8. Striped marlin abundance: Standardisation of CPUE

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8.1 Introduction

We present standardisations of catch per unit effort (CPUE) for striped marlin using data collected from two different fisheries operating off the east coast of Australia, these being:

1. Eastern Tuna and Billfish Fishery (ETBF) longline sector, and;

2. Southeast charter boat fishery.

The ETBF analysis considers standardised CPUE on two levels, these being whole fishery, and smaller core catch regions. The analyses of core catch regions looks at potential inter-regional variation in standardised CPUE (as a proxy for abundance) and whether any evidence exists for localised depletions. One of the core catch regions, region B (Map 8.1) corresponds to the region for which charter boat data was collected, facilitating an analyses of fishery interactions presented in the preceding chapter. The CPUE standardisations presented in the current chapter use general additive models, at both the level of the probability of catching the species, and at the level of non-zero CPUE, with these being combined to produce an abundance index. Note that comparisons between the standardised and the nominal commercial CPUEs are discussed in Chapter 5.

The main reason for standardising CPUE is to attempt to remove from the data any variation due to effects other than fish abundance. This usually involves a multivariate statistical technique with CPUE as the dependent variable explained by a number of independent explanatory variables, including year (Gavaris 1980, Kimura 1981, Olsen and Laevastu 1983). Other explanatory variables include area, fishing vessel, gear characteristics, and factors that might indicate targeting, such as hooks per basket and live bait usage. To the extent that the explanatory variables account for all the variation in CPUE other than variation in abundance and random noise (*i.e.* catchability can then be assumed constant over time), the year effect estimates the trajectory of abundance over time. In addition, environmental variables such as sea surface temperature and southern oscillation index may also be used as explanatory variables, although there is a danger that broader-scale environmental variables may affect abundance rather than catchability.

Traditionally standardised CPUE series are produced using generalised linear models (GLM) (McCullagh and Nelder 1989) and most models have either been lognormal GLMs, with zero observations excluded, lognormal GLMs with an added constant, or variations on the delta lognormal model (Gavaris 1980, Kimura 1981, 1988). Alternatively it has been assumed that the catch taken for a given effort has a Poisson distribution, which allows for the inclusion of the zero catch information in the analysis (McCullagh and Nelder 1989).

In this analysis a general additive model (GAM) technique was used (Hastie and Tibshirani 1990, Chambers and Hastie 1992). GAMs are a flexible class of models that can be used either as the main analysis tool (Kleiber and Bartoo 1998 and Fewster *et al.* 2000) or as an exploratory tool (Wise *et al.* 2002) before constructing more formal analysis using, for example, GLMs. The GAM technique allows numerical independent variables to have nonlinear effects on the dependent variable as determined by a smoothing algorithm (Cleveland 1979). Thus the effect of an independent variable is only constrained by the smoothing algorithm and is the major difference between the GAM and GLM.

A distinctive feature of catch and effort data is that it is often “zero inflated”. That is, the data contain more zeros (*i.e*. in this case, longline operations or charter fishing days for which no marlin were caught) than might be predicted from standard error models used with GLMs (Ridout *et al*. 1998). If this feature of the data is ignored, and a standard Poisson error models is applied, problems with inference may occur as the Poisson assumption may not be an adequate approximation to the distribution of the catch data (McCullagh and Nelder 1989). In an attempt to overcome this problem, some studies have applied a small arbitrary constant either to zero catches or to all records when using log-transformed data. However this method may introduce a significant bias if there are reasonable numbers of catches with varying effort (Caputi 1996). Other studies have ignored the zero catches altogether, however this method runs the risk of overlooking important trends in abundance indicators. For example, it is possible that non-zero CPUE may remain constant over time suggesting that the stock is fished sustainably, but actually the number of zero catches is increasing over the time period indicating that the stock is in decline (Stefansson 1996).

An appropriate solution is to consider both sources of information, in other words, presence/absence data to indicate the level of probability of catching the species, and presence-only data which indicates the level of non-zero CPUE (Barry and Welsh 2002, Campbell *et al*. 2002). The methodology used here was to model the data in these two steps, firstly modelling the association between the presence and absence in the catch of the species and any explanatory variables, and secondly modelling the relationship between abundance and the explanatory variables, conditional on the species being present in catch. A combined abundance index is then created from these analyses, which takes into account trends from both these data series.

The GAM models were used in an effort to gain information pertaining to the following questions:

1. What do longline CPUE data indicate about trends in abundance of striped marlin off the east coast of Australia, and is there any evidence for variation between regions, or of localised depletions?

