).

Quarter	**Mean ratio**	**Median ratio**	**Interquartile range**
1	37.82	0.23	0.94
2	61.67	0.20	0.63
3	48.84	0.20	0.60
4	61.95	0.25	0.92

Bycatch ratio by method in the target BYX 2 trawl fishery
(where BT=bottom trawl, MW=midwater trawl)

Method	**Mean ratio**	**Median ratio**	**Interquartile range**
BT	29.75	0.16	0.99
MW	54.02	0.23	0.73

Appendix 1: *– continued*

Bycatch ratio by ground in the target SKI 2 trawl fishery (where n≥ 5)

Ground	Mean ratio	Median ratio	Interquartile range
East Cape	0.76	0.01	0.02
Tolaga	4.35	0.01	0.05
Tuaheni	0.53	0.01	0.03
Ritchie	5.52	0.29	11.00
Nth Madden	18.42	0.02	0.71
Madden	2.18	0.001	0.006
Sth Madden	75.37	0.75	150.24
Motukura	20.09	1.08	9.57
Kaiwhata	7.35	7.35	0.00
Palliser	16.02	0.01	0.54
Cook Strait	1.74	0.01	0.01

Bycatch ratio by fishing year in the target SKI 2 trawl fishery

Fishing year	Mean ratio	Median ratio	Interquartile range
1988–89	0.01	0.01	0.01
1989–90	0.13	0.01	0.01
1990–91	0.08	0.01	0.01
1991–92	1.10	0.01	0.01
1992–93	3.98	0.01	0.20
1993–94	5.53	0.02	0.50
1994–95	5.64	0.01	0.25
1995–96	15.97	0.01	0.10
1996–97	1.50	0.01	0.10

Bycatch ratio by quarter in the target SKI 2 trawl fishery
(where 1=Oct–Dec, 2+Jan–Mar, 3=Apr–Jun, 4=Jul–Sep).

Quarter	**Mean ratio**	**Median ratio**	**Interquartile range**
1	1.32	0.01	0.05
2	2.42	0.01	0.16
3	2.53	0.01	0.05
4	37.86	0.02	0.99

Bycatch ratio by method in the target SKI 2 trawl fishery
(where BT=bottom trawl, MW=midwater trawl)

Method	**Mean ratio**	**Median ratio**	**Interquartile range**
BT	2.35	0.01	0.07
MW	30.48	0.12	0.43

