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EXECUTIVE SUMMARY

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Recent trends in CPUE for the BYX 3 alfonsino (*Beryx splendens*) fishery, and fishery interactions between alfonsino and bluenose (*Hyperoglyple antarctica*), were examined. The principal objective of the study was to determine whether trends in CPUE from the target BYX 3 fishery were likely to enable monitoring of the relative abundance of alfonsino in BYX 3.

A standardised CPUE index was constructed. The CPUE data set included target trawl records from the East Chathams fishery from 1995–96 to 1999–2000. Five separate models were initially considered and, based on the diagnostics of the models, one option was preferred. However, all models were limited by the small data set, the high variation in the observed catch rates, and changes in the distribution of fishing effort over the study period.

For the preferred model option, annual CPUE indices varied between years and did not yield any systematic trend in CPUE from the fishery. The indices had a high standard deviation and, therefore, the time series is capable only of detecting large changes in catch rate between years. In contrast, unstandardised CPUE declined considerably from 1995 to 2000. This discrepancy is partially explained by a change in the distribution of fishing effort. Overall, the CPUE models have limited immediate application for monitoring the abundance of alfonsino in the BYX3 fishery. However, the recent decline in catches, in particular the decline in proportion of large catches (those exceeding 5 t) suggests that the fishery warrants further monitoring.

Bluenose represents an important bycatch in the target BYX 3 trawl fishery. Between 1995–96 and 1999–2000, the fishery yielded a bycatch of 100–150 t of bluenose annually, mostly from the East Chathams fishery. This represented 20–30% of the total BNS 3 catch taken during the same period. Trends in the bycatch of bluenose from the East Chathams fishery were examined to determine whether there was potential for the fishery to reduce the current level of bluenose bycatch. Bycatch rates were determined by fishing area and the factors influencing the level of bycatch were investigated using a generalised linear modelling approach.

Trends in the ratio of alfonsino and bluenose catch reveal differences in the level of bycatch between fishing areas, although for some areas the ratio was highly variable between years. The results of the GLM modelling were equivocal and were not sufficiently reliable to identify any key factors that may influence the level of bluenose catch. However, trends in the model coefficients were broadly comparable to the differences in the unstandardised bycatch ratios between fishing areas.

1. INTRODUCTION

The annual catch from the BYX 3 fishery increased from 1994–95 with the development of the target trawl fishery, principally in the area to the southeast of the Chatham Islands (Langley & Walker 2002). During 1995–96 to 1998–99, the total catch from the BYX 3 fishery was around the level of the TACC of 1010 t, although the annual catch declined to 743 t in 1999–2000 (Annala et al. 2001).

The analysis of trends in catch and effort from the target alfonsino fishery was proposed as a potential option for monitoring trends in the abundance of alfonsino in BYX 3. Several analyses of CPUE data from the more established BYX 2 target fishery have been undertaken, although the results are equivocal (Horn 1988, Horn & Massey 1989, Stocker & Blackwell 1991, Langley 1995, Blackwell 2000). Details of the various analyses of BYX 2 CPUE data were summarised by Langley & Walker (2002).

In 2000, the Inshore Fishery Assessment Working Group rejected the most recent analysis of CPUE data from BYX 2 as an index of stock abundance, largely due to significant changes in the operation of the fishery over the period included in the analysis (Blackwell 2000). However, in the absence of other monitoring within the BYX 3 fishery, it was proposed to investigate the utility of CPUE data from the target fishery in this area.

Within the BYX 2 fishery, bluenose (BNS 2) has frequently been caught as an important bycatch of the target alfonsino fishery (Annala et al. 2001). Trends in the level of bluenose bycatch have been shown to vary with respect to fishing ground within BYX 2 (Langley 1995). The development of the BYX 3 target fishery has been partly attributable for the large increase in the level of BNS 3 catch in recent years (Starr & Langley 2001). In 1995–96 to 1999–2000, the BYX 3 target fishery accounted for 20–30% of the total BNS 3 catch, with the remainder of the catch taken by other trawl and line fisheries (Starr & Langley 2001). An investigation of the factors contributing to the level of bluenose bycatch from the BYX 3 fishery may identify fishing practices that would minimise the bycatch of bluenose.

The work summarised in this report was conducted under MFish research project BYX2000/01, Characterisation of the alfonsino fishery in BYX 3, as requirements of project objectives 2 and 3. The specific project objectives are as follows.

1. To characterise the BYX 3 fishery by analysis of existing commercial catch and effort data and data from other sources; and make recommendations on appropriate methods to monitor or assess the status of this Fishstock.

2. To develop a standardised CPUE index for the BYX 3 fishery using data from the catch and effort database up to the end of the 1999–2000 fishing year.

3. Describe the interaction between the fisheries for alfonsino and bluenose in QMA 3.

The results of objective 1 were documented by Langley & Walker (2002) and the document provides background information on recent trends in the operation of the commercial fishery and summarises the results of previous CPUE analyses of alfonsino fisheries, principally from BYX 2.

2. CPUE DATASET

The CPUE analysis of catch and effort data from the BYX 3 fishery was restricted to the target trawl fishery operating in the Eastern Chathams area. This fishery accounted for most of the recent increase in catch from the BYX 3 fishery and operates within a relatively discrete area (Langley & Walker 2002). All target trawls from this sector of the fishery were reported in TCEPR format.

The CPUE data set was limited to the five core vessels that had completed at least 100 trawls (midwater and bottom trawls) and/or had operated in the fishery for at least three fishing years between 1995–96 and 1999–2000. These vessels were either factory vessels processing the catch to the dressed state (Vessels A and C) or ice vessels landing the catch unprocessed (Vessels B, D, and E). Before 1995–96, only limited data were available from the fishery and these records were excluded from the analysis.

From 1995–96 to 1999–2000, the BYX 3 fishery was dominated by the bottom trawl method and only a small proportion of fishing was by midwater trawl. The operation of the two fishing methods is different and, consequently, the relationship between CPUE and the potential explanatory variables may differ between the two gear types. On this basis, the few midwater trawl records were excluded from the data set and the CPUE analysis used target bottom trawls only.

The variables included in the CPUE dataset are described in Table 1. Error checking of the initial data set was detailed by Langley & Walker (2002).

3. DATA SUMMARY

The dataset included 200–300 trawls conducted annually in the East Chathams fishery between 1995–96 and 1999–2000. These trawls accounted for an annual BYX 3 catch of about 450–550 t during 1995–96–1997–98, although the catch declined in the two more recent years to 300–350 t (Table 2).

The first two years of the dataset comprised trawls conducted by two vessels only. Three vessels operated in the fishery in 1997–98 and 1998–99 and another vessel was active in 1999–2000. Only one vessel participated in the fishery throughout the five-year period (Table 3). Four of the vessels operating in the fishery were 37–45 m in length (overall length): the other vessel was 62 m in length. Vessel B operated in the fishery for three years, but fished exclusively in one year using midwater trawl gear. Therefore, despite completing less than 100 bottom trawls in only two years, the vessel still satisfied the criteria for inclusion in the CPUE analysis.

Within the East Chathams area, most of the trawls were directed at a limited number of geographical features (Table 4). A high proportion of the trawls were conducted on five specific features (subareas S1, S2, S3, S5, and S7), while a smaller number of trawls were conducted in subareas S4 and S6 (Figure 1). For the CPUE analysis, these latter two areas were amalgamated in a separate category that also included other trawls outside the main subareas fished (Other category).

There was no apparent trend in the duration of individual trawls during the period studied, with the exception of slightly shorter trawl duration in the first year of the time-series (Table 2, Figure 2). However, the unstandardised catch rate of alfonsino, expressed as the average catch per trawl and the average catch per hour, declined by 60–70% during the five-year period (see Table 2). The trend in catch rate is consistent with the observed decline in the proportion of trawls catching at least 5 t of alfonsino between 1995–96 and 1999–2000 and a corresponding increase in the proportion of smaller catches (less than 1 t) (Figure 3). There was no apparent trend in the proportion of nil catches over the period, generally about 15–20% of all trawl records (see Table 2).

4. CPUE MODELLING

A standardised CPUE analysis of the East Chathams alfonsino fishery was conducted based on the methods of Vignaux (1992, 1994).

Several model options were initially considered in the CPUE analysis relating to the treatment of zero catch records and the inclusion of vessel parameters (Table 5). For three of the model options, records with a zero catch of alfonsino were excluded. In the *Alldata* model these records were included in the dataset and assigned a nominal value of 1 kg.

Due to the small number of vessels included in the dataset, most model options included the variable *vessel* as a categoric variable to account for differences in fishing power between vessels. The *VesselE* model included only data from the one vessel that persisted in the fishery over the five-year period. This vessel accounts for a significant proportion of the catch and effort records and, consequently, dominates the CPUE analysis. However, the separate model options were investigated to determine the extent of the influence of the other vessels on the annual CPUE indices.

For three model options (1, 2, and 4), the natural logarithm of the alfonsino catch (kg) from the trawl was used to determine the CPUE estimate (dependent variable) in the model. For these options, trawl duration was introduced as a potential predictor variable in the model enabling the model to determine the most appropriate relationship between trawl catch and trawl duration.

As an alternative measure of CPUE, the *CRate* model used the logarithm of catch (kg) per hour as the CPUE estimate (Option 3). However, this measure imposes the assumption of a constant linear relationship between catch and trawl duration. An examination of unstandardised catch rates from the fishery revealed catch rates were greatest for short duration trawls (less than 15 minutes) and declined with increasing trawl duration up to 30 minutes. Catch rates were relatively constant, at a low level, for trawls of between 30 minutes and 2 hours (Figure 4).

The binomial model (Option 5) used the presence or absence of alfonsino catch in the trawl as the CPUE estimate for the model.

For each model option, the relevant CPUE estimate (the dependent variable) was tested against the predictor variables summarised in Table 1. All continuous variables were offered to the model as third order polynomial functions.

The CPUE estimate was regressed against each of the predictor variables to determine which explained the most variability in CPUE. This selected variable was then included in the model and the CPUE regressed against the selected variable and each of the other predictor variables to determine the next most powerful variable. The stepwise regression was continued until the remaining variables contributed no significant explanatory power to the model (less than a 5% increase in the R^2 value).

Annual indices were determined relative to a base year of 1995–96. The standard deviation of the annual indices was determined following Vignaux (1992).

For each model option, the model fit was investigated through an examination of the model residuals and quantile-quantile plots (Chambers et al. 1983). The predicted relationship between CPUE and each of the main variables included in the model was also examined.

For the *Vesselcat* model, interaction terms between *fishing year* and *vessel* and *fishing year* and *subarea* were also examined. The interaction terms were fitted in the *Vesselcat* model while fixing the regression coefficients for the other model variables.

4.1 Results

4.1.1 Vesselcat model

The *Vesselcat* CPUE model resulting from the stepwise regression procedure has the following structure:

$$\begin{aligned} CPUE_t = {} & M + vessel_{l,t} + month_{m,t} + fishing\ year_{n,t} + A\,start\ time_t + B\,start\ time_t^{\wedge 2} \\ & + C\,start\ time_t^{\wedge 3} + subarea_{o,t} + E_t \end{aligned}$$

where	$CPUE_t$	is the catch per unit effort for the t[th] tow,
	M	is the overall mean for log($CPUE_t$),
	$vessel_{l,t}$	is the regression coefficient for the l[th] vessel,
	$month_{m,t}$	is the regression coefficient for the m[th] month,
	$fishing\ year_{n,t}$	is the regression coefficient for the n[th] fishing year,
	A	is the linear regression coefficient for *start time*,
	B	is the quadratic regression coefficient for *start time*,
	C	is the cubic regression coefficient for *start time*,
	$subarea_{r,t}$	is the regression coefficient for the r[th] subarea,
	E_t	is the error in log(CPUEt).

Vessel was the best predictor variable followed by the categoric variable *month*. The *fishing year* was included in the model as the third variable and *start time* was included at the fourth iteration as a third order polynomial function. *Subarea* was the final variable included in the model. The CPUE model explained 13.5% of the variation in the logarithm of catch per trawl (Table 6). Diagnostic plots indicate a reasonable pattern in the residuals, although the quantile-quantile plot indicates a deviation from the normal distribution of the residuals (Figure 5).

The *vessel* coefficients derived from the *Vesselcat* model revealed that one vessel (Vessel C), the largest vessel in the fleet, had a higher catch rate than the remainder of the fleet (Figure 6).

The fishery was concentrated during the summer and, consequently, *month* coefficients derived from the CPUE model do not encompass the entire fishing year. However, the coefficients indicate that catch rates were highest between November and February (Figure 6).

The CPUE model indicates a strong diurnal trend in the catch rates from the fishery, with highest catches taken around midnight and lowest catches during midday (Figure 6).

The *subarea* coefficients indicate higher catch rates were achieved in subareas S2 and S7: catch rates were comparable between the other areas fished (Figure 6). However, the coefficients have broad confidence intervals and, consequently, differences between *subareas* are not significant.

There is considerable variation in the annual indices derived from the model for the 1995–96 to 1999–2000 period. The 1997–98 and 1998–99 indices were comparable to the 1995–96 base-year, but the indices for 1996–97 and 1999–2000 were lower, at 60% and 50% of the base index, respectively (Table 7 and Figure 7). However, the differences between the annual indices are not significant due to the high standard error of the indices.

The inclusion of the *fishing year/vessel* interaction term separately in the *Vesselcat* model revealed divergent trends in annual catch rate for the five vessels operating in the fishery. Catch rates for the single vessel participating in the fishery throughout the five-year period (Vessel E) were relatively constant (Figure 8). However, two vessels operating in the fishery for two successive years (Vessels A and C) both showed an increase in catch rate in the second year. The improved efficiency of these vessels may be attributable to increased experience in the fishery. The converse trend was apparent for Vessel D with a declining trend in catch rate between 1997–98 and 1999–2000.

The interaction between *fishing year* and *subarea* revealed catch rates were relatively constant within subareas S3, S5, and S7 between 1995–96 and 1999–2000, but were more variable in other areas (Figure 9). Catch rates from subarea S1 declined between 1998–99 and 1999–2000, while catch rates from subarea S2 declined from 1995–96 to 1996–97, recovered in the two subsequent years, and declined in 1999–2000.

4.1.2 VesselE model

The *VesselE* model included the same variables as the *Vesselcat* CPUE model, with the exception of the *vessel* variable. The model explained only 7.4% of the variation in the logarithm of the catch from the single vessel. An examination of the model coefficients for the *month, start time,* and *subarea* variables revealed similar trends to those described for the *Vesselcat* model. However, the trend in the annual indices for the individual vessel was different from that of the entire fleet. The two sets of indices are comparable in 1995–96, 1996–97, and 1999–2000, but diverge during the intervening years. The *VesselE* index increased to a peak in 1998–99 to a level 1.8 times the 1995–96 base year (Figure 10).

The differences in the annual indices between the two models appear largely attributable to differences in the distribution of fishing effort between the main subareas fished. In 1997–98 and 1998–99, most of the fishing within subarea S2 was conducted by Vessel E and this area accounted for a high proportion of all CPUE records for the vessel. This subarea was characterised by a higher catch rate in these two fishing years from the *Vesselcat* model (see Figure 6), but translated to a high annual index in the *VesselE* model because the *VesselE* model probably had too few contrasting records to estimate the relative catchability between the subareas.