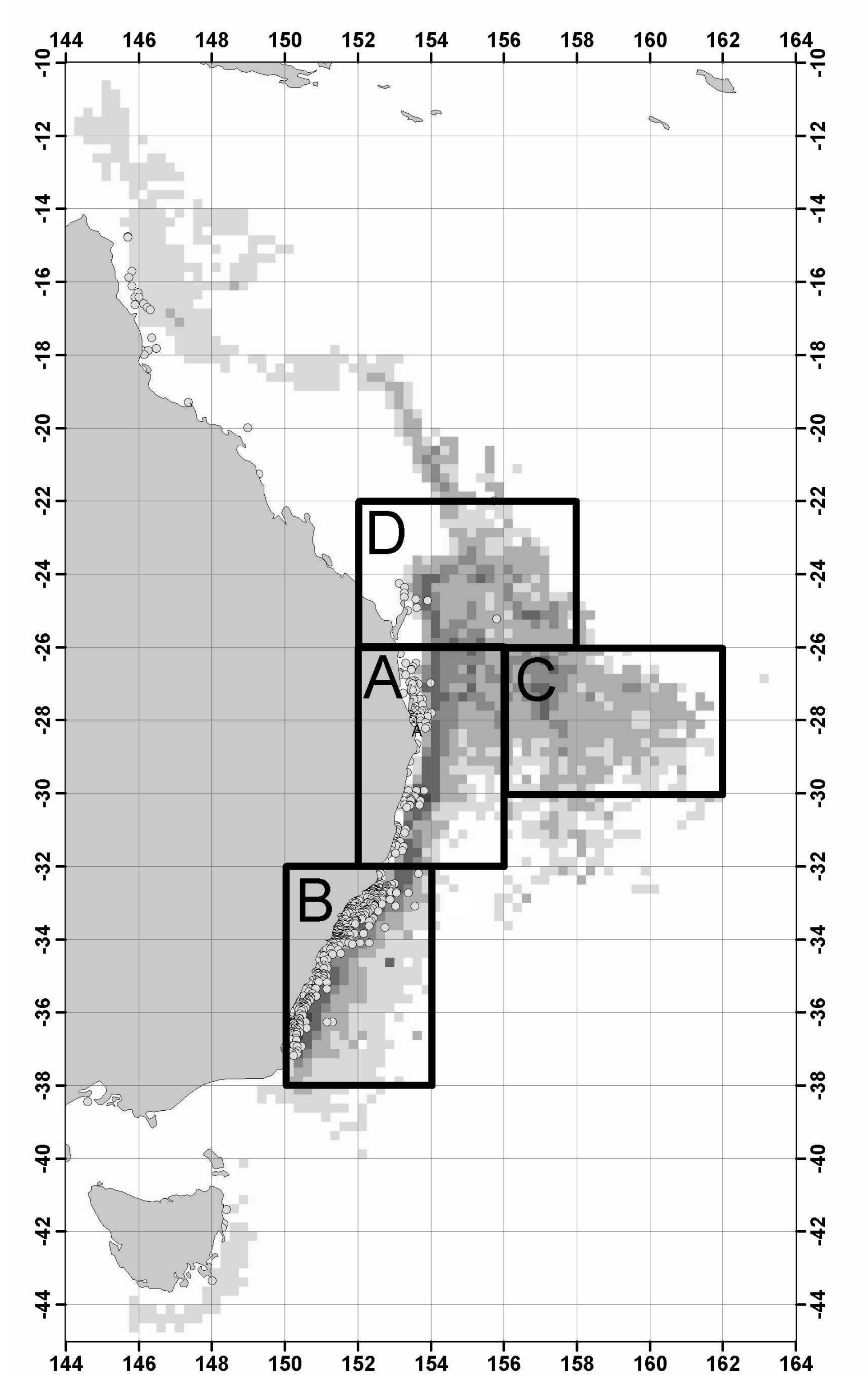
2. What do charter boat catch rate data indicate about trends in abundance of striped marlin off the southeast coast of Australia? Do these match longline catch rate trends?

3. What environmental, gear related and regional factors affect the variability in catch rates for striped marlin? What do these relationships imply about the biology and catchability of the species?

8.2 Methods

8.2.1 Data collection

Eastern Tuna and Billfish longline fishery data: Longline data from this fishery was sourced from the Australian Fisheries Management Authority catch and effort logbooks. Logbook data is filled out by longline fishing captains after each fishing operation, and submitted to the AFMA for entry onto their electronic database. It should be noted that domestic longline data drawn from logbook records can suffer from errors in reporting, and from inconsistent or incomplete format of reporting (most detail catches by species, but others only record total catch per set etc). Other errors such as species misidentification can also introduce an unknown but probably small degree of error into the database.



Map 8.1 – Four core catch regions for which abundance indices for striped marlin were determined, based on domestic longline catch and effort records. Core regions are overlaid on density plot of mean annual catch (red) of striped marlin by longline, and tag-releases by recreational fishery (yellow dots). These regions were chosen to facilitate both current abundance analyses and the interactions analyses presented in Chapter 7.

For the ETBF longline fishery, catch and effort data is recorded in logbooks on an operation by operation basis. Nominal catch rates are calculated as the number of fish caught per 1000 hooks, for each fishing operation. Other ETBF longline data considered in the modelling process included date (Year), start latitude (Latitude), start longitude (Longitude) and start time (Start time) of each set. In addition the number of hooks per basket (HPB), life-bait status (BLS) and the use of light-sticks (LS) were used as possible indicators for targeting.

Charter boat data: Catch and effort data from 11 charter boats operating in a 6º latitudinal band stretching between Port Stephens and Merimbula, off the central and southeastern coast off Australia, were collected during 2002. A full description of this data set, and of the nominal catch and effort trends extracted from the data set are provided in full in Chapter 7. A number of limitations to the data collected are also described in Chapter 7, and these should be kept in mind when considering the results from the current catch rate standardisation

Environmental data: The environmental information used as independent explanatory variables included the one degree weekly satellite based Sea Surface Temperature (SST) data (obtained from International Research Institute for Climate Research online database, 2002) and the monthly Southern Oscillation Index anomies (SOI)(obtained from Commonwealth Bureau of Meteorology online archives, 2002). These were added into the longline and charter boat databases. In the Eastern Tuna and Billfish Longline Fishery SST values were assigned to each set contained within each one-degree grid. In the charter boat fishery SST values were assigned to the daily trip data assuming that the trip was within one degree of the port from which the fishing trip originated.

All data was used with some minor restrictions. Eastern Tuna and Billfish Longline Fishery effort was restricted to be greater than 40 hooks per operation and less than 40 hooks per basket. Charter vessel and port information was used only when there was greater than 50 fishing days per vessel or per port respectively. To ensure consistency in analyses of data from both these fisheries, dates from the ETBF longline sector and the charter boat fishery were restricted to the period January 1990 to December 2001, and January 1990 to September 2002 respectively.

8.2.2 Models

The nominal catch rates described above are commonly used as a basis to determine abundance. This follows the classic fisheries assumption that catch divided by effort is proportional to the population size. The relationship is expressed in the form

$$\text{CPUE} = \frac{C}{E} = qN$$

where CPUE is the catch per unit effort, C is the catch, E is the effort, N is the population size and q is the catchability coefficient (Hilborn and Walters 1990). This assumption allows the use of CPUE as an index of abundance. However caution is necessary as the relationship is variable and the catchability coefficient may change due to changes in fishing technology and may also vary unpredictably with time.