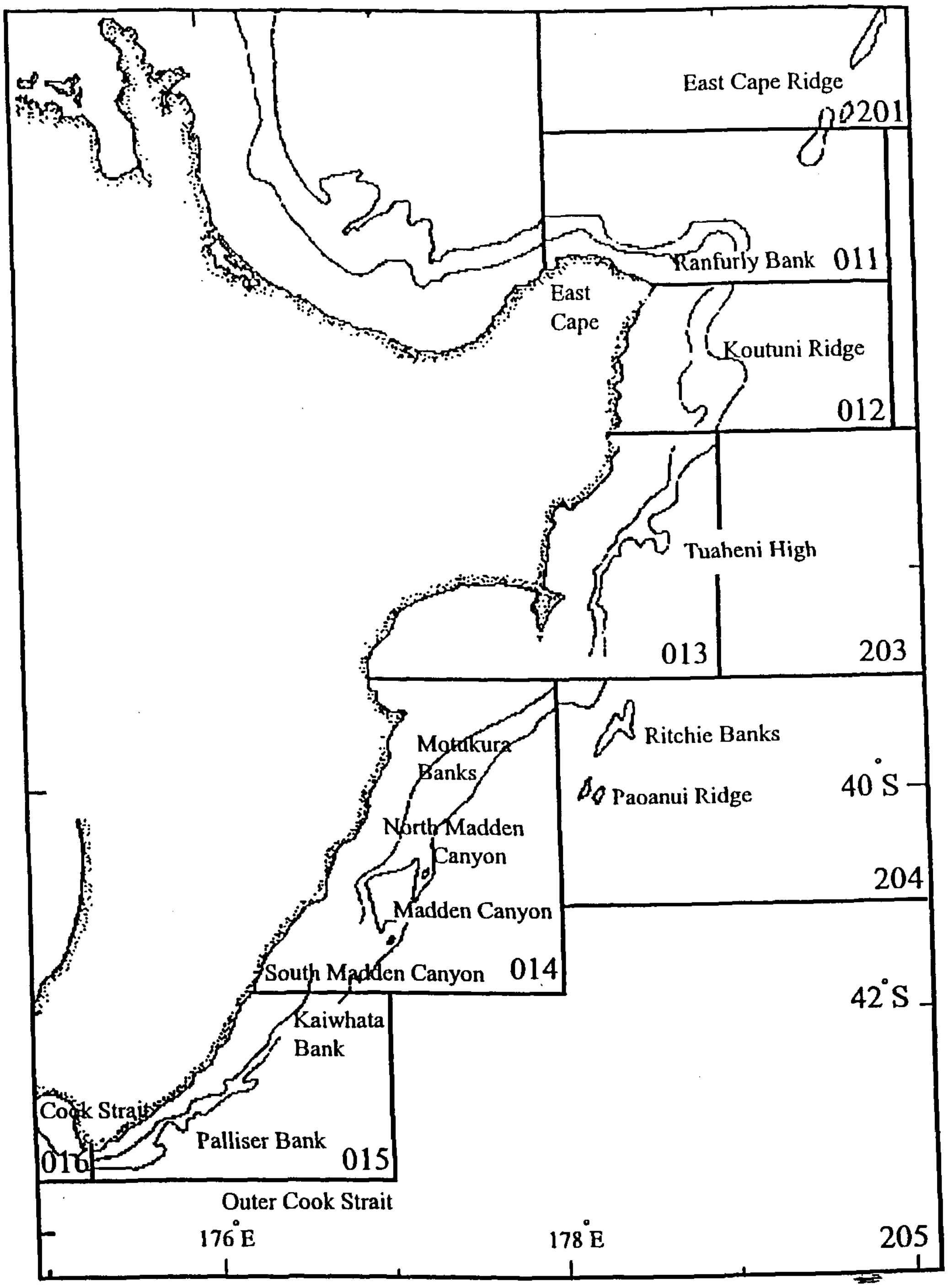

Figure 1: The bluenose fishery in QMA 2 showing inshore (011-016) and deepwater (201-205) statistical reporting areas. Major fishing grounds are also shown.

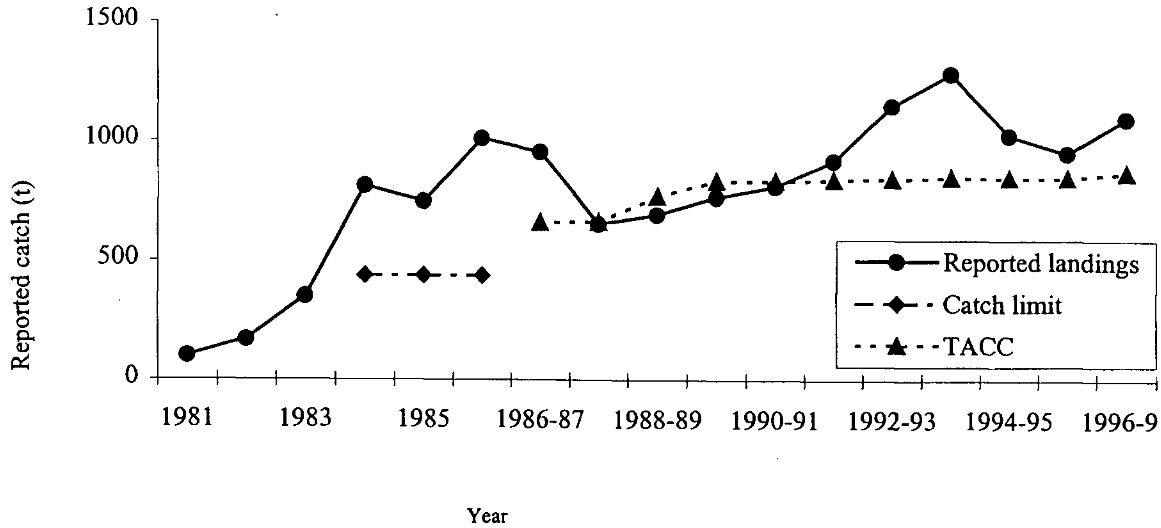

Figure 2: BNS 2 reported catch and catch limits 1981 to 1996–97
Calendar year 1981 to 1986, Fishing year 1986–87 to 1996–97
Catch limit 1984–86 TACC 1986–87 to 1996–97