4.1.3 Crate model

The *Crate* Model included the same variables as both the *Vesselcat* and *VesselE* CPUE models, namely *subarea, vessel, month, fishing year,* and *start time.* However, the order of importance of the variables differed from the two other models and the *Crate* model explained a higher proportion of the variation in the CPUE expression (R^2 24%) (Table 8). Nevertheless, despite the higher apparent explanatory power of the *Crate* model, the *Vesselcat* model actually has a lower residual deviance due to the lower total variation in CPUE expression log (catch) compared to log (catch per hour).

Diagnostic plots indicate a reasonable pattern in the residuals, although the Q-Qplot indicates a deviation from the normal distribution of the residuals (Figure 11).

An examination of the regression coefficients for each of the variables included in the *Crate* model revealed similar trends to those described for the *Vesselcat* model (see above). The annual indices for the two models were very similar, diverging only slightly in the last three years of the series (see Figure 10).

4.1.4 Alldata model

The *Alldata* CPUE model, with the inclusion of zero alfonsino catches in the dataset, included *start time, vessel, month, duration, subarea,* and *end time* as significant variables in the model (Table 9). These variables explained 18.2% of the total variation in the logarithm of catch (kg) per trawl. However, *fishing year* was not included in the model as the inclusion of the variable was below the 5% threshold for improvement in the explanatory power of the model.

An examination of the residuals of the *Alldata* model revealed a very poor fit largely due to the inability of the model to cope with the relatively high proportion of zero catches (18% of all records) (Figure 12).

4.1.5 Binom model

The *Binom* model included the variable *start time* as a third order polynomial function at the first iteration followed by the categoric variable *vessel*. The third variable included in the model was *duration* and *end time* and *month* were included at the fourth and fifth iteration, respectively. The final variable included in the model was *subarea* (Table 10). The explanatory power of the model was low (R^2 of 17%) indicating that the model does not adequately predict the presence/absence of alfonsino catch in the trawl. The *Binom* model does not include *fishing year* as an explanatory variable.

5. DISCUSSION

Five CPUE models were considered for the Eastern Chatham target BYX 3 trawl fishery. Of the five options, the *Vesselcat* model is preferred, largely by default due to the poor performance of the other models. The *VesselE* model includes data from the one vessel that consistently operated in the fishery throughout the five-year period. However, the exclusion of data from the remainder of the fleet reduces the dataset considerably, particularly in some years, and the annual indices derived from the model are poorly determined.

In comparison to the *Vesselcat* model, the CPUE index of catch per hour (*Crate* model) results in an increase in the explanatory power of the model. However, the increase in explanatory power is solely due to the reduction in variation in the dataset due to the standardisation of trawl catches in terms of catch per hour. However, the CPUE expression assumes a constant relationship between trawl catch rate and trawl duration. An examination of the unstandardised trawl catch rates shows this assumption is not valid and the *Crate* model does not allow the flexibility for this relationship to be parameterised in the CPUE model. The fit to the CPUE data from the *Crate* model is comparable, if not a slight improvement, to the *Vesselcat* model. Annual indices from the two models are very similar.

The *Alldata* model represents a very poor fit to the data due to the high proportion of zero catches in the dataset. The *Binom* model was a further attempt to account for the high proportion of zero catches. However, the model variables explained only a relatively small proportion of the presence/absence of alfonsino catch in the trawl. This suggests that the occurrence of a zero catch is more likely attributable to other factors associated with the operation of the fishery that are not included in the available data set. The fishery is concentrated on several hill features and zero catches may represent trawls that have either missed the hill altogether or come fast on contact with the bottom. There does not appear to be an annual trend in the presence/absence of alfonsino catches that would suggest monitoring the proportion of zero trawls would be generate a useful index for monitoring the fishery.

The annual CPUE indices from the *Vesselcat* model vary between years and do not indicate any systematic trend in catch rate from the fishery. However, the indices have a high standard deviation due, in part, to the few annual records available from the fishery. Consequently, the current CPUE time-series would be capable of detecting only large changes in catch rate between fishing years or a strong declining trend over several years.

There are also apparent conflicting annual trends in catch rate between individual vessels and, to a lesser extent, between individual subareas fished. The catch rates of one vessel declined during the three most recent years, while annual catch rates were relatively constant for the longest established vessel in the fishery. There is also an indication that catch rates improve with increased experience in the fishery, as indicated by higher catch rates by two vessels during the second year of their participation in the fishery.

While the CPUE index reveals no significant trend in the standardised catch rate from the fishery, unstandardised catch rates have declined considerably from 1995–96 to 1999–2000. The apparent discrepancy between the two sets of indices is at least partially explained by a change in the distribution of fishing effort. Since 1997–98, there has been an increase in the proportion of trawls conducted during the day (0800 to 1700) when catch rates are predicted to be low by the CPUE model (Figure 13). Similarly, during the same period there has been a higher proportion of trawls conducted during September–October when catch rates are generally lower (Langley & Walker 2002). Nevertheless, the unbalanced nature of the CPUE dataset, particularly with respect to fishing year, means that actual changes in catch rate are potentially obscured by the parameterisation of the other variables included in the model.

Overall, the CPUE models presented in this report appear to have limited immediate application for monitoring the abundance of alfonsino in the BYX 3 target fishery or the wider BYX 3 stock. This is due largely to the high variation in catch rates from the fishery and the small number of annual catch and effort records from the fishery. In the longer term, there may be sufficient contrast in the catch rate data from the target fishery to detect a decline in the abundance of alfonsino, although the CPUE data would be capable of detecting only a large-scale decline.

The BYX 3 target fishery operates in a small area, restricted to a few hill features fished to the southeast of the Chatham Islands. The areal extent of the trawls included in the CPUE dataset is extremely limited relative to the known distribution of alfonsino within BYX 3. Consequently, trends in CPUE data from the target fishery should be considered specific to the area of the fishery only rather than indicative of trends in abundance for the wider BYX 3 stock.

During the initial development of the East Chathams target alfonsino fishery there has been no systematic trend in the annual indices from the standardised CPUE analysis. However, the relatively low CPUE index for the 1999–2000 fishing year and the decline in unstandardised catch rates, in particular the decline in the proportion of larger catches (over 5 t) and the recent drop in the level of target catch from the fishery means that the fishery warrants further monitoring.

6. BNS/BYX INTERACTION

6.1 Fishery summary

Between 1989–90 and 1998–99, the level of catch from the BNS 3 fishery steadily increased from 132 t to 739 t (Figure 14). The BNS 3 TACC was increased to 350 t in 1992–93 and annual catches consistently exceeded the TACC since 1994–95. The increase in catch from BNS 3 has been attributed to the development and expansion of several fisheries operating along the Chatham Rise, principally the target ling, bluenose, and hapuku longline fisheries and the target hoki and alfonsino trawl fisheries (Starr & Langley 2001) (Figure 15).

Before 1995–96, the bluenose bycatch from the BYX 3 alfonsino fishery was minimal. In 1995–96, the bluenose catch from the fishery increased to 90 t and the annual reported catch in subsequent years has been 100–150 t (Table 11). Most of the recent increase in bluenose bycatch from the alfonsino trawl fishery has been associated with the development of the target trawl fishery to the southeast of the Chatham Islands. However, in 1999–2000 a significant proportion of the catch was taken from outside the main alfonsino fishing grounds (Other) (Table 11). Most of this catch was taken in a few trawls on the northern edge of the Chatham Rise in statistical area 404.

The bluenose bycatch was predominantly taken by bottom trawl method with the exception of the 1995–96 fishing year when a high proportion of the catch was taken by midwater trawl (Table 11).

Most (77%) of the bluenose catch from the East Chathams fishery has been taken from subareas S2 and S5; these areas accounted for 50% of the total alfonsino catch from the fishery (see Langley & Walker 2002) (Table 12). For subarea S2, 70–90 t of bluenose catch was reported in both 1995–96 and 1996–97, although catches have been lower, about 15–30 t, in subsequent years. Annual bluenose catches from subarea S5 were about 30–60 t from 1996–97 to 1999–2000.

Between 1995–96 and 1999–2000, the five core vessels operating in the target bottom trawl BYX 3 fishery accounted for an annual bluenose bycatch of 60–80 t, with the exception of the 1996–97 year when 128 t of bluenose was caught. Overall, annually the bluenose bycatch represented 15–23% of the weight of the catch of the target species (Table 12).

However, there was considerable variation in the relative proportion of bluenose and alfonsino in the catch between fishing years. For subarea S2, the bycatch ratio (BNS:BYX) increased slightly between 1995–96 and 1996–97 and steadily declined over the subsequent years (Figure 16). The bycatch ratio from the S5 was relatively low in 1995–96 and 1996–97, but substantially increased in the subsequent year and the catch of the two species has been comparable over the remainder of the period studied. The bycatch ratio from the S7 fishery was low throughout the 1995–96 to 1999–2000 period (Figure 16).

Annually, a high proportion of the trawls reported no bycatch of bluenose (see Table 2) or a small bycatch (less than 100 kg). Few large catches (over 5 t) were taken, although these trawls accounted for a significant proportion of the total annual catch in some years. In most years, at least 50% of the bluenose catch was taken from trawls with a bluenose catch of less than 2 t, with the exception of 1998–99 when a high proportion of the trawls caught no bluenose and the catch was dominated by a few larger catches (5–10 t) (Figure 17, Figure 18, and Figure 19).

The high proportion of zero and small catches of bluenose corresponded to most of the trawls having a small proportion of bluenose in the catch relative to the catch of alfsonsino. However, about 10% of the trawls yielded catches that were predominantly bluenose (Figure 20).

6.2 GLM modelling

A generalised linear modelling approach was used to examine the factors that may influence the relative level of bluenose bycatch from the BYX3 target bottom trawl fishery. The initial catch and effort dataset was equivalent to that used in the CPUE analysis of the target fishery, principally bottom trawl records from the five main vessels operating in the fishery from 1995–96 to 1999–2000 (see Section 2). The potential explanatory variables included in the CPUE modelling are presented in Table 1.

The analysis considered three separate dependent variables as indicators of relative abundance of bluenose; the logarithm of bluenose catch (kg), the presence/absence of bluenose in the trawl catch, and the proportion of bluenose in the combined bluenose and alfonsino catch from the trawl. The number of records in the data set for each option varied according to the inclusion of zero (or small) catches of bluenose and alfonsino (Table 13).

For each BNS model option, the generalised linear model was fitted following the procedures described in Section 4. The significant predictor variables were examined to investigate the factors contributing to the relative bycatch rate of bluenose from the fishery.

6.3 Results

6.3.1 Non zero model

The *Non zero* model included the categoric variables *subarea* and *fishing year* at the first and second iterations, respectively (Table 14). The continuous variable *byx catch* was included at the third iteration as a third order polynomial function, followed by the categoric variable *vessel*. The other two significant variables included in the model were *bottom depth* and *speed*, both included as third order polynomial functions. In total, the six significant variables explained 23% of the variation in the logarithm of bluenose non-zero catch (Table 14). An examination of the model diagnostics revealed no strong trend in the residuals from the model.

The *subarea* coefficients from the *Non zero* model indicate larger catches of bluenose were taken in subareas S1, S2, and S5 and from trawls outside the main features, while trawls in subareas S3 and S7 have lower catches of bluenose (Figure 21). The high coefficient for the S1 area was derived from a small number of records (19) and has a high standard error. The *fishing year* coefficients indicate the catch rate of bluenose increased between 1995–96 and 1997–98 and then declined over the subsequent years.

The *Non zero* model indicates a positive correlation between the trawl catch of bluenose and alfonsino for catches up to about 7 t (Figure 21). For larger alfonsino catches, the predicted catch of bluenose from the trawl declines. This may relate to the schooling behaviour of the two species, with larger catches of alfonsino taken from schools dominated by the species. Smaller catches may be on more dissaggregated schools of both species.

Most of the *vessel* coefficients are relatively similar, with the exception of Vessel B which has a higher catch rate of bluenose compared to the other vessels in the fleet, while catches of bluenose by Vessel E were generally small (Figure 21).

While *bottom depth* was included in the model as a significant variable, the predicted difference in bluenose catch rate is negligible over the main depth range fished (270–500 m) (Figure 21). The model also predicts highest catches of bluenose were achieved from trawls conducted at speeds between 3.0–3.5 knots, although overall trawl speed had a small effect on the bluenose catch (Figure 21).

6.3.2 Binom model

The *Binom* model included the categoric variable *vessel* at the first iteration followed by the *end time* variable as a third order polynomial function. The variable *subarea, byx catch*, and *month* were included at the third, fourth, and fifth iterations, respectively. These variables accounted for 31% of the variation in the presence or absence of bluenose in the catch (Table 15).

The *vessel* coefficients of the *Binom* model revealed a high variation in the probability of catching bluenose between the five vessels in the fleet, with vessels A and C having a relatively low encounter rate (Figure 22). The model also indicates a diurnal trend in the probability of catching bluenose, with a high probability of catching bluenose between 22:00 and 05:00 declining to a daily low during mid-afternoon (16:00). The probability of catching bluenose was lowest in *subarea* S1, while the probability of catching bluenose was relatively comparable for the other main areas fished (Figure 22).

The model indicated that the probability of catching bluenose in a trawl increased with an increase in the catch of alfonsino (*byx catch*) to a peak of 5 t. For larger catches of alfonsino, the model predicted that the probability of catching bluenose declined, although the relationship was poorly determined (Figure 22). The coefficients of the *month* variable indicate a higher probability of catching bluenose during April, although the individual coefficient has a very high associated variance. There is no apparent seasonal trend in the probability of catching bluenose.

6.3.3 BNSprop model

An initial examination of the CPUE estimate (proportion bluenose) in the *BNSprop* model (Option 3) revealed a highly skewed distribution, with a high proportion of records with a small proportion of bluenose in the catch (see Figure 20). Several options for transformation of the data were investigated and the cube root provided the best approximation of normality.

The *BNSprop* model included five significant variables, accounting for a total of 27% of the variation in the cube root of the proportion of bluenose in the trawl catch (Table 16). The categoric variables *subarea, fishing year,* and *vessel* were included at the first, second, and third iterations, respectively. The categoric variable *month* was included at the fourth iteration and *bottom depth* was the last variable to enter the model, included as a third order polynomial function.

The *subarea* coefficients of the *BNSprop* model do not reveal a significant difference in the proportion of bluenose in the catch between the main areas fished with the exception of a lower proportion of bluenose in the trawl catches from subarea S1 and, to a lesser extent, S2 (Figure 23).

A higher proportion of bluenose was present in the catch from the 1996–97 *fishing year* than in the other years included in the dataset. The *vessel* coefficients show that one vessel (Vessel B) had a lower proportion of bluenose in the catch than the other four vessels in the core fleet (Figure 23). The *month* coefficient for September was highest, indicating a higher bycatch of bluenose during that period compared to the remainder of the year. There was a general decline in the proportion of bluenose in the catch with increasing fishing depth (Figure 23).

An examination of the residuals of the model revealed a poor fit to the data largely due to the high proportion of records with no bluenose catch (zero proportion).