GAMs were fitted firstly using a logistic regression with a binomial response for the presence/absence data (PA models) and secondly using a Gaussian response for the presence-only data (Log(CPUE) models). The form of these models for the Eastern Tuna and Billfish Longline Fishery were:

PA~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(LogEffort)+s(HPB) and

Log(CPUE)~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(HPB), and the form of these models for the charter boat fishery were:

PA~s(Year)+s(SST)+s(SOI)+Vessel+Port and

Log(CPUE)~s(Year)+s(SST)+s(SOI)+Vessel+Port.

A number of gear and fishing methods related factors were suspected to affect catchability of striped marlin by longline, however data pertaining to some of these factors, specifically bait status (live or dead) and use of light sticks, were not available until later in the time series, due to changes in logbook recording formats. Consequently, further models were investigated for the ETBF longline sector over a reduced temporal period (1997-2001), so as to include the variables relating to life-bait status (BLS) and the use of light-sticks (LS). The form of these models were:

PA~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(LogEffort)+s(HPB)+s(BLS)+s(LS) and

Log(CPUE)~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(HPB)+s(BLS)+s(LS).

8.2.3 Analyses

The GAM analyses were carried out using SPLUS (Insightful Corporation). Variable selection was performed using backwards elimination with the Akaike Information Criterion (AIC) statistic being used to differentiate between potential models. Continuous variables were considered for the model in three formulations either as smooth terms (using a cubic B-spline with default degrees of freedom in SPLUS), linear terms or null (*i.e.* excluded). Factor variables (*i.e.* charter boat fishery vessel and port variables, and Eastern Tuna and Billfish Fishery life-bait status and light-stick use variables) were either included as a factor or excluded if found not significant.

Subsequent temporal trends were estimated using mean values (or median if a factor) calculated for each variable over the entire database. Thus indices were determined for both the presence/absence data and the presence-only data. The form of these indices were

$$\text{Index} = \frac{e^{PA}}{1+e^{PA}} \text{ and } e^{Log(CPUE)} \text{ respectively.}$$

These models provide two forms of information. The presence/absence model predicts the level of the probability of success of catching the species and the presence-only model predicts how abundant the species should be when present. To provide an overall index of abundance the two indices were combined, simply by multiplying them together.

GAM analyses were carried out for the entire longline and charter fisheries between 1990 and 2001 using both absence/presence data and presence-only data. In addition to allow for the possibility that abundance varies independently in different regions, separate longline analyses was repeated for the four core areas A-D (See Map 8.1). These analyses involved all variables with the exception of live-bait status and the use of light-sticks data, which are only available for a reduced time period (1997-2001). Further GAM analyses were carried out for the reduced time period to investigate the influence of the bait life status and light stick variables.

8.3 Results

8.3.1 ETBF: entire fishery

In all instances the backward stepwise regression did not reduce the number of model variables (Figures 8.1-8.6). In three cases the need for a smoothing function to fit longitude was found not to be significant and a linear regression was fitted instead (Figures 8.3a, 8.3b and 8.4a). All final models (*i.e.* models resulting from the stepwise procedure) explained only a small amount of deviance yet their statistical effect was significant (Table 8.1).

The relative effects of different variables and factors upon catch rates are presented in Figures 8.1-8.8. In each figure, the solid trend line represents the mean relative effect of the variable upon catch rates, while the dashed lines either side of the mean represent the margin of error or uncertainty. These error margins tend to increase or "fan out" when there is little underlying data upon which the mean line is calculated. Thus the following description of data trends only attempts to infer trends where these error bounds are small (*i.e.* close to the mean line).

The temporal pattern for the final model for the entire fishery shows an increasing trend over the entire period for the presence/absence data and a declining trend for the presence-only data between 1997 and 2000 with a slight increase in 2001 (Figures 8.1a and 8.1b). Due the large uncertainties in the temporal variable prior to 1997 it is not possible to confidently infer the trend prior to this period. When these indices are combined (Figure 8.8) the catch rates generally indicate an increase through the 1990s and 2000/2001.

Most of the environmental and gear related variables depict similar trends between the presence/absence and presence-only models, with the exception of longitude. In general higher values occur between 20°S-37°S latitude, for sets put in the water between 5-10 am (*i.e.* daytime sets), 22°C-26°C SST and positive SOI anomalies. There is some indication of an increasing trend in catch rates occurring with decreasing number of hooks per basket (i.e. shallower sets), but due to the large uncertainties it is not possible to infer the trend with any certainty. The longitude variable between 145°E and 160°E depict an increasing trend in the presence/absence model and a decreasing trend in the presence-only model. The effort variable, which is only in the presence/absence model shows an increasing trend with increasing effort.

The inclusion of bait-life status and the use of light-sticks data, which are only available for a reduced time period (1997-2001), though statistically significant only slightly reduce the deviance (Table 8.2). In both models the use of lights-sticks was associated with lower catch rates (Figures 8.6a and b). Live bait appears to increase the index values compared to dead bait in the presence/absence model, while mixed live and dead bait produces an intermediate result (8.6a). The result is inconclusive for the presence-only model (Figure 8.6b). The other fitted variables depict similar trends to those in the whole fishery (Figures 8.1a and b).

8.3.2 ETBF: core regions

The relationships between variables in the models with catch rates, for models analysing the four core areas A-D, are similar to the patterns apparent from the whole fishery analyses. The main exceptions are the differences in temporal CPUE trends between each of the core regions, and between these regions and the whole fishery temporal pattern. Additionally, for the core regions, it is often not possible to infer trends due to the large uncertainties (Figures 8.2-8.5) in the model fit (often due to lack of underlying data). When comparing between models note that the range for the latitude and longitude differs, as consequently does the range for the other variables.