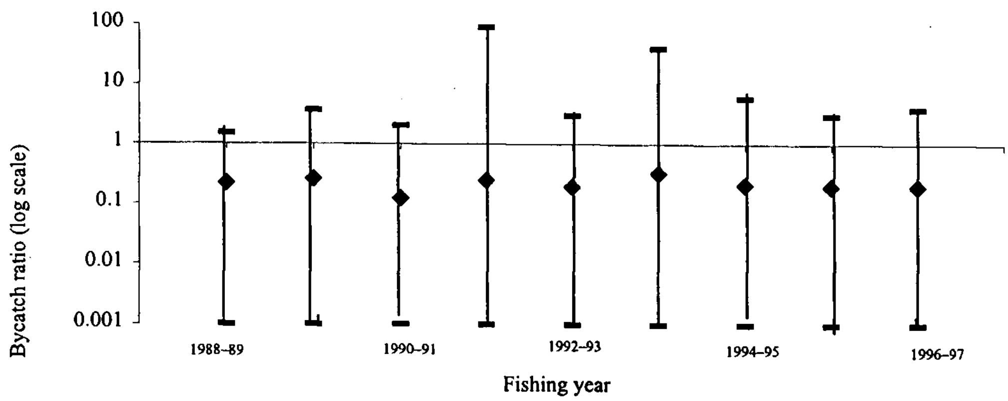

Figure 3: Median and interquartile range for bycatch ratio by fishing year in the BYX 2 target trawl fishery 1988–89 to 1996–97

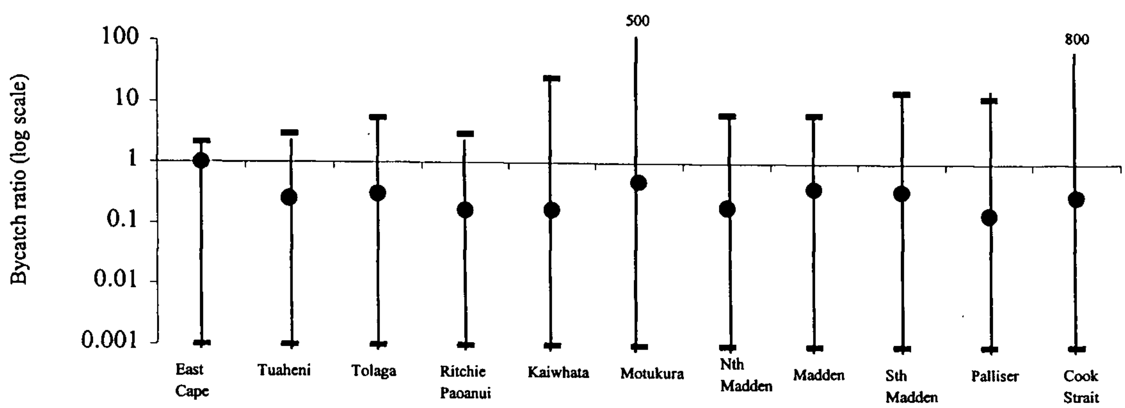

Figure 4: Median and interquartile range for bycatch ratio by ground in the BYX 2 target trawl fishery 1988–89 to 1996–97

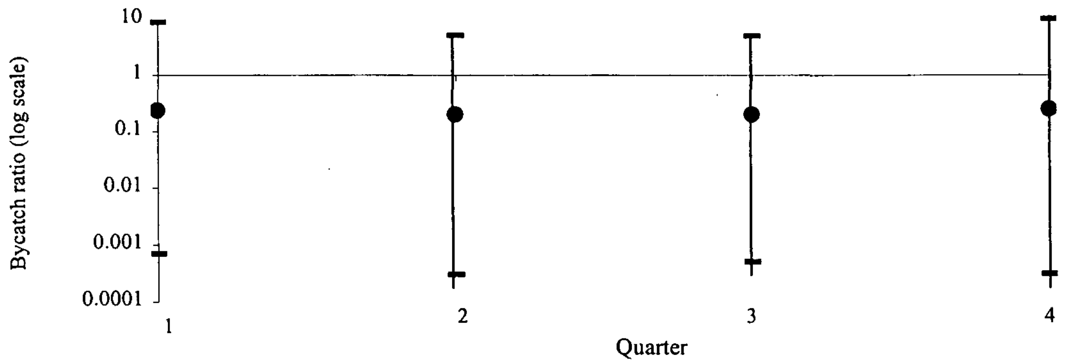

Figure 5: Median and interquartile range for bycatch ratio by quarter in the BYX 2 target trawl fishery 1988–89 to 1996–97