6.4 Discussion

The three BNS 3 models were derived from different subsets of the data and due, in part, to the relatively small number of records, the models are relatively sensitive to the different data selection criteria. Nevertheless, there are some consistent trends in the parameters derived from the models from the BYX 3/BNS 3 fishery. For example, the observed decline in the proportion of bluenose in the catch with increasing depth from the *BNSprop* model is consistent with the decline in the catch rate of bluenose with increasing depth from the *Non zero* model. Depth was not included as a significant factor in the *Binom* model. However, the *subarea* variable is a strong proxy for bottom depth, with a high proportion of the trawls from *subarea* S2 in the shallower depth range (less than 350 m). This may partly explain the high probability of catching bluenose from trawls in that area.

Both the *Non zero* model and the *Binom* model reveal a comparable trend in bluenose catch rate with respect to the level of alfonsino catch. For both models, the bycatch of bluenose is predicted to increase to reach a peak at around 5-10 t catch of the target species and decline for greater catches. This may relate to the schooling behaviour of alfonsino, with larger catches principally taken from aggregations of fish dominated by alfonsino. The *byx catch* variable was not included in the *BNSprop* model as the variable was included in the denominator of the dependent variable.

There is a consistency in the *fishing year* coefficients when comparing the catch rates of bluenose (*Non zero* model) with the proportion of bluenose in the catch (*BNSprop* model). However, the *vessel* coefficients are contrary between these models, with Vessels B and C having a higher catch rate from the (*Non zero* model), but Vessel B having a relatively low proportion of bluenose in the catch, although the coefficient for Vessel C is comparable to the other vessels (*BNSprop* model). This may be partly explained by the high *vessel* coefficient for Vessel C from the alfonsino CPUE model (*Vesselcat*). The higher catches of alfonsino will correspond to a lower proportion of bluenose in the catch and, therefore, a lower vessel coefficient from the *BNSprop* model. Vessel B also has a higher probability of catching bluenose (bluenose *Binom* model) indicating catches may be smaller but more frequent.

The converse is evident for the *month* effects from the *BNSprop* model that indicate a higher proportion of bluenose in the catch during September. This is consistent with the lower *month* coefficient for September from the alfonsino CPUE model (*Vesselcat*). The lower catch rate of alfonsino will elevate the proportion of bluenose in the mixed catch of the two species.

The difference in the catch rates of alfonsino and bluenose between subareas also directly influence the *subarea* coefficients from the *BNSprop* model. The alfonsino CPUE model (*Vesselcat*) predicts relatively high catch rates of alfonsino from subarea S2 and higher catch rates from S7, while the bluenose CPUE model (*Non zero*) predicts decreasing catch rates from subareas S7, S2, and S3 (Figure 24). The subarea S5 and the amalgamated area "Other" have catch rates of alfonsino and bluenose comparable to the reference subarea (S1).

The low *subarea* coefficients for S2 and S3 from the *BNSprop* model are consistent with the high catch rate of alfonsino in S2 and the low bluenose catch rates in S2 and S3 (Figure 24). The high occurrence of bluenose in the catches from S2 and S3 (bluenose *Binom* model) is inconsistent with these observations, for while the frequency of bluenose catches from this area is high, the magnitude of individual bluenose catches from S2 is relatively low.

7. CONCLUSIONS

1. The East Chathams target BYX 3 fishery developed from 1994–95 and supported annual alfonsino catches of 600–700 t between 1995–96 and 1998–99. The annual catch from the fishery declined to 419 t in 1999–2000. Most of the catch is taken from seven seamounts to the southeast of the Chatham Islands (Langley & Walker 2002).

2. Unstandardised catch rates of alfonsino from the main vessels operating in the East Chathams target BYX 3 fishery declined by over 60% between 1995–96 and 1999–2000 due, in part, to a decline in the proportion of trawls yielding larger catches (over 5 t).

3. In contrast, standardised catch rates derived from GLM modelling (*Vesselcat* model) of the target catch and effort data revealed no systematic trend in CPUE between 1995–96 and 1999–2000, although catch rates in 1999–2000 were about 50% of those in 1995–96. However, the power of the CPUE model was limited due to the small number of records (200–350 per annum) and the high variability in observed catch rate. Consequently, the annual indices derived from the CPUE model are poorly determined.

4. There were considerable changes in the annual distribution of the data records over the study period in a number of the significant variables included in the CPUE model, principally *vessel, subarea, month,* and *start time.* The unbalanced nature of the data set means that the parameterisation of the variables in the model may obscure annual changes in standardised catch rate. The CPUE model also reveals conflicting annual trends in catch rate between individual vessels and, to a lesser extent, between individual subareas fished. Some of the changes in the distribution of fishing effort may be attributable to vessels avoiding large bycatches of bluenose in recent years.

5. Overall, it is considered that the standardised CPUE indices derived for the East Chathams target BYX 3 fishery do not represent a reliable index of abundance for either the East Chathams fishery or the wider BYX 3 stock. In the longer term, there may be sufficient contrast in the catch rate data from the target fishery to detect a decline in the abundance of alfonsino, although such an analysis would be capable of detecting only a large decline. Further, the utility of any resulting index would be restricted to the specific area of the fishery. The areal extent of the current target fishery is extremely limited relative to the known distribution of alfonsino within BYX 3 and, consequently, any trends in CPUE data from the target fishery are unlikely to be indicative of trends in abundance for the wider BYX 3 stock.

6. Bluenose represents an important bycatch of the target BYX 3 trawl fishery. Between 1995–96 and 1999–2000, the fishery yielded a bycatch of 100–150 t of bluenose annually, mostly from the East Chathams fishery. This represented about 20–30% of the total BNS 3 catch taken during the same period.

7. Annually, a high proportion of the East Chathams target BYX 3 trawls reported no bycatch of bluenose or a small bycatch (less than 100 kg). Most of the total annual bluenose bycatch from the fishery comprised catches of less than 2 t. Few large catches (over 5 t) were taken, although these accounted for a significant proportion of the total annual bluenose catch from the fishery in some years.

8. Most of the bluenose bycatch from the East Chathams target BYX 3 fishery was taken from two main features (subareas S2 and S5). Overall, the annual bluenose bycatch represented about 20% of the weight of the target alfonsino catch. However, the bycatch ratio varied between the main subareas fished during the study period.

9. The factors influencing the relative level of bluenose bycatch in the East Chathams target BYX 3 fishery were investigated using a generalised linear modelling approach. Three separate model options were considered, with each model including a different dependent variable and subset of the data. Consequently, the parameterisation of the variables included in the model varied between the three options. The *subarea* variable was included in each of the three models and although the coefficients are broadly consistent with trends in unstandardised catch, the relative level of predicted bycatch for each *subarea* differed between models. The few records included in the analysis and the variability in observed bluenose bycatch means the resulting models have limited explanatory power. Consequently, the results of the GLM models are not sufficiently reliable to identify possible changes

to current fishing practice that would result in a reduction in the level of bycatch from the target alfonsino fishery.

10. The ratio of alfonsino to bluenose catch from the main features fished in the East Chathams fishery indicates that it may be possible to minimise the level of bluenose bycatch by concentrating target fishing on certain features. However, it is unknown whether individual features could support a higher level of alfonsino catch and fishing effort. Further, the availability of alfonsino associated with a particular feature may vary and, therefore, require a vessel to fish in several areas to achieve reasonable catches during a fishing trip.

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Table 1: *Types and descriptions of the variables used to model CPUE.*

Variable	Type	Description
$CPUE_t$	Continuous	CPUE measured in kilogrammes of alfonsino caught per trawl
$CPUE_{hr}$	Continuous	CPUE measured in kilogrammes of alfonsino caught per hour trawled (i.e., alfonsino catch/hour).
Fishing Year	Categorical	Fishing year
Month	Categorical	Month of year
Start time	Continuous	Time of day at the start of the trawl
End time	Continuous	Time of day at the end of the trawl
Duration	Continuous	Duration of trawl
Vessel	Categorical	Unique vessel code
Bottom depth	*Continuous*	Depth of bottom at the start of the trawl (m)
Speed	Continuous	Trawling speed in knots
Subarea	Categorical	Subarea fished
Vessel length	Continuous	Overall length of the vessel (m)
Vessel power	Continuous	Power of the vessel's engines (kW)
Vessel tonnage	Continuous	Gross tonnage of the vessel (metric tonnes)

Table 2: Summary of catch and effort records from the East Chathams target BYX 3 bottom trawl fishery for the core vessels in the fishery for the 1995–96 to 1999–2000 period. The table includes the proportion of trawls with a nil catch of alfonsino (BYX) and bluenose (BNS) and the overall ratio of the catch of the two species.

Variable	Fishing year				
	1995–96	1996–97	1997–98	1998–99	1999–2000
BYX catch (t)	446.4	578.6	487.7	346.0	301.2
BNS catch (t)	69.8	128.2	80.9	80.9	64.7
Number of trawls	192	300	237	339	341
Number vessels	2	2	3	3	4
Total duration fished (h)	40.2	111.6	86.1	133.3	108.8
Trawl duration (h)	0.21	0.37	0.36	0.39	0.32
BYX catch per trawl (t)	2.3	1.9	2.1	1.0	0.9
BYX catch per hour (t)	11.1	5.2	5.7	2.6	2.8
Percentage zero BYX	14.6	14.0	18.1	27.4	15.5
Percentage zero BNS	29.7	42.7	46.0	76.1	48.1
Ratio BNS/BYX	0.156	0.222	0.166	0.234	0.215

Table 3: Number of catch and effort records for bottom trawls by vessel and fishing year for the core vessels in the target BYX 3 East Chathams fishery.

Vessel	Fishing year					Total
	1995–96	1996–97	1997–98	1998–99	1999–2000	
A	-	-	-	209	51	260
B	54	-	-	-	15	69
C	-	106	119	-	-	225
D	-	-	36	52	49	137
E	138	194	82	78	226	718
Total	192	300	237	339	341	1 409

Table 4: Number of catch and effort records for bottom trawls by subarea and fishing year for the core vessels in the target BYX 3 East Chathams fishery.

Subarea	Fishing year					Total
	1995–96	1996–97	1997–98	1998–99	1999–2000	
S1	4	2	6	38	46	96
S2	109	171	52	42	152	526
S3	39	32	21	69	52	213
S4	2	9	10	19	14	54
S5	7	53	34	36	40	170
S6	0	0	1	11	2	14
S7	23	26	105	81	20	255
Other	8	7	8	43	15	81
Total	192	300	237	339	341	1 409

Table 5: Summary of CPUE model options initially considered in BYX 3 analysis, including the CPUE estimate, the treatment of zero BYX catch records and the inclusion of vessel variables in the CPUE model.

Option	Model	CPUE estimate	Zero catch records	Vessel predictor	No. of records
1	*Vesselcat*	Log of catch (kg)	Excluded	Categoric	1 150
2	*VesselE*	Log of catch (kg)	Excluded	Vessel E only	642
3	*Crate*	Log of catch per hour (kg/h)	Excluded	Categoric	1 150
4	*All data*	Log of catch (kg)	Included	Categoric	1 409
5	*Binom*	Binomial (no catch/catch)	Included	Categoric	1 409

Table 6: Variables included in the stepwise regression of the *Vesselcat* CPUE model in order of importance.

Variable	% R^2 at iteration					
	1	2	3	4	5	6
Vessel	4.10					
Month	3.29	7.91				
Fishing Year	3.79	5.95	10.46			
Start time	3.18	6.72	10.19	12.49		
Subarea	2.17	5.13	9.89	11.85	13.46	
Duration	0.36	4.22	8.00	10.63	12.81	14.12
Speed	0.48	4.09	8.27	10.55	12.73	13.78
Bottom depth	0.31	4.63	8.91	11.32	12.98	13.63
End time	2.85	6.35	9.86	12.18	12.87	13.86
% improvement		92.9	32.2	19.4	7.8	NS

Table 7: Year indices with standard deviation and regression coefficients for the *Vesselcat* CPUE model, n = number of records.

Fishing year	n	Regression coefficient	Year Index	s.d.
1995–96	164	0.000	1.000	NA
1996–97	258	-0.466	0.628	0.180
1997–98	194	-0.067	0.935	0.296
1998–99	246	-0.018	0.982	0.309
1999–2000	288	-0.628	0.534	0.151

Table 8: Variables included in the stepwise regression of the *CRate* CPUE model in order of importance.

Variable	% R^2 at iteration					
	1	2	3	4	5	6
Subarea	12.17					
Vessel	10.51	16.10				
Month	5.35	15.33	19.10			
Fishing Year	5.40	14.59	18.47	21.85		
Start time	4.20	14.41	18.50	21.13	23.70	
Speed	0.01	12.56	16.17	19.63	22.03	24.00
Bottom depth	7.60	13.83	16.51	19.80	22.72	24.31
End time	4.04	14.13	18.13	20.76	23.38	24.04
% improvement		32.3	18.6	14.4	8.5	NS

Table 9: Variables included in the stepwise regression of the *All data* CPUE model in order of importance.

Variable	% R^2 at iteration						
	1	2	3	4	5	6	7
Start time	8.11						
Vessel	5.53	13.01					
Month	2.49	10.54	15.11				
Duration	0.52	9.24	14.27	16.29			
Subarea	4.37	10.95	13.63	15.97	17.26		
End time	7.51	9.47	13.79	16.04	17.19	18.16	
Fishing Year	2.87	10.19	13.28	15.65	16.94	17.84	18.69
Speed	0.18	8.27	13.04	15.87	16.97	18.06	18.82
Bottom depth	1.02	8.91	13.16	15.27	16.49	17.31	18.21
% improvement		60.4	16.1	7.8	5.6	5.2	NS

Table 10: Variables included in the stepwise regression of the *Binom* CPUE model in order of importance.

Variable	% of null deviance at iteration						
	1	2	3	4	5	6	7
Start time	6.12						
Vessel	5.11	11.40					
Duration	0.76	7.32	12.92				
End time	5.62	8.91	12.91	14.50			
Month	2.82	9.37	12.60	14.36	16.23		
Subarea	5.01	10.36	12.03	13.69	15.50	17.08	
Fishing Year	1.83	7.83	11.60	13.07	14.70	16.59	17.38
Speed	0.09	6.32	11.50	13.02	14.58	16.44	17.33
Bottom depth	1.30	7.22	11.52	13.04	14.60	16.30	17.31
% improvement		86.3	13.3	12.2	11.9	5.2	NS

Table 11: Summary of bluenose bycatch (tonnes) from the target alfonsino trawl fishery by gear type, fishery area, and fishing year. The definitions of the fishery areas were presented by Langley & Walker (2002).