Table 8.1. Comparison of the final backward stepwise regression CPUE index with the null for each region in the Eastern Tuna and Billfish Fishery (ETBF).

	Residual degrees of freedom	Residual deviance	Change in degrees of freedom	Change in deviance	F value	P value
Presence/absence model for ETBF						
Null model	76124.0	87697.6				
Final model	76092.7	68355.8	31.4	19341.8	632.4	<0.001
Presence-only model for ETBF						
Null model	20008.0	9269.5				
Final model	19980.0	8548.2	28.0	721.3	60.2	<0.001
Presence/absence model for area A						
Null model	16596.0	21570.8				
Final model	16564.8	19579.0	31.2	1991.7	66.0	<0.001
Presence-only model for area A						
Null model	5873.0	2635.9				
Final model	5845.0	2347.9	28.0	288.0	25.6	<0.001
Presence/absence model for area B						
Null model	18707.0	19252.2				
Final model	18676.0	15291.5	31.0	3960.8	124.9	<0.001
Presence-only model for area B						
Null model	3936.0	1959.6				
Final model	3908.0	1667.2	28.0	292.5	24.5	<0.001
Presence/absence model for area C						
Null model	6834.0	9473.3				
Final model	6805.8	8656.4	28.2	817.0	29.8	<0.001
Presence-only model for area C						
Null model	3475.0	1431.2				
Final model	3450.0	1251.3	25.0	179.9	19.8	<0.001
Presence/absence model for area D						
Null model	8698.0	11683.8				
Final model	8669.2	10198.8	28.8	1485.0	52.2	<0.001
Presence-only model for area D						
Null model	3448.0	1568.8				
Final model	3420.0	1340.6	28.0	228.2	20.8	<0.001

Table 8.2. Comparison of the final backward stepwise regression CPUE indices with the null, for the Eastern Tuna and Billfish Fishery (ETBF).

	Residual degrees of freedom	Residual deviance	Change in degrees of freedom	Change in deviance	F value	P value
Presence/absence model						
Null model	49033.0	62463.6				
Final model[1]	49001.6	50945.1	31.4	11518.6	396.0	<0.001
Final model[2]	48998.6	50888.8	3.0	56.3	20.4	<0.001
Presence-only model						
Null model	16374.0	7468.1				
Final model[1]	16346.0	6897.3	28.0	570.8	48.4	<0.001
Final model[2]	16343.0	6877.7	3.0	19.6	15.5	<0.001

Final model[1] is of the respective forms:

PA~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(LogEffort)+s(HPB) and

Log(CPUE)~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(HPB).

Final model[2] is of the respective forms:

PA~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(LogEffort)+s(HPB)+s(BLS)+s(LS) and

Log(CPUE)~s(Year)+s(Latitude)+s(Longitude)+s(StartTime)+s(SST)+s(SOI)+s(HPB)+s(BLS)+s(LS).

Table 8.3. Comparison of the final backward stepwise regression CPUE index with the null for charter boat fishery in area B.

	Residual degrees of freedom	Residual deviance	Change in degrees of freedom	Change in deviance	F value	P value
Presence/absence model						
Null model	1314.0	1709.8				
Final model	1295.2	1396.0	18.8	313.8	17.4	<0.001
Presence-only model						
Null model	465.0	191.3				
Final model	457.0	164.5	8.0	26.8	9.3	<0.001

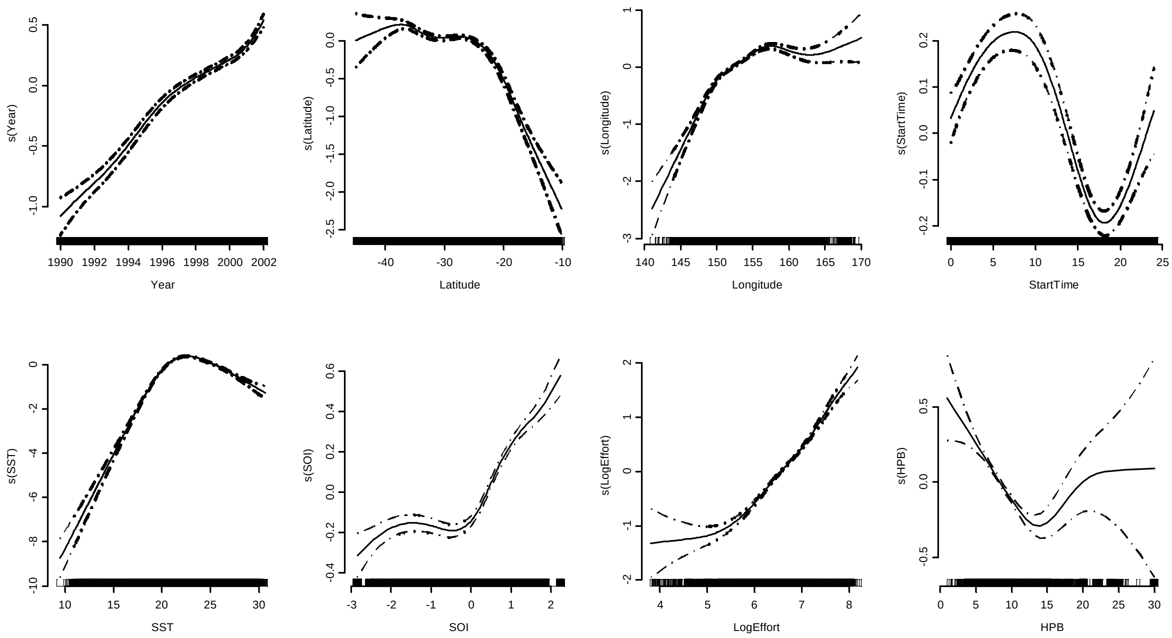


Figure 8.1a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery in entire region.