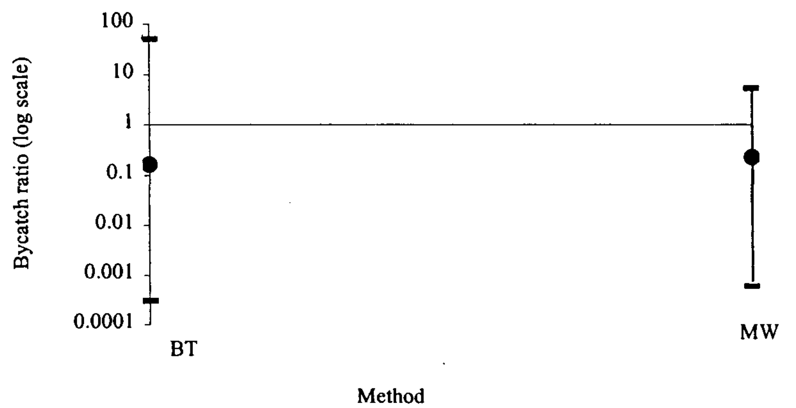

Figure 6: Median and interquartile range for bycatch ratio by method in the BYX 2 target trawl fishery 1988–89 to 1996–97

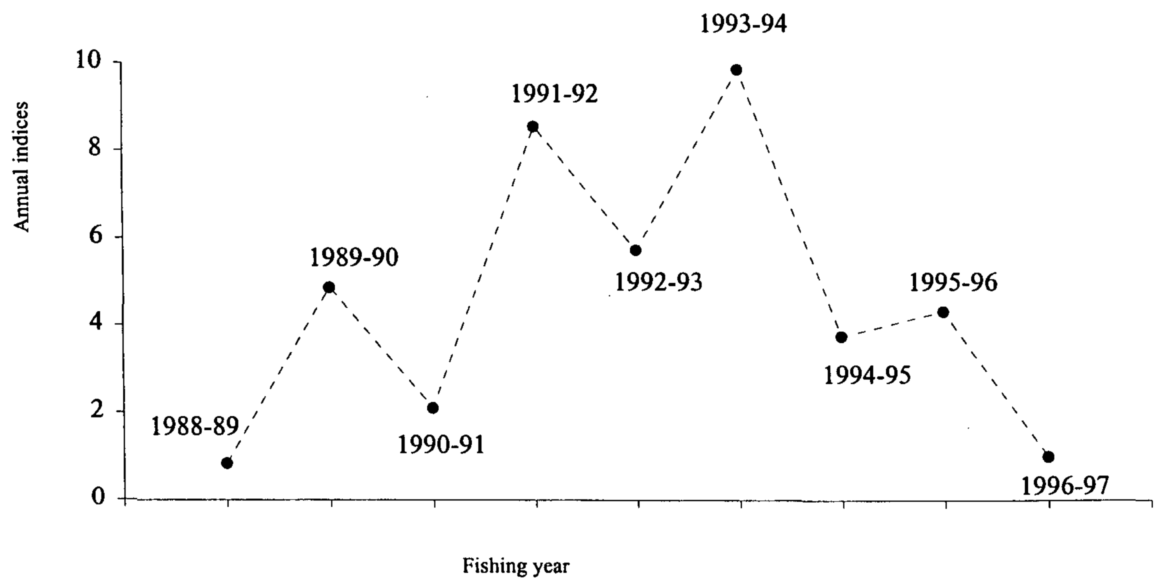

Figure 7: Annual indices of bycatch ratio by fishing year in the BYX 2 target trawl fishery 1988– to 1996–97