Fishing year	Gear type: Bottom trawl East Chathams	Bottom trawl Kaikoura	Bottom trawl Mernoo	Bottom trawl Other	Midwater trawl East Chathams	Midwater trawl Kaikoura	Midwater trawl Mernoo	Midwater trawl Other	Total catch
1989–90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1990–91	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	7
1991–92	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	1
1992–93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1993–94	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1
1994–95	0.2	0.0	0.3	0.0	1.2	0.0	10.2	1.8	14
1995–96	51.1	0.0	0.0	0.0	39.0	0.0	0.0	0.0	90
1996–97	129.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	130
1997–98	84.2	0.0	0.0	0.0	19.1	0.0	19.6	0.0	123
1998–99	119.2	0.0	15.0	4.1	8.7	0.0	5.6	0.0	153
1999–2000	69.9	0.0	0.0	54.0	0.0	0.0	2.7	4.0	131
Percent of total	69.9	0.0	2.4	9.0	10.5	1.3	6.0	0.9	

Table 12: Summary of total alfonsino (BYX) and bluenose (BNS) catch (tonnes) and number of trawls (BT and MW) from the East Chathams target alfonsino trawl fishery by subarea and fishing year.

Fishing Year		Subarea: S1	S2	S3	S4	S5	S6	S7	Other	Total
1993–94	Trawls	0	0	0	14	0	0	0	4	18
	BYX	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.2	7.2
	BNS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1994–95	Trawls	0	1	48	20	0	0	0	9	78
	BYX	0.0	0.0	15.8	4.8	0.0	0.0	0.0	4.5	25.1
	BNS	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	1.4
1995–96	Trawls	4	114	24	2	39	0	7	6	196
	BYX	0.7	278.6	73.1	0.0	92.7	0.0	5.3	0.0	450.4
	BNS	0.0	70.9	7.6	0.0	11.4	0.0	0.3	0.0	90.2
1996–97	Trawls	3	174	32	7	54	0	28	6	304
	BYX	17.7	226.6	54.1	6.3	220.2	0.0	84.0	13.5	622.4
	BNS	0.0	88.5	3.0	0.0	35.1	0.0	3.0	0.0	129.6
1997–98	Trawls	6	54	31	13	39	1	111	9	264
	BYX	11.1	142.4	68.6	7.3	35.3	0.4	365.3	26.9	657.3
	BNS	4.5	31.6	2.9	0.0	34.8	0.0	25.6	3.8	103.2
1998–99	Trawls	38	43	119	32	59	41	143	52	527
	BYX	63.0	94.8	94.7	20.7	63.7	53.3	158.9	84.1	633.2
	BNS	0.1	13.2	3.5	1.0	64.3	5.9	10.5	29.3	127.8
1999–2000	Trawls	54	157	64	22	41	0	83	19	440
	BYX	43.2	191.4	51.7	3.4	26.8	0.0	99.5	2.9	418.9
	BNS	5.4	20.8	2.0	0.0	32.3	0.0	4.9	4.5	69.9
Total	Trawls	105	543	318	110	232	42	372	105	1827
	BYX	135.7	933.8	358.0	49.5	438.7	53.7	713.0	132.1	2 814.5
	BNS	10.0	225.0	20.4	1.0	177.9	5.9	44.3	37.6	522.1

Table 13: Summary of CPUE model options initially considered in BNS 3 analysis, including the CPUE estimate, the treatment of zero BNS catch records, and the inclusion of vessel variables in the CPUE model.

Option	Model	CPUE estimate	Zero catch records	Vessel predictor	No. of records
1	*Non zero*	Log of catch (kg)	Excluded	Categoric	693
2	*Binom*	Binomial (no catch/catch)	Included	Categoric	1 409
3	*BNSprop*	BNS catch/(BNS catch + BYX catch)	See note 1	Categoric	615

Note: only trawl records with a combined bluenose and alfonsino catch exceeding 100 kg were included in the data set.

Table 14: Variables included in the stepwise regression of the *Non zero* bluenose CPUE model in order of importance.

Variable	% R^2 at iteration						
	1	2	3	4	5	6	7
Subarea	7.62						
Fishing year	5.70	13.32					
BYX catch	2.57	11.44	17.18				
Vessel	5.30	10.19	15.29	20.09			
Bottom depth	3.19	10.36	14.75	18.72	21.42		
Speed	0.65	8.31	13.90	18.07	21.15	22.56	
Month	2.22	8.91	14.87	18.66	20.80	22.39	23.67
Duration	0.46	7.72	13.50	17.36	20.12	21.44	22.59
Start time	0.19	7.67	13.41	17.53	20.25	21.68	22.85
End time	0.29	7.77	13.52	17.58	20.32	21.72	22.89
% improvement		74.8	29.0	16.9	6.6	5.3	NS

Table 15: Variables included in the stepwise regression of the bluenose binomial (*Binom*) CPUE model in order of importance.

Variable	% of null deviance					
	1	2	3	4	5	6
Vessel	18.52					
End time	3.49	23.41				
Subarea	14.69	23.21	26.86			
BYX catch	7.29	22.87	26.22	29.23		
Month	8.91	20.63	25.20	28.49	31.29	
Bottom depth	10.82	21.28	24.89	27.46	29.92	31.94
Fishing year	7.06	19.80	24.40	27.51	29.99	31.86
Speed	0.33	18.70	23.55	27.19	29.60	31.35
Duration	10.05	20.47	24.83	27.34	29.80	31.69
Start time	3.57	23.39	23.43	27.12	29.48	31.47
% improvement		25.3	14.7	8.8	7.0	NS

Table 16: Variables included in the stepwise regression of the *BNSprop* model in order of importance.

Variable	% R^2 at iteration					
	1	2	3	4	5	6
Subarea	13.24					
Fishing year	7.03	20.08				
Vessel	2.15	15.74	23.47			
Month	5.18	15.75	22.82	25.62		
Bottom depth	1.63	15.05	20.66	24.52	27.01	
Speed	4.66	15.88	21.78	24.71	26.33	27.74
Duration	1.61	13.92	20.52	23.68	25.76	27.21
Start time	1.25	13.92	20.57	23.77	25.86	27.26
End time	1.27	14.05	20.78	23.99	26.05	27.44
% improvement		51.7	16.9	9.2	5.4	NS

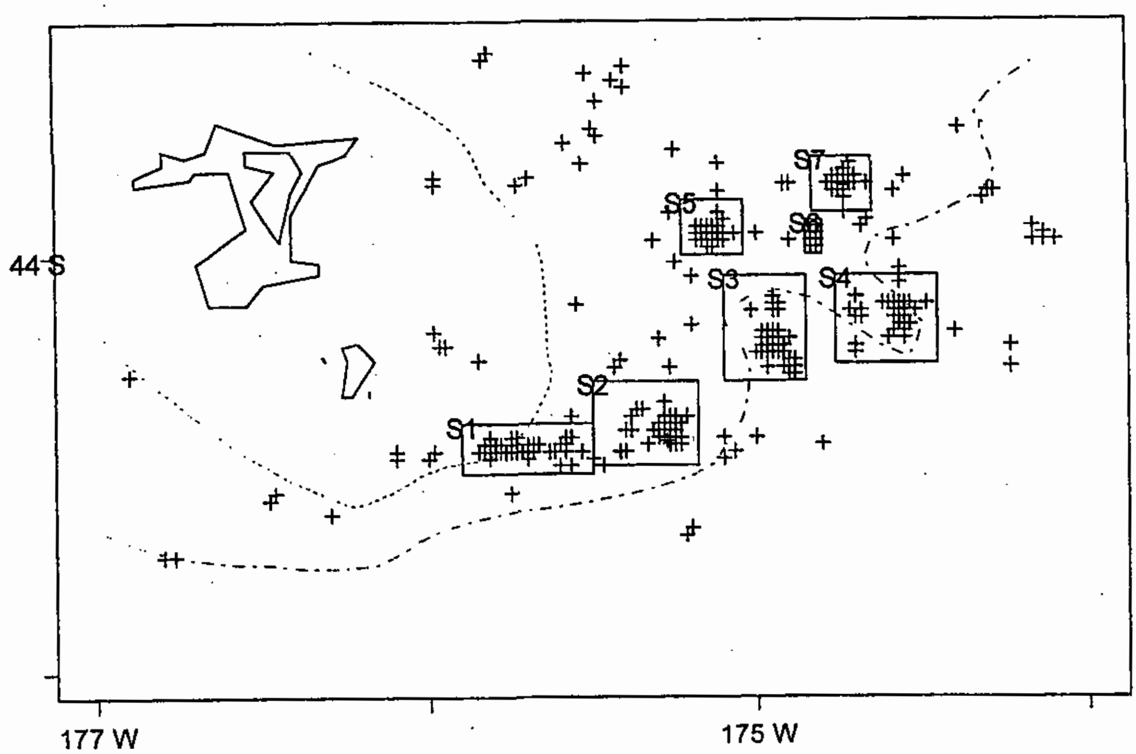


Figure 1: Location of target alfonsino trawl positions in the Eastern Chathams area of BYX 3 during the 1989–90 to 1999–2000 period. The boxes denote the main features fished in the area (source: MFish TCEPR data).

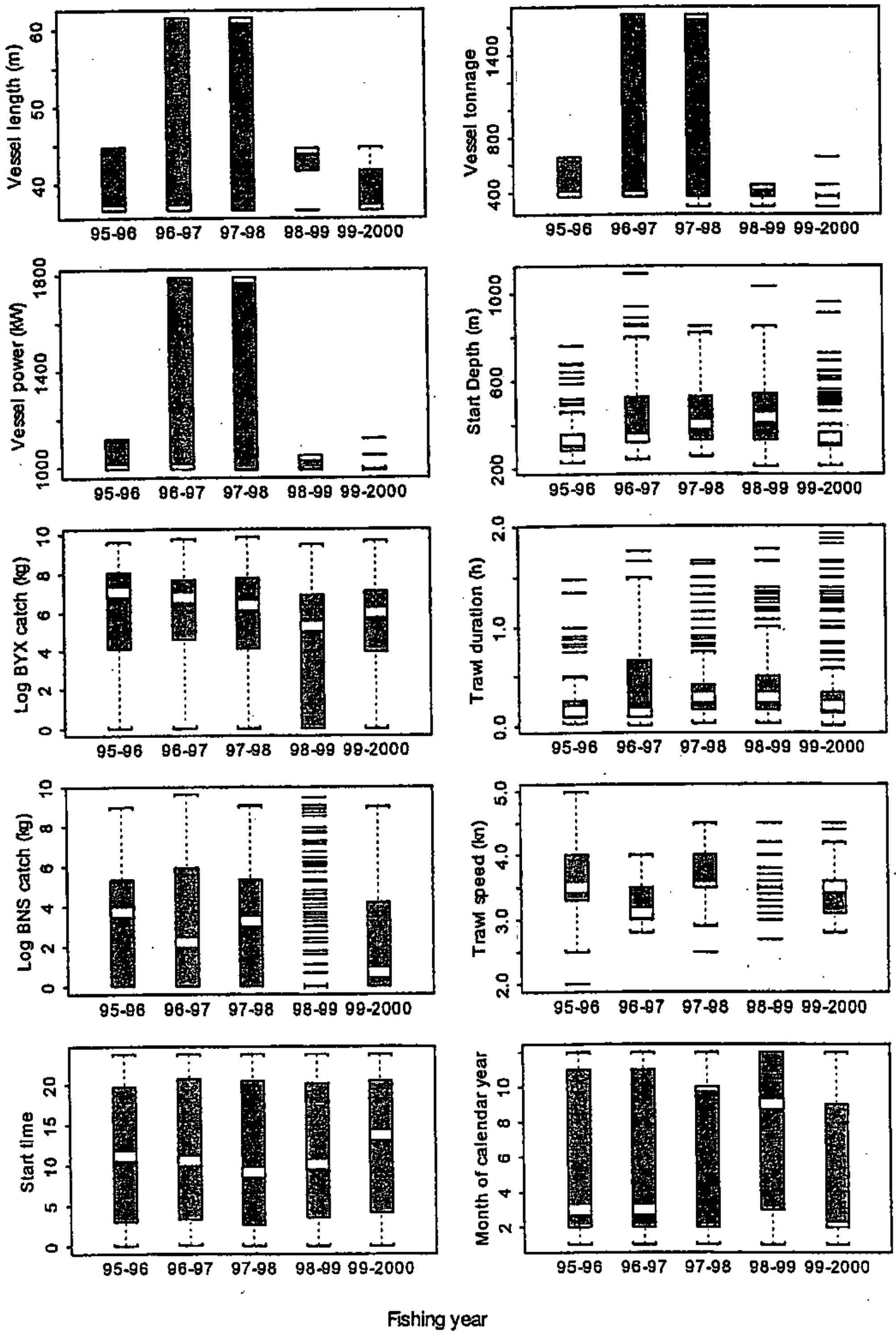


Figure 2: Summary of the main variables included in the CPUE dataset by fishing year. The lower and upper boundaries of the box represent the inter-quartile range of the data, the line inside the box represents the median value, the whiskers represent 1.5 times the inter-quartile range, and the horizontal lines represents outliers beyond 1.5 times the inter-quartile range.

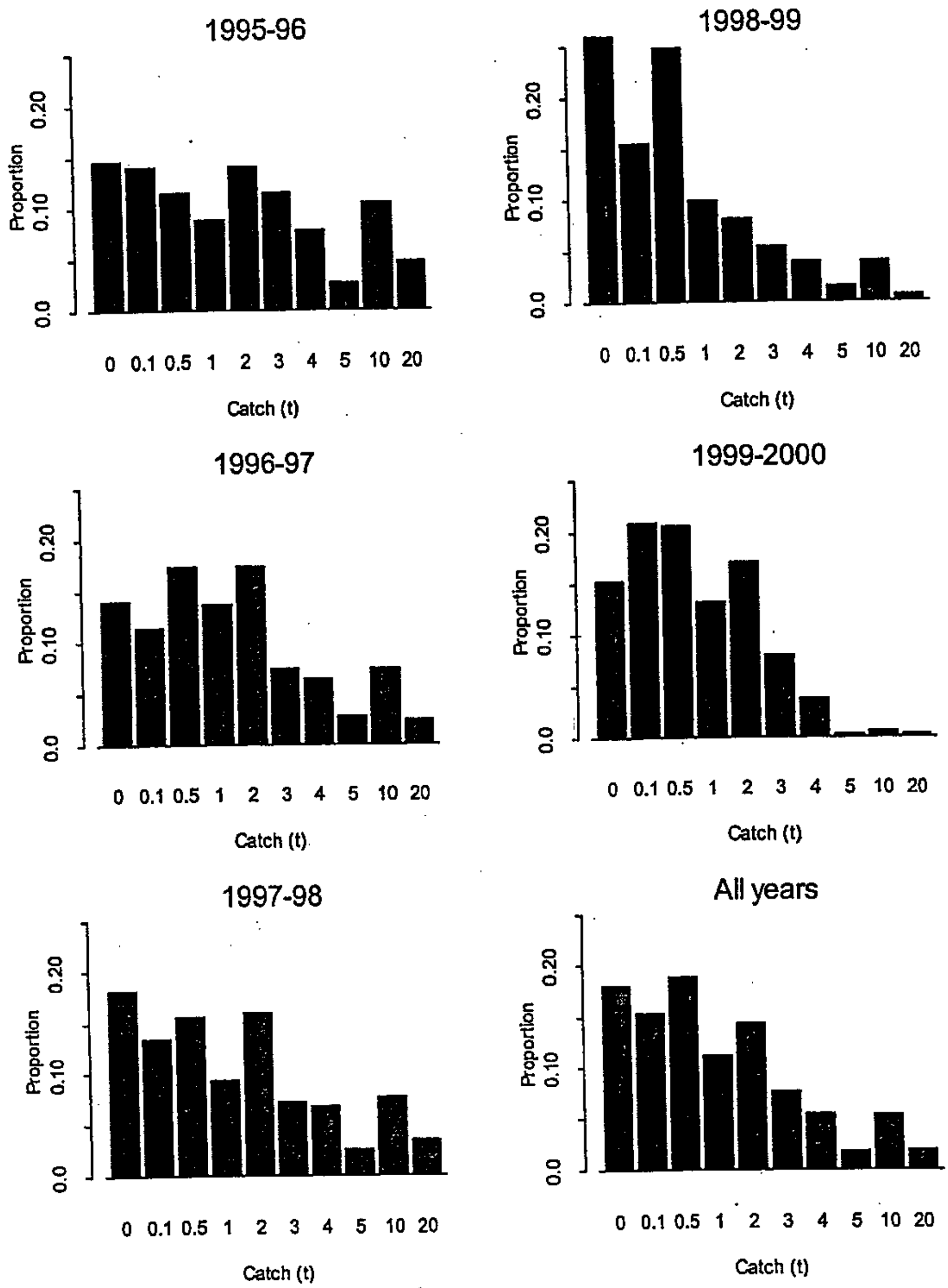


Figure 3: Proportional frequency distributions of target alfonsino trawl catch records from the East Chatham Rise CPUE data set by alfonsino catch (t) and fishing year. The labels on the x-axis represent the upper limit of each category.