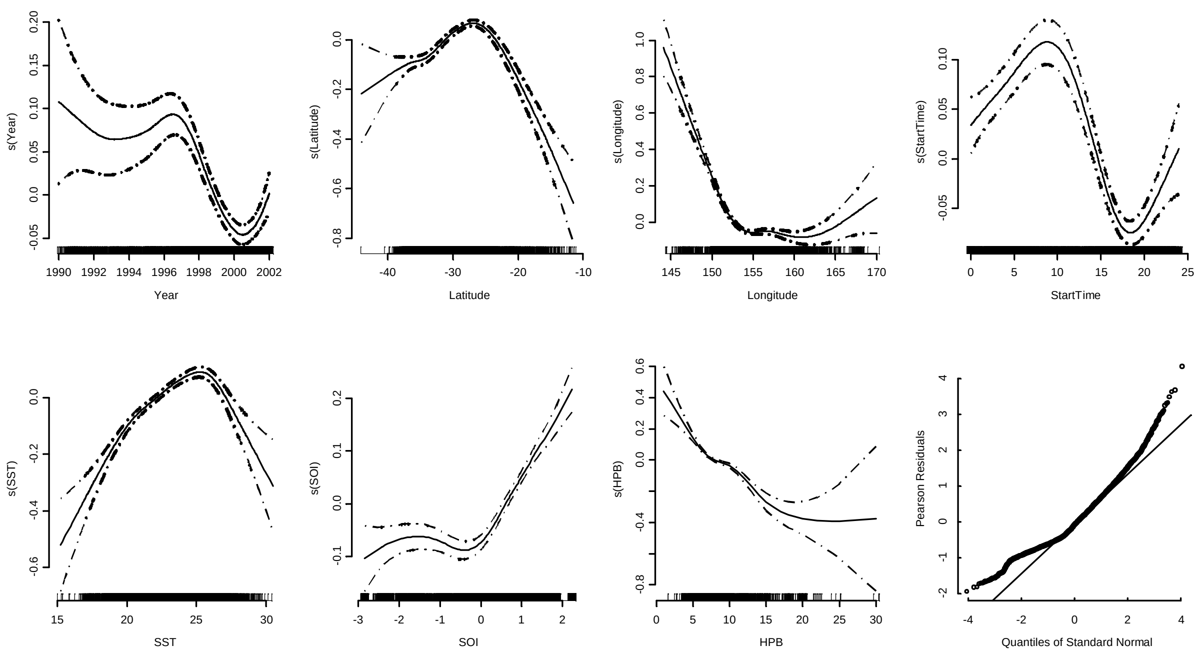


Figure 8.1b. GAM model for striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery in entire region.

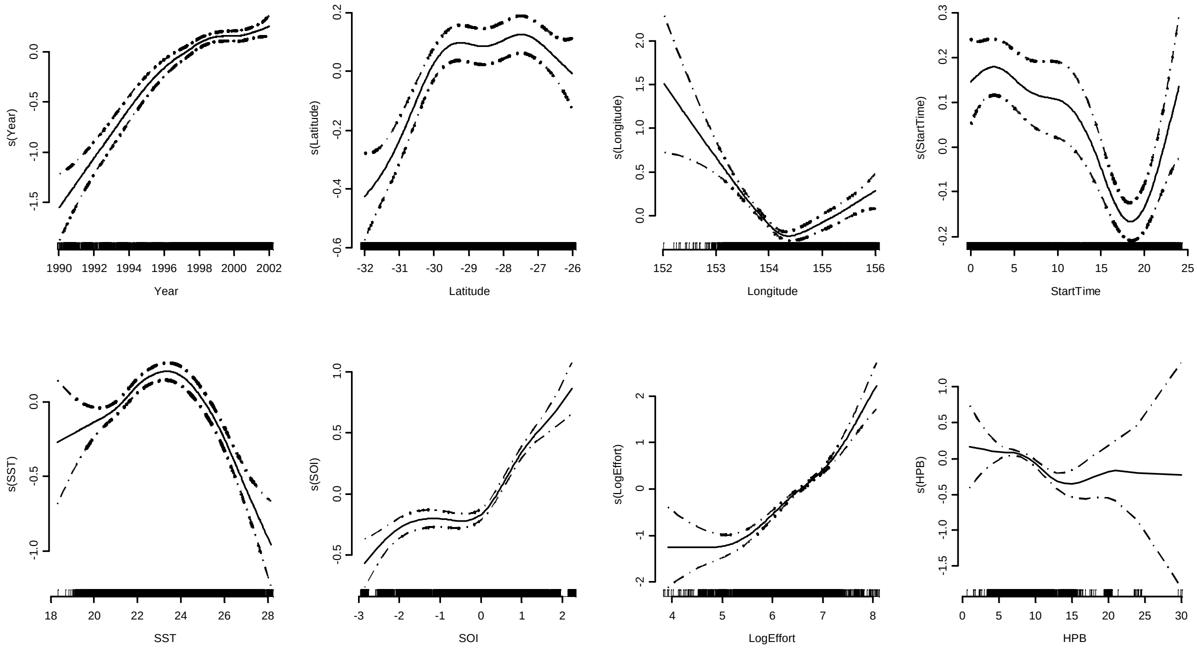


Figure 8.2a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery in region A.