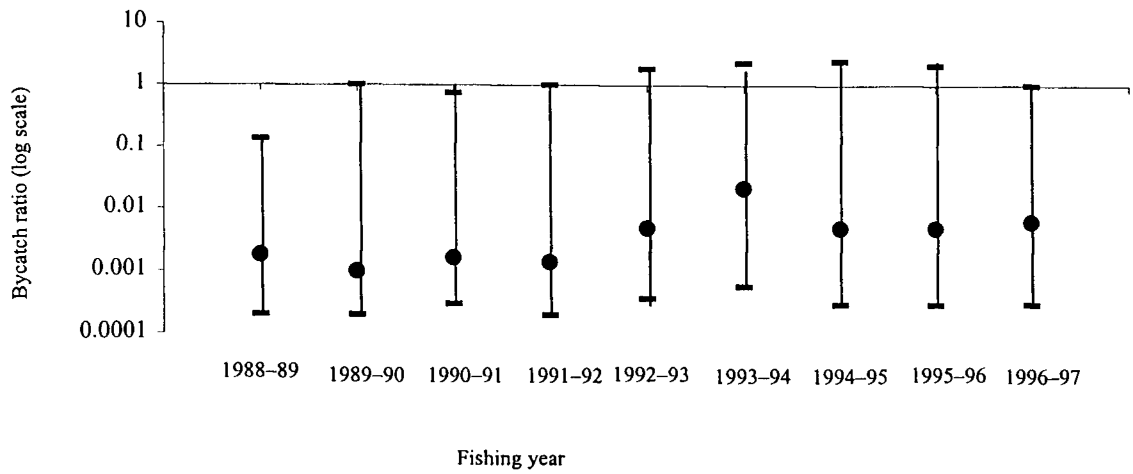

Figure 8: Median and interquartile range for bycatch ratio by fishing year in the SKI 2 target trawl fishery 1988–89 to 1996–97

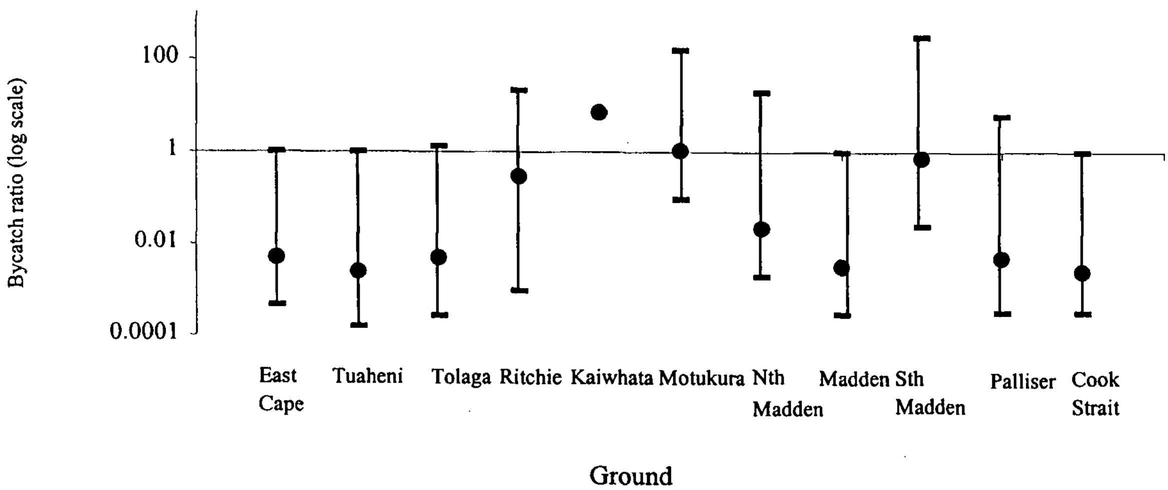

Figure 9: Median and interquartile range for bycatch ratio by ground in the SKI 2 target trawl fishery 1988–89 to 1996–97