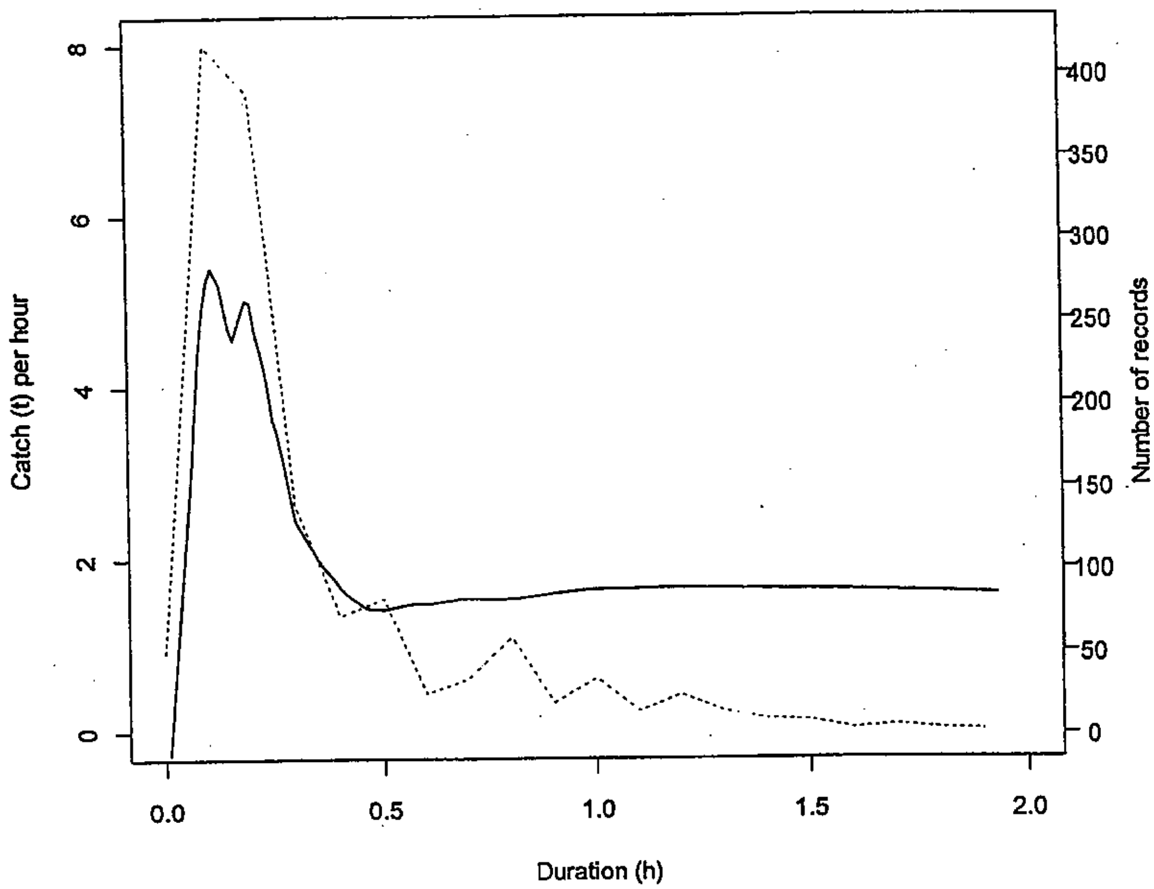
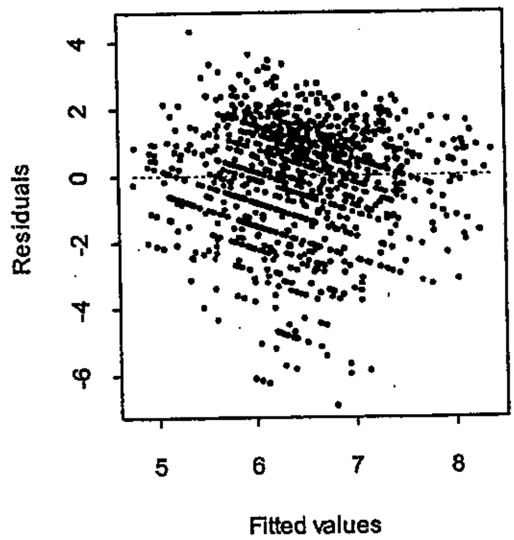


Figure 4: Relationship between alfonsino catch rate and trawl duration. The solid line represents the lowess fit to the data and the dashed line represents the number of records in the dataset.



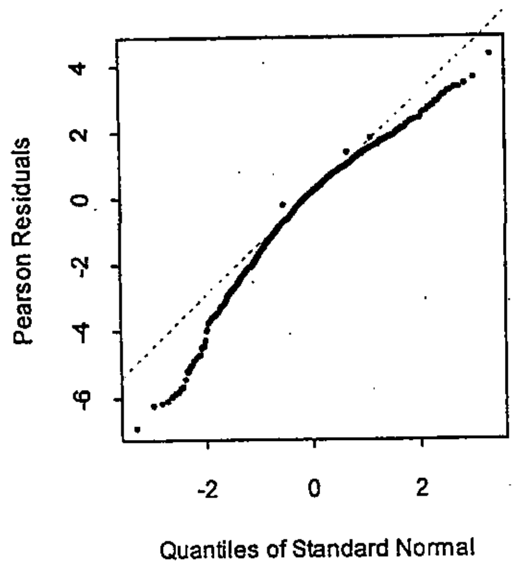


Figure 5: Diagnostics of the *Vesselcat* BYX 3 CPUE model fit; the residuals versus the predicted values from the model (top) and quantile-quantile plot (bottom).

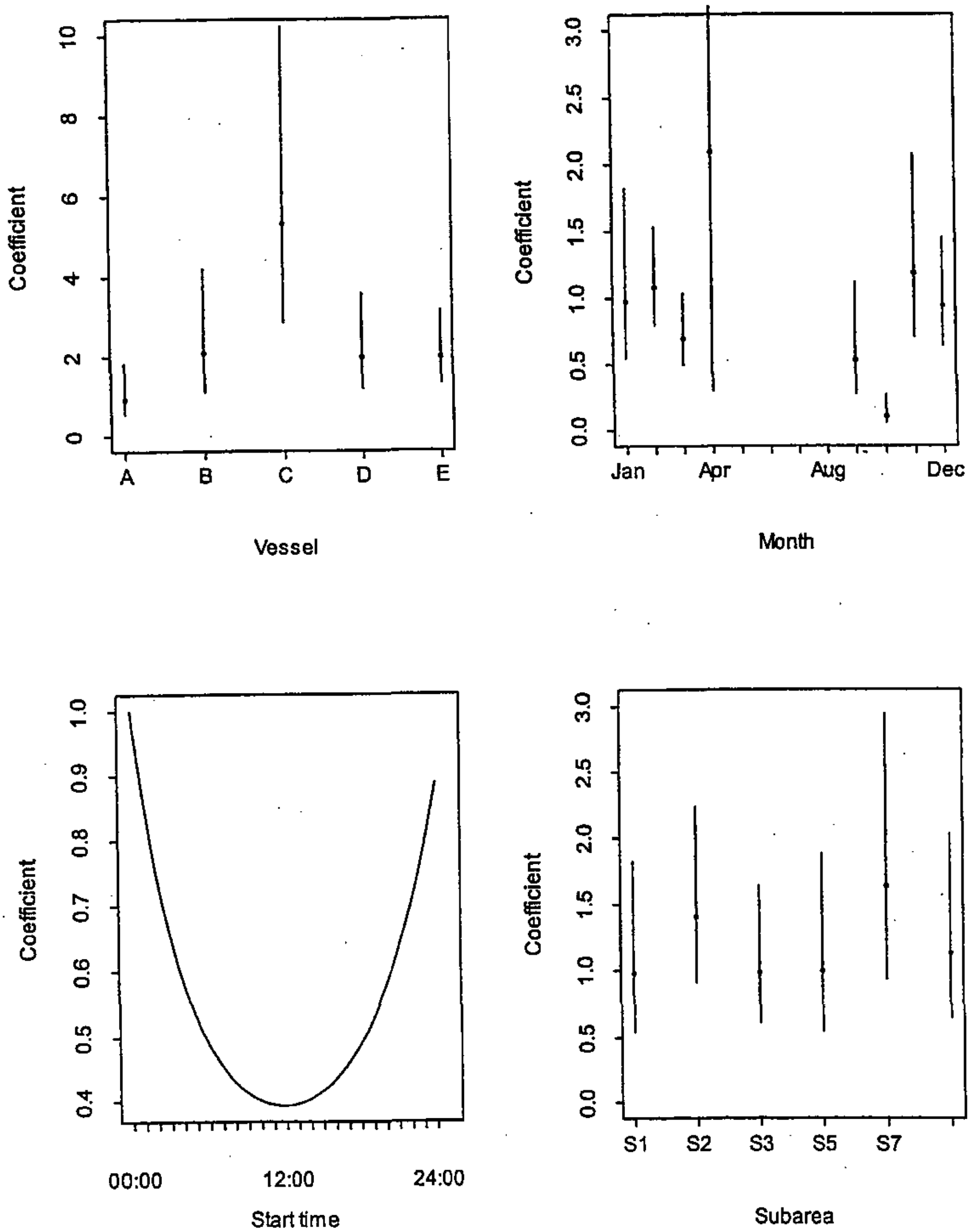


Figure 6: The predicted relationships between alfonsino catch (exponentiated coefficients) and the significant variables included in the *Vesselcat* CPUE model. The confidence intervals represent +/- two times the standard error.

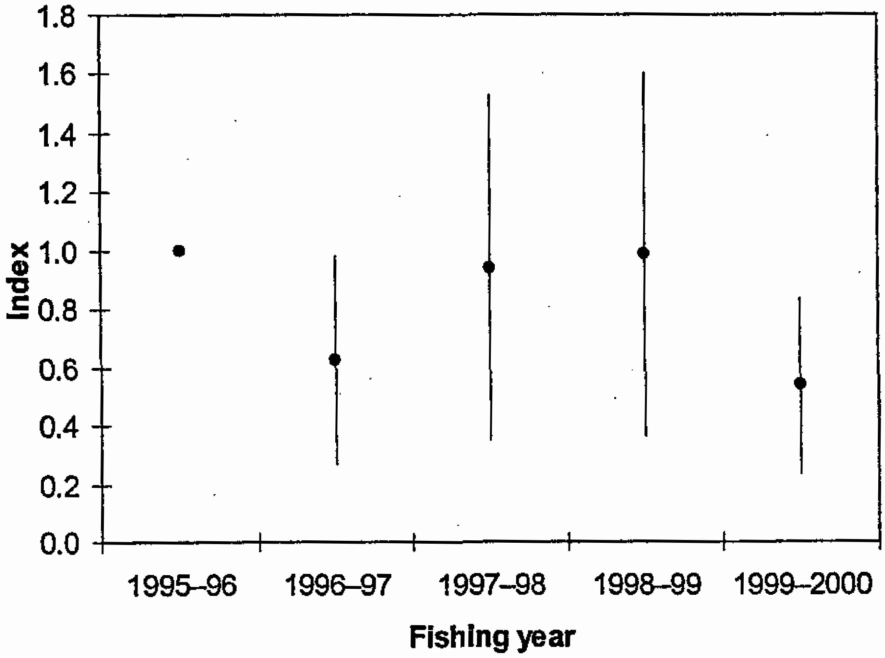


Figure 7: Annual indices from the *Vesselcat* CPUE model (error bars +/- 2 standard deviations).

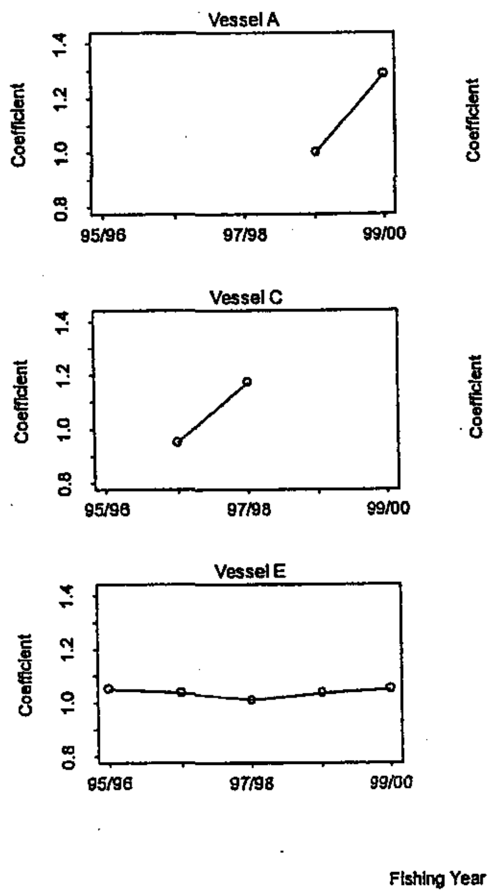


Figure 8: Annual coefficients derived for each vessel from the inclusion of the interaction between fishing year and vessel in the *Vesselcat* CPUE model. Only coefficients derived from at least 25 records are presented.