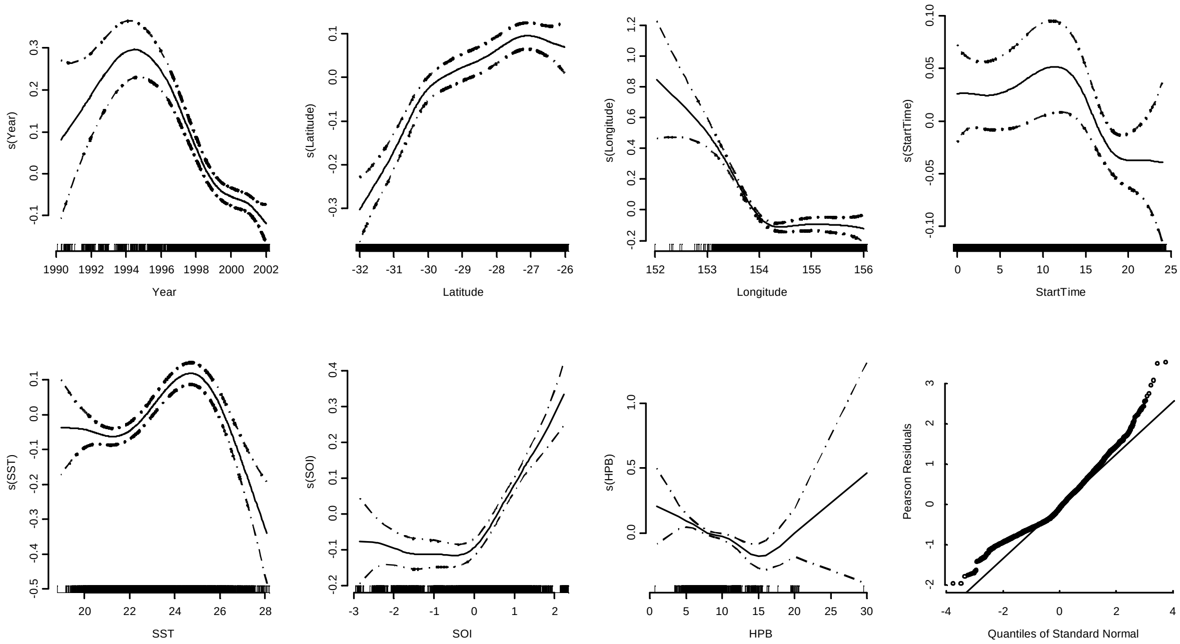


Figure 8.2b. GAM model for striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery in region A.

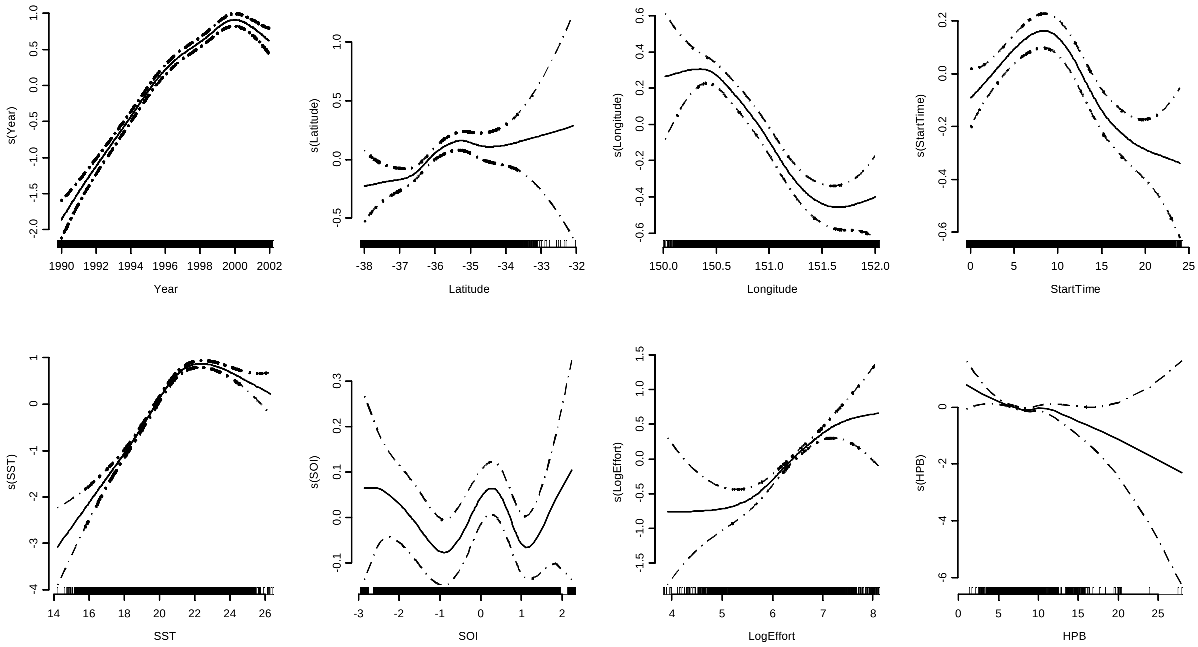


Figure 8.3a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery in region B.