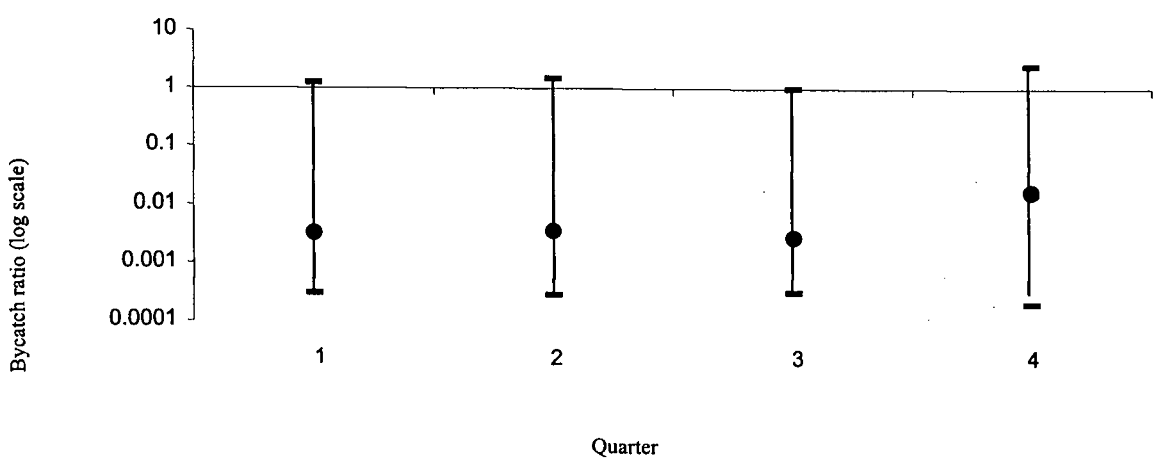

Figure 10: Median and interquartile range for bycatch ratio by quarter in the SKI 2 target trawl fishery 1988–89 to 1996–97

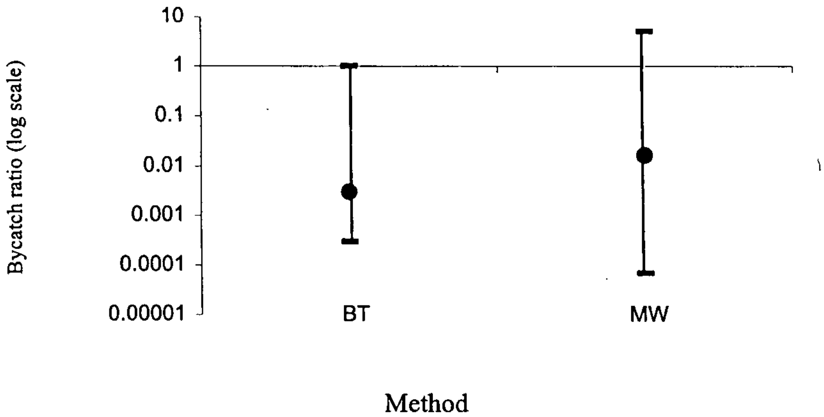

Figure 11: Median and interquartile range for bycatch ratio by method in the SKI 2 target trawl fishery 1988–89 to 1996–97

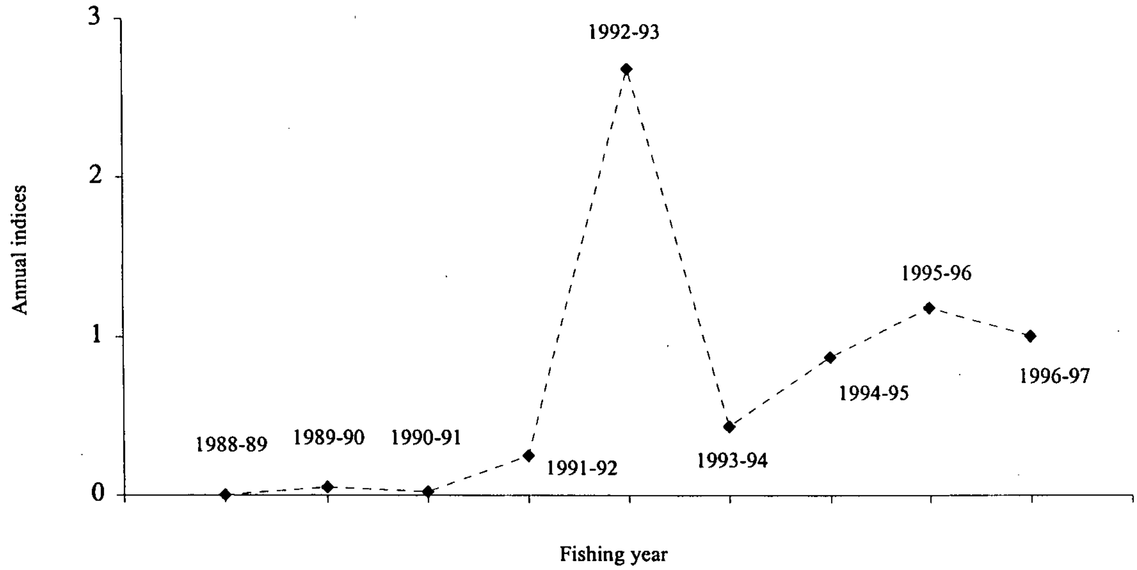

Figure 12: Annual indices of bycatch in the SKI 2 target trawl fishery 1988–89 to 1996–97