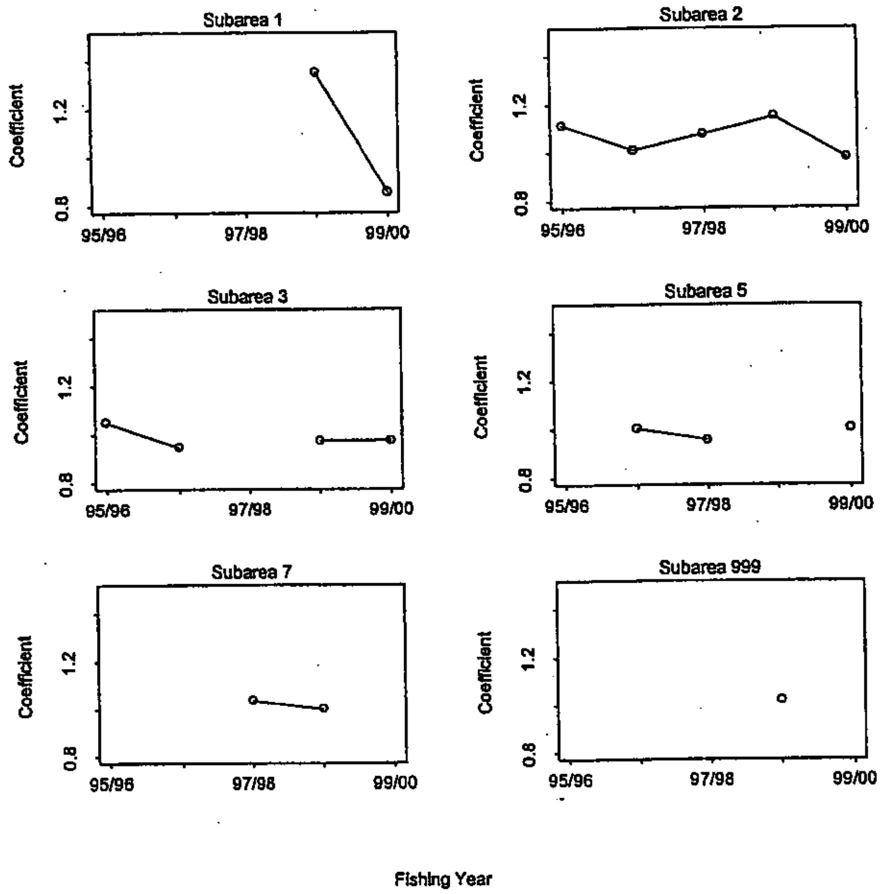


Figure 9: Annual coefficients derived for each subarea from the inclusion of the interaction between fishing year and subarea in the *Vesselcat* CPUE model. Only coefficients derived from at least 25 records are presented.

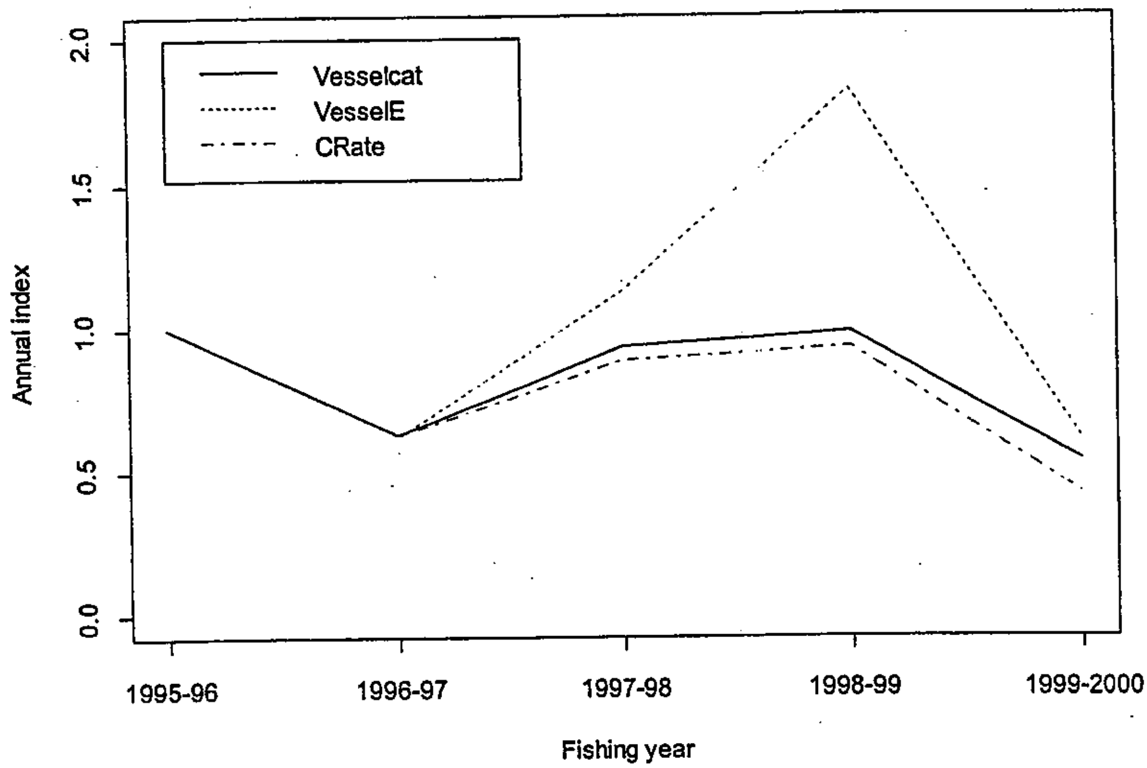


Figure 10: A comparison of the annual indices derived from the *Vesselcat*, *VesselE*, and *Crate* BYX 3 CPUE models.

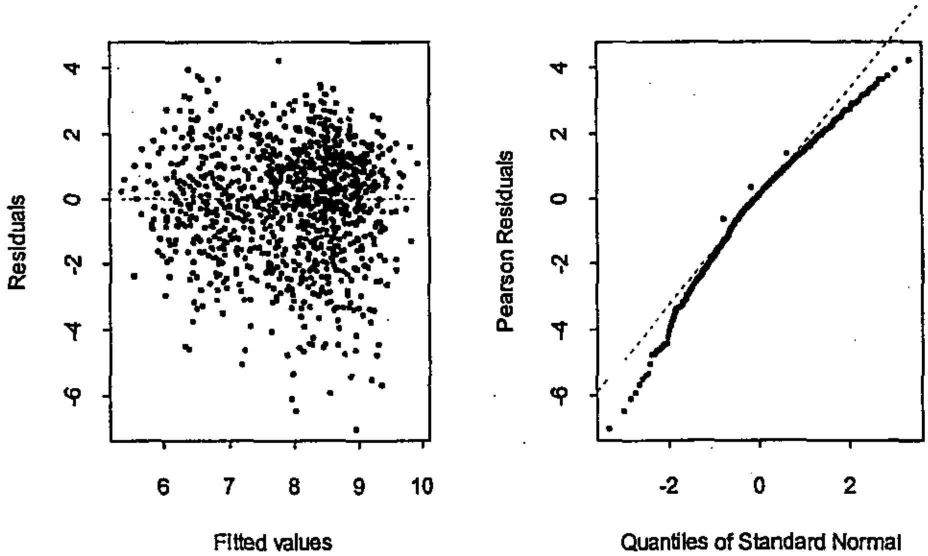


Figure 11: Diagnostics of the *Crate* BYX 3 CPUE model fit; the residuals versus the predicted values from the model (top) and quantile-quantile plot (bottom).

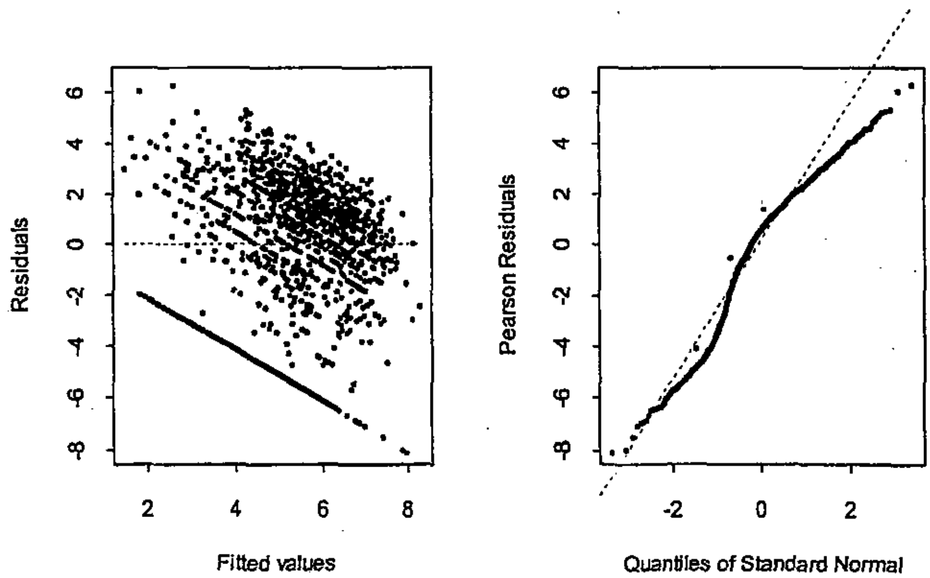


Figure 12: Diagnostics of the *All data* BYX 3 CPUE model fit; the residuals versus the predicted values from the model (top) and quantile-quantile plot (bottom).

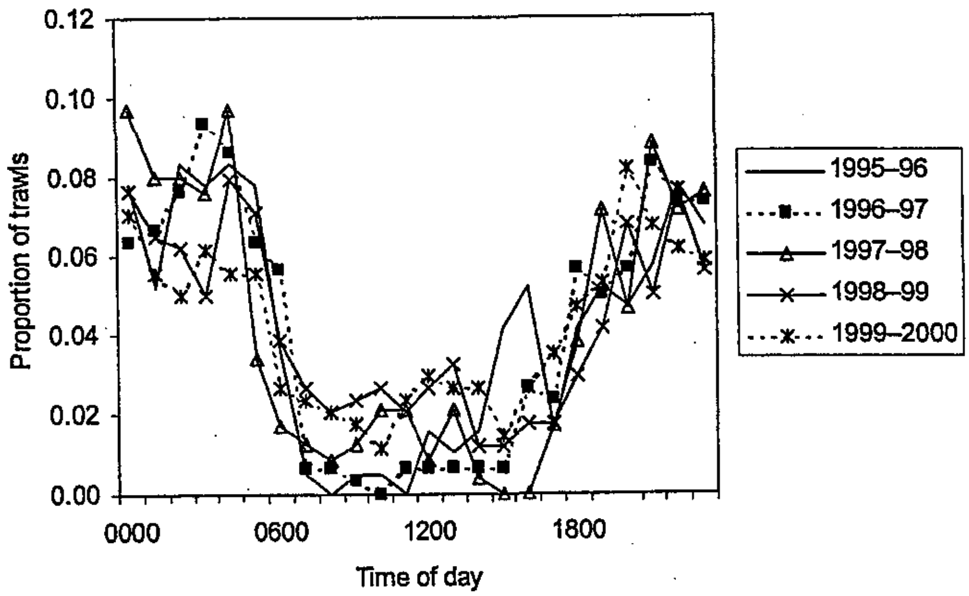


Figure 13: Proportional distribution of the number of trawls conducted in the East Chathams target BYX 3 fishery by time of the day and fishing year.

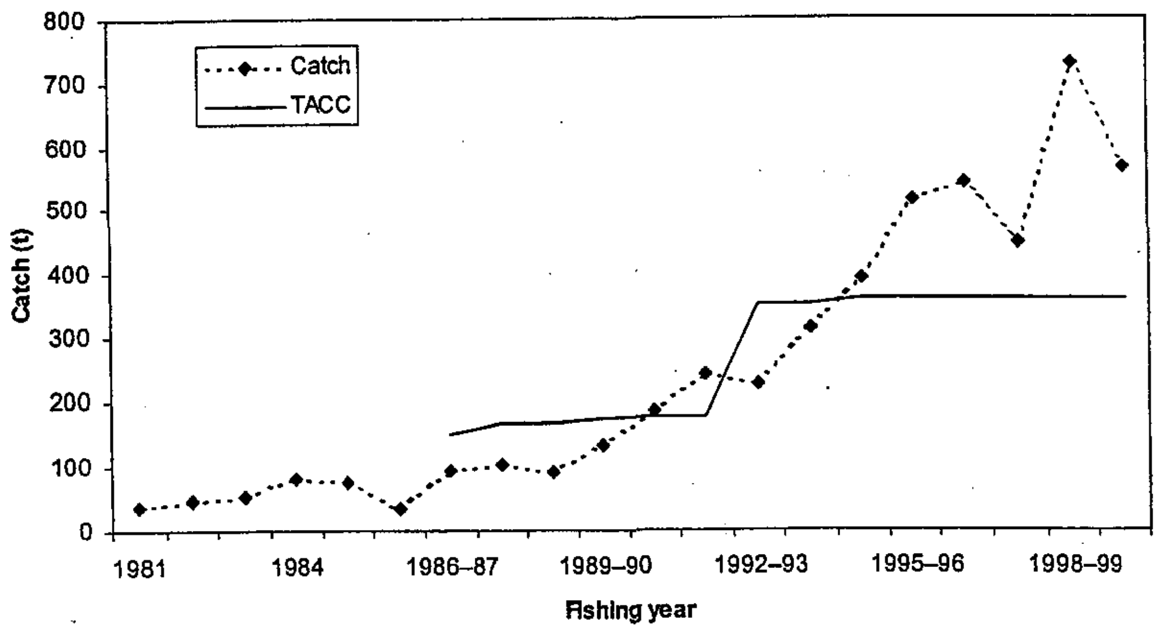


Figure 14: Annual catch and TACC for the BNS 3 fishery, 1981 to 1999–2000 (Source Annala et al. 2001).

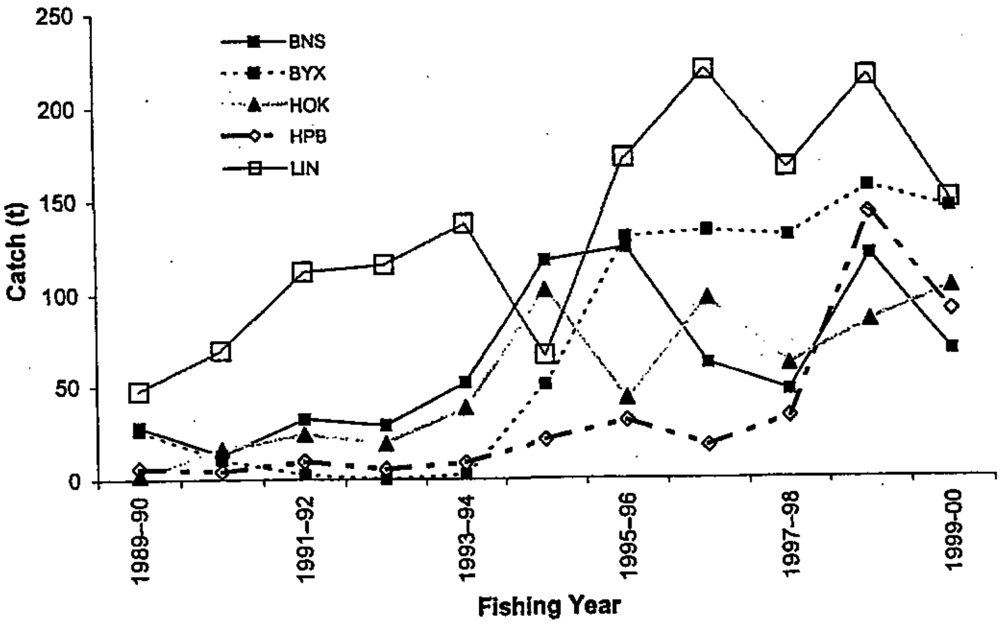


Figure 15: Annual trend in the BNS 3 catch reported for the main target fisheries (source: Starr & Langley 2001).