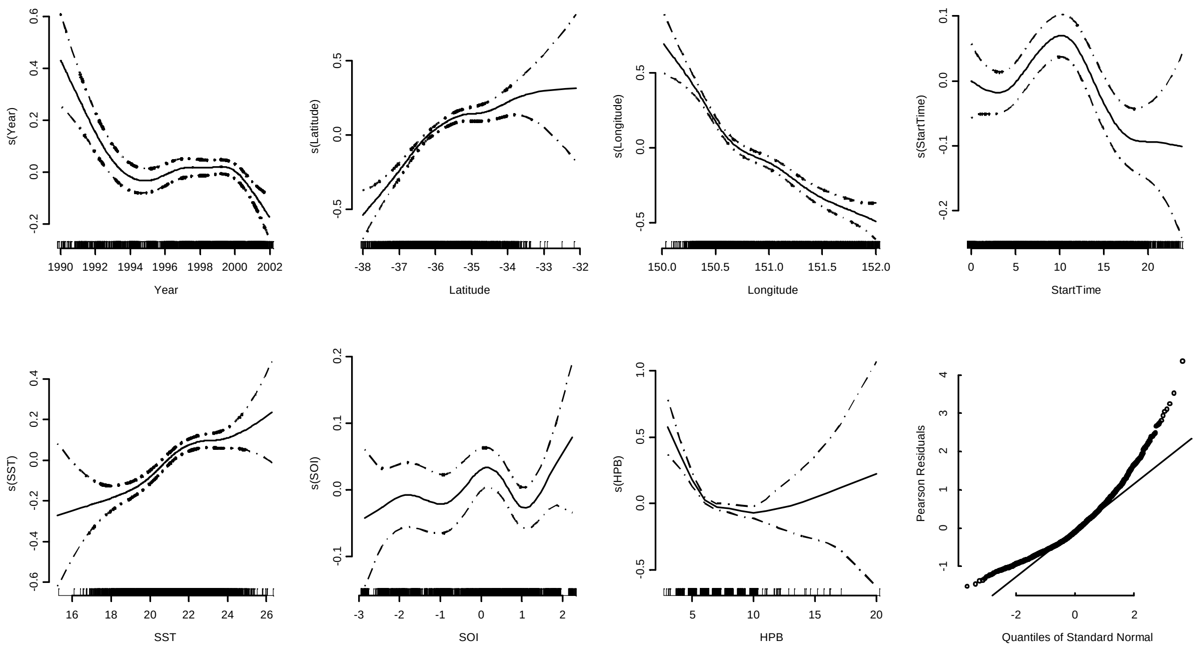


Figure 8.3b. GAM model for striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery in region B.

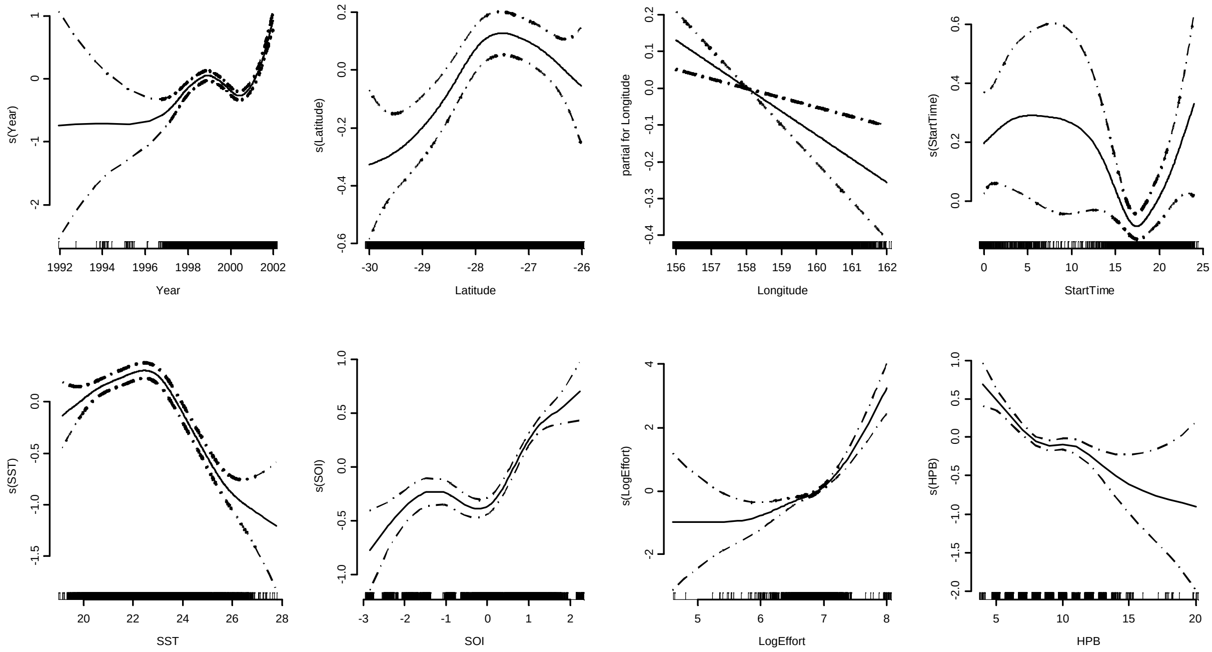


Figure 8.4a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery in region C.

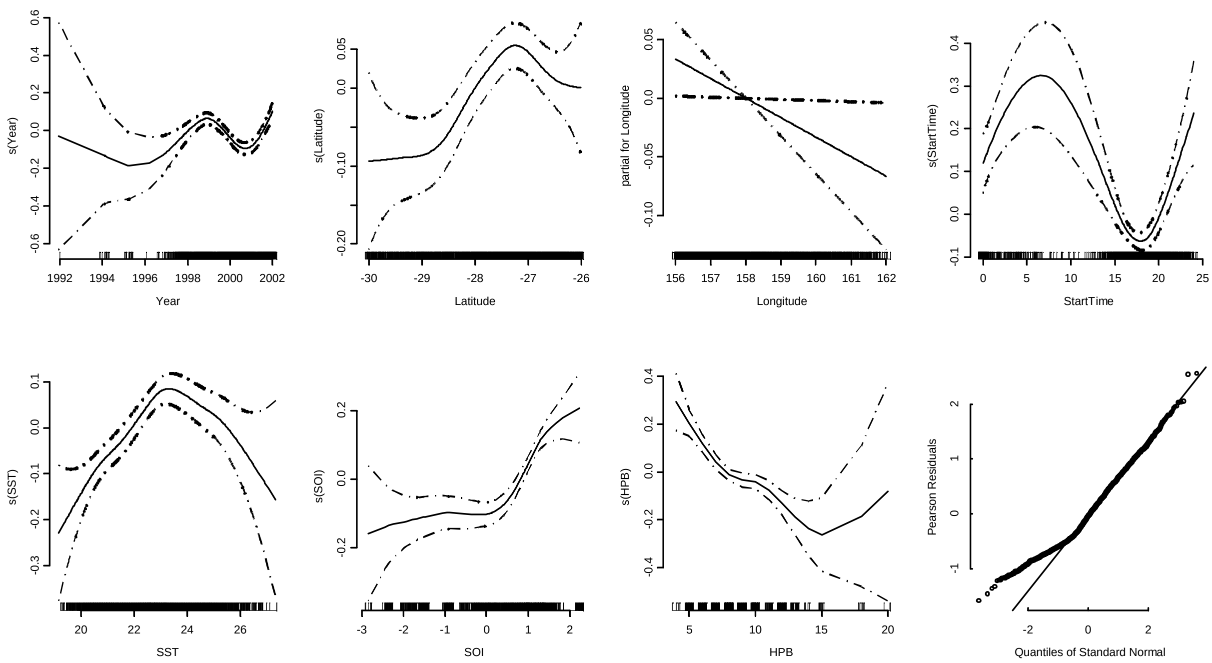


Figure 8.4b. GAM model in striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery for region C.