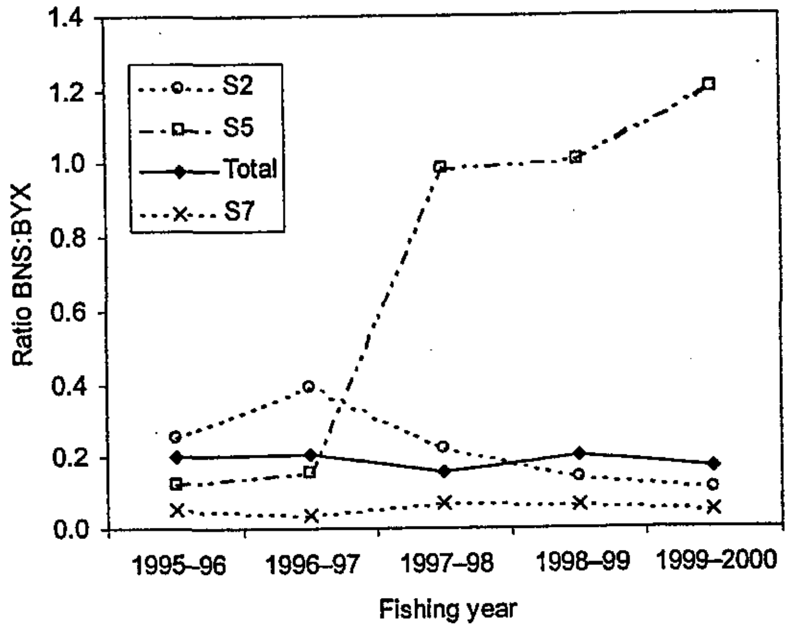


Figure 16: The ratio of bluenose to alfonsino catch from the target East Chathams BYX 3 fishery by subarea and fishing year for the subareas where most of the alfonsino and bluenose catch was taken.

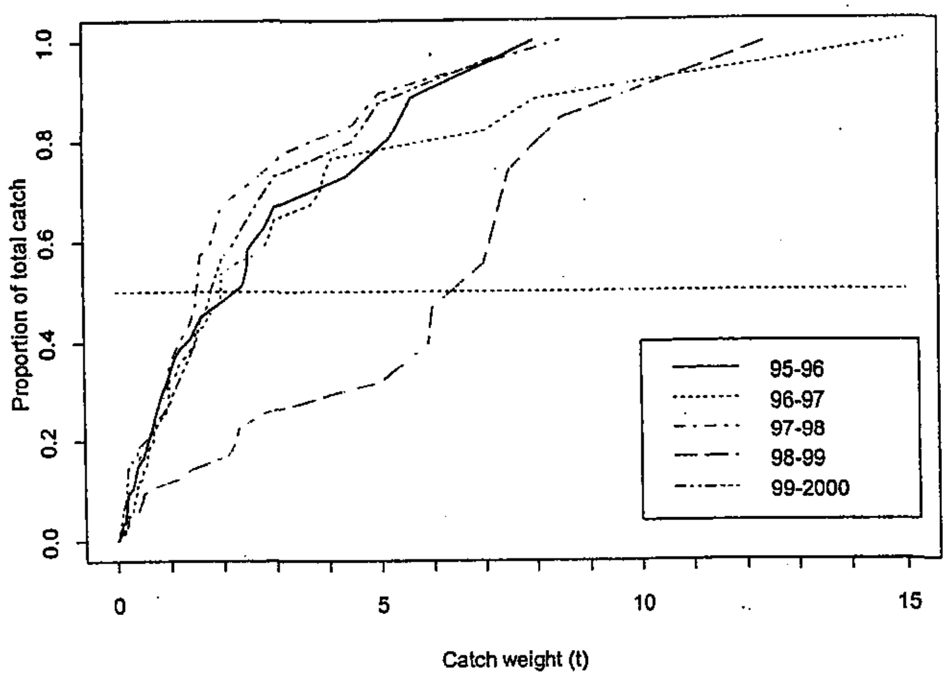


Figure 17: Cumulative proportion of the total bluenose bycatch by bluenose catch (t) from the target East Chathams BYX 3 fishery.

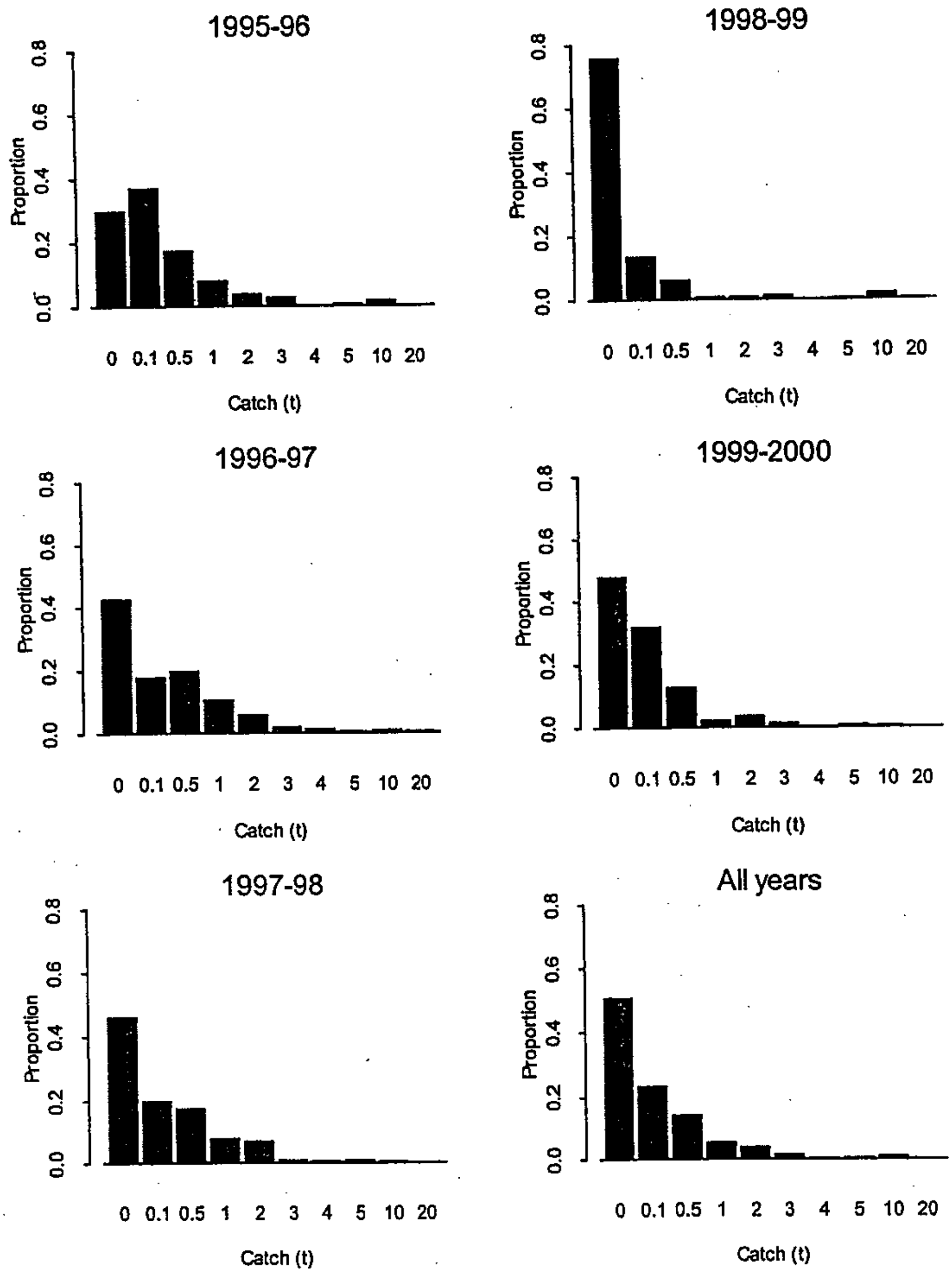


Figure 18: Proportional frequency distributions of bluenose bycatch from the East Chatham Rise target alfonsino fishery by bluenose catch size and fishing year.

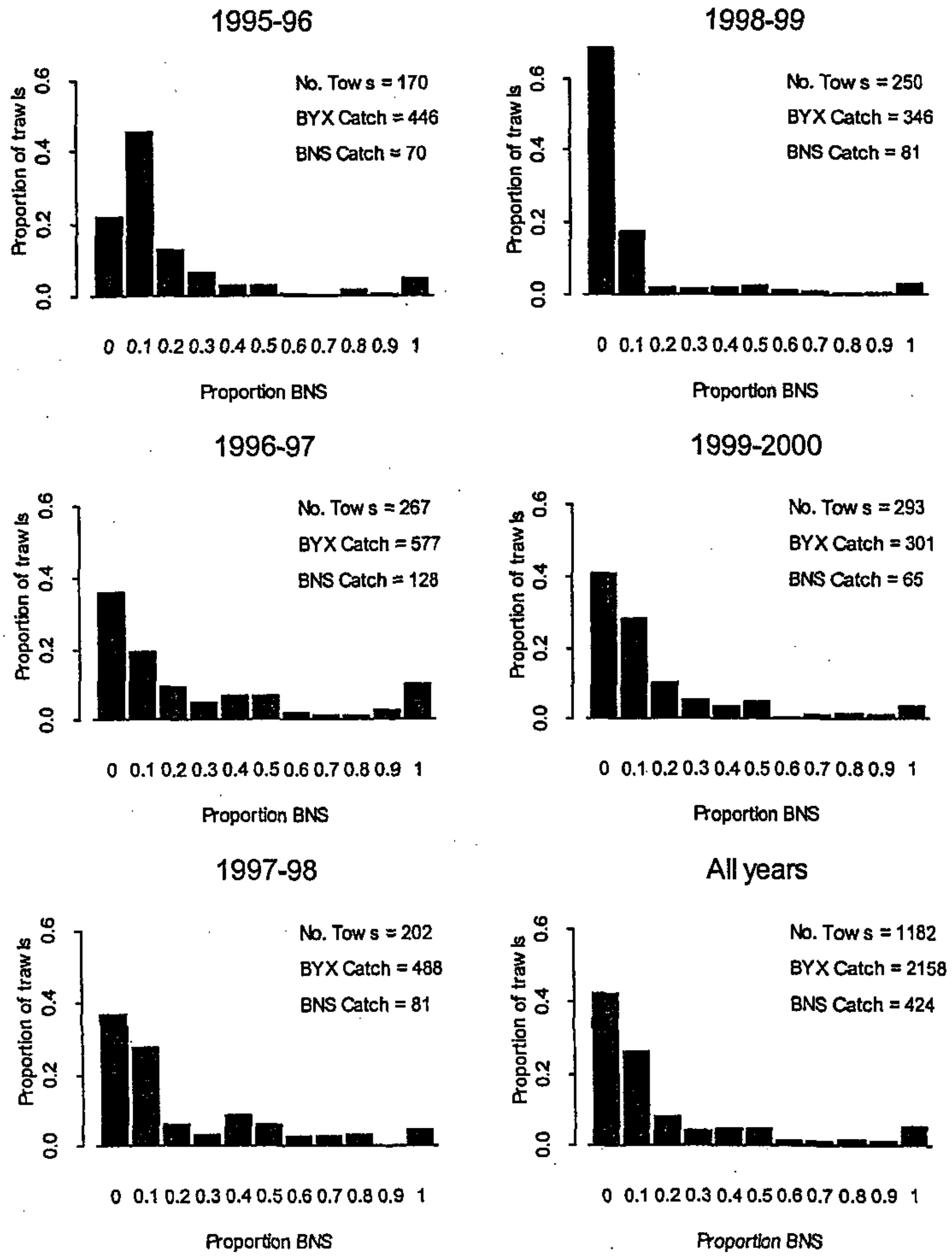


Figure 19: Frequency distribution of BYX 3 target trawls with respect to the proportion (by weight) of bluenose in the combined bluenose and alfonsino catch for trawls with a non-zero catch. The number of trawl records and the total weight of alfonsino and bluenose (tonnes) are also presented.

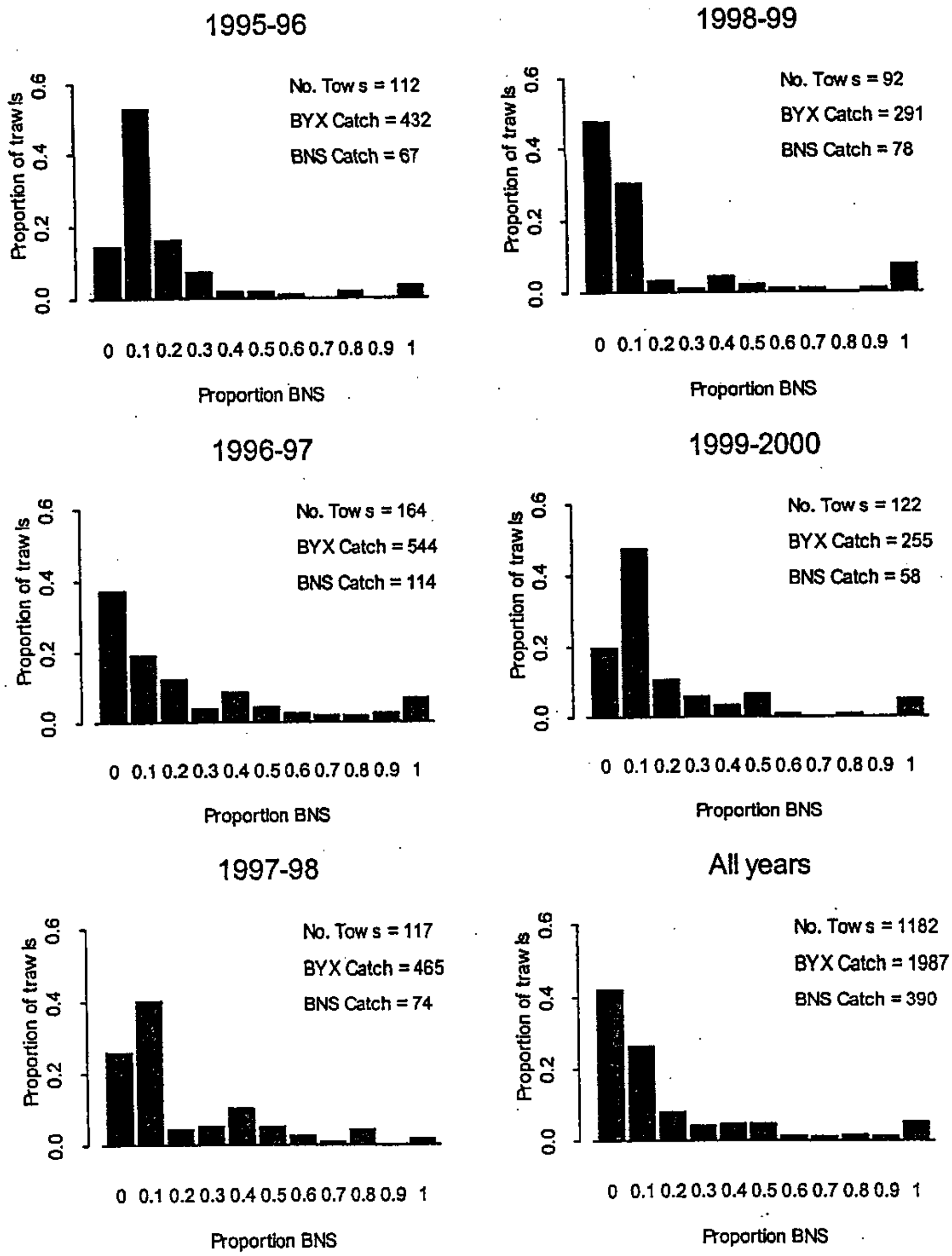


Figure 20: Frequency distribution of BYX 3 target trawls with respect to the proportion (by weight) of bluenose in the combined bluenose and alfonsino catch for trawls with a combined catch exceeding 1 tonne. The number of trawl records and the total weight of alfonsino and bluenose (tonnes) are also presented.

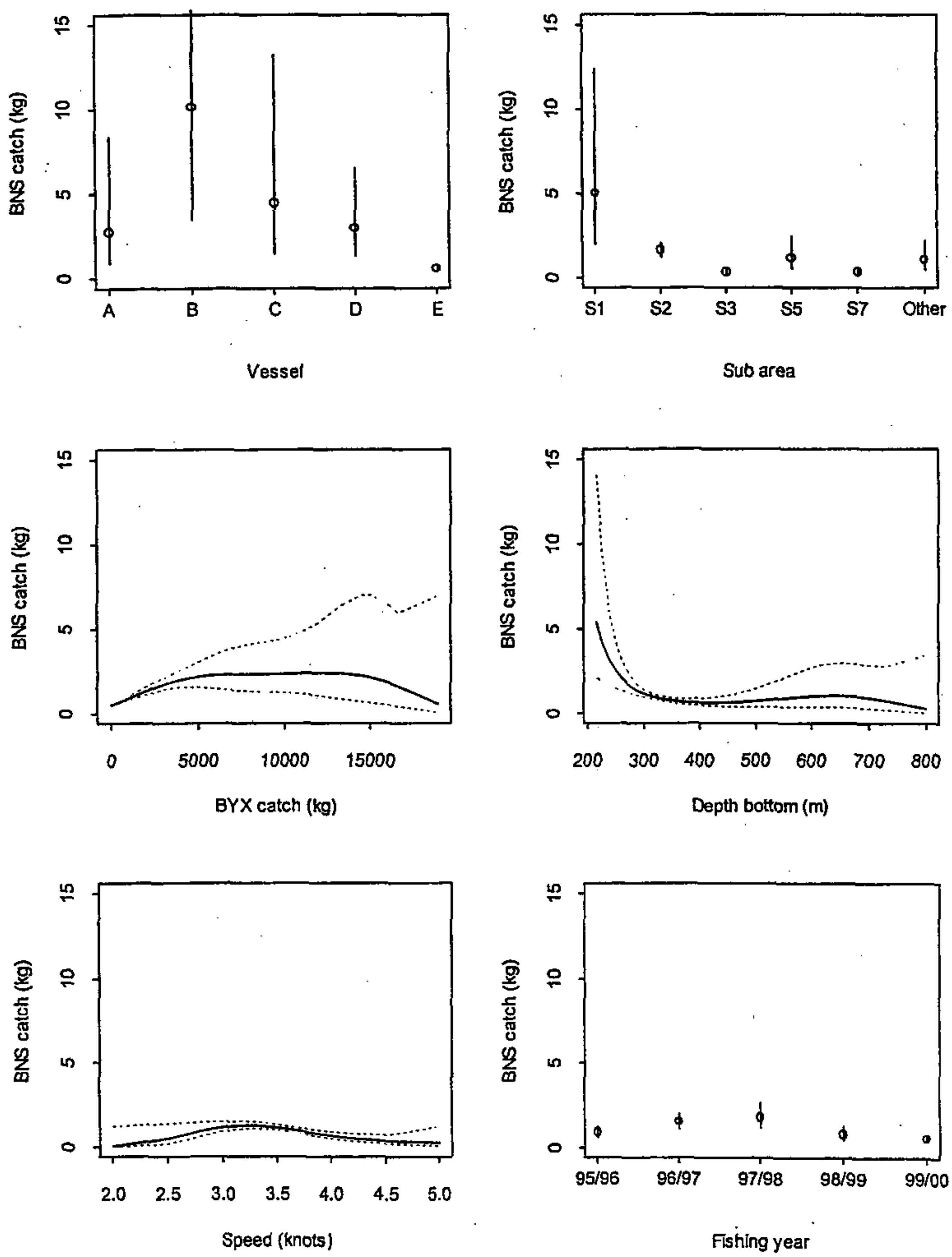


Figure 21: The predicted relationships between bluenose catch and the significant variables included in the *Non zero* bluenose CPUE model. The confidence intervals represents +/- 2 standard error.

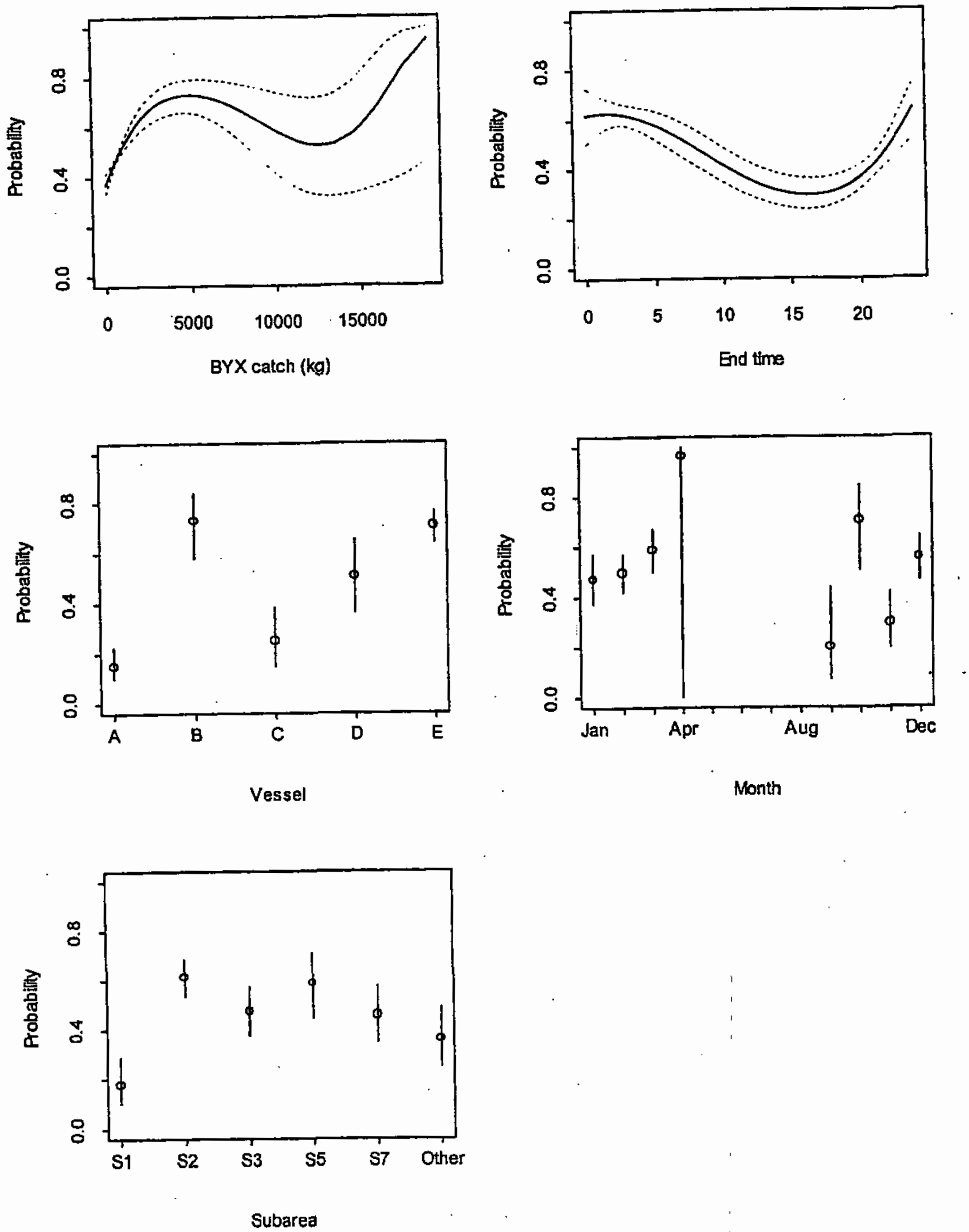


Figure 22: The predicted probability of catching bluenose for each of the significant variables included in the bluenose binomial (*Binom*) CPUE model. The confidence intervals represents +/- 2 standard error.

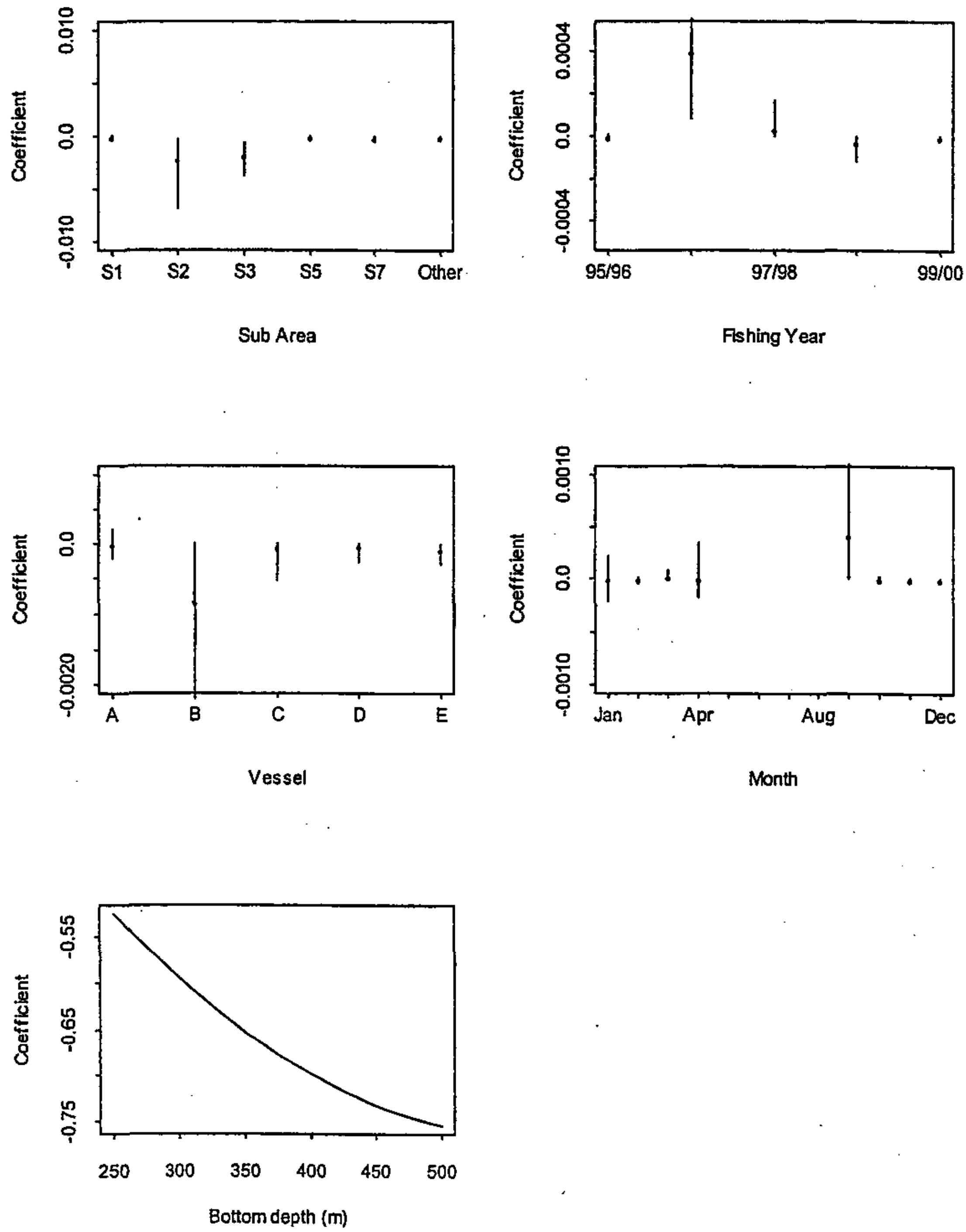


Figure 23: The predicted relationships between the proportion of bluenose in the catch (exponentiated coefficients) and the significant variables included in the *BNSprop* model. The confidence intervals represents +/- 2 standard error.

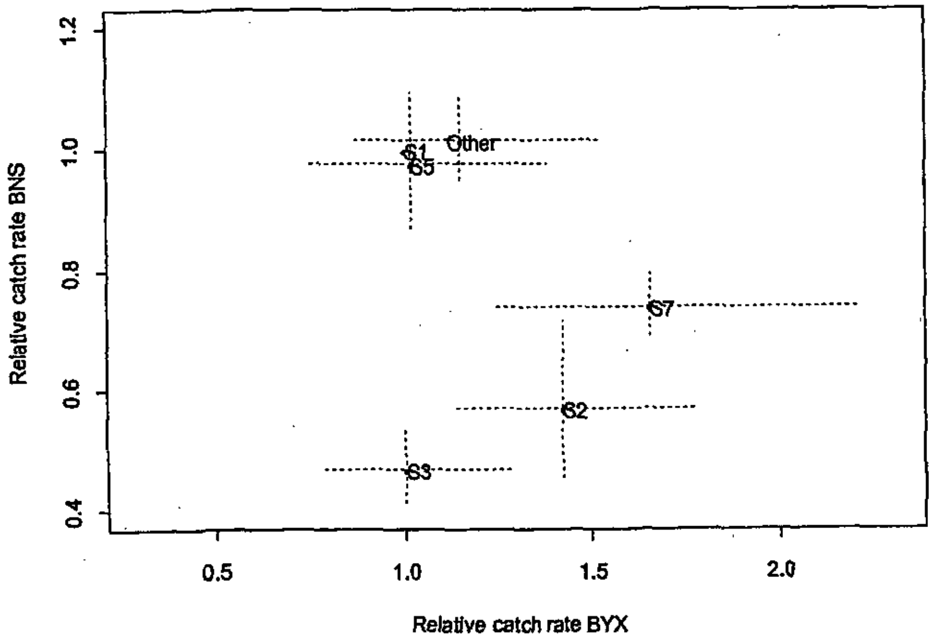


Figure 24: A comparison of the *subarea* coefficients from the alfonsino (*Vesselcat*) and bluenose (*Non zero*) CPUE models. The lines represent the standard error associated with the *subarea* coefficients. Data from the S4 and S6 subareas are amalgamated in the "Other" category.