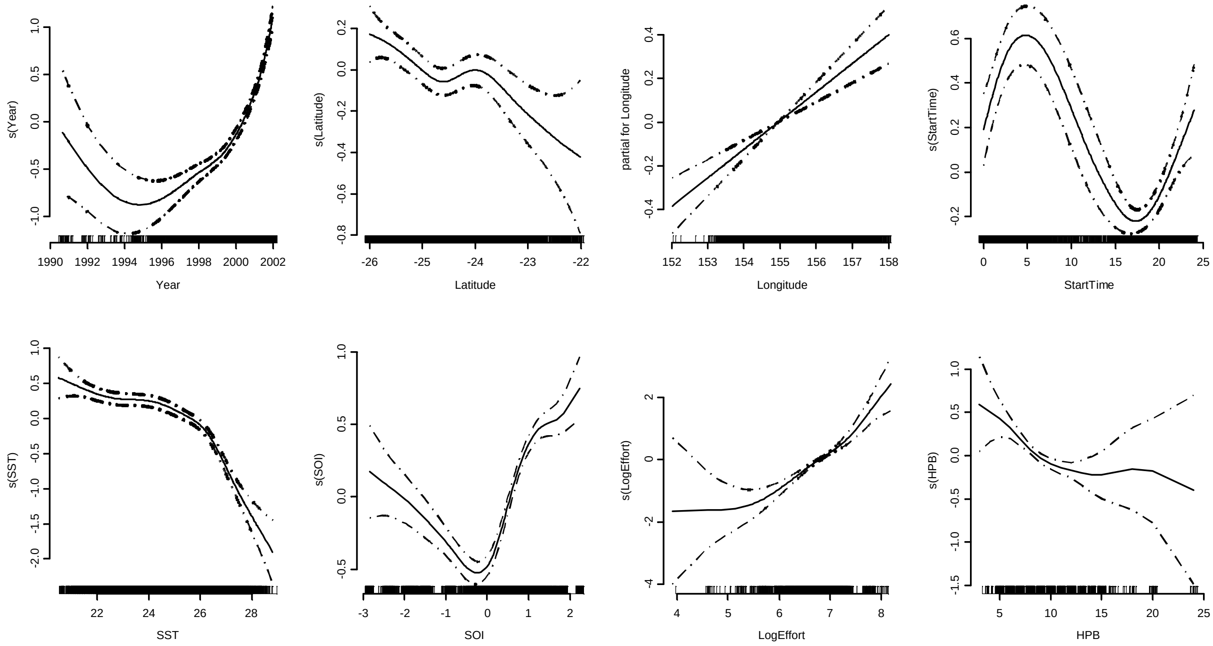


Figure 8.5a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery in region D.

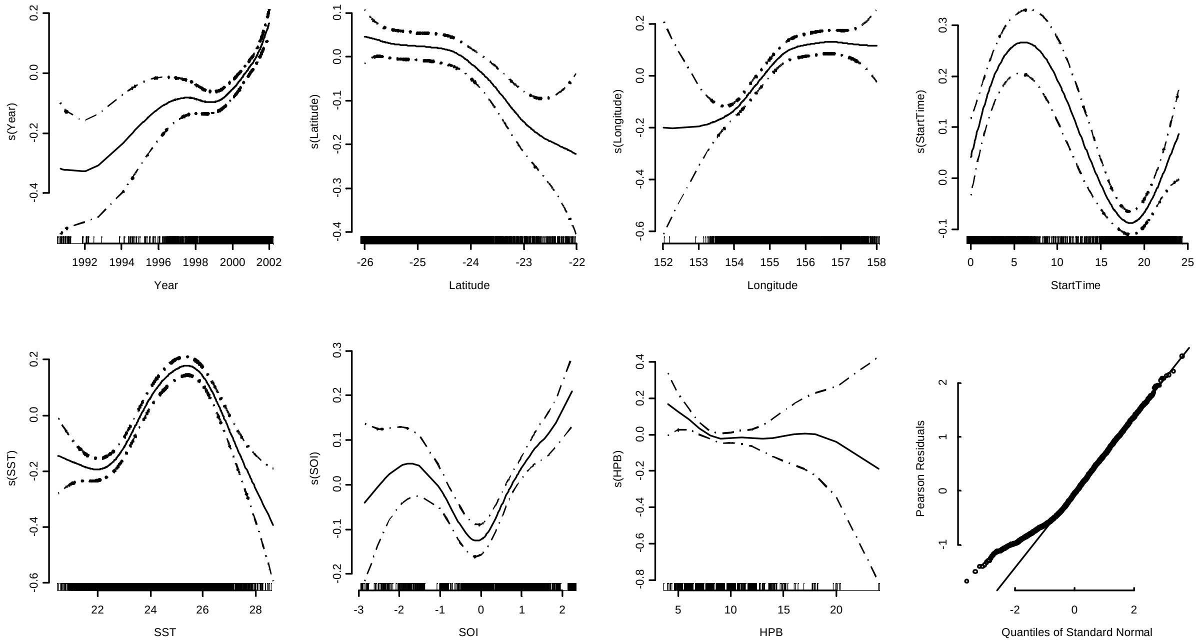


Figure 8.5b. GAM model for striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery in region D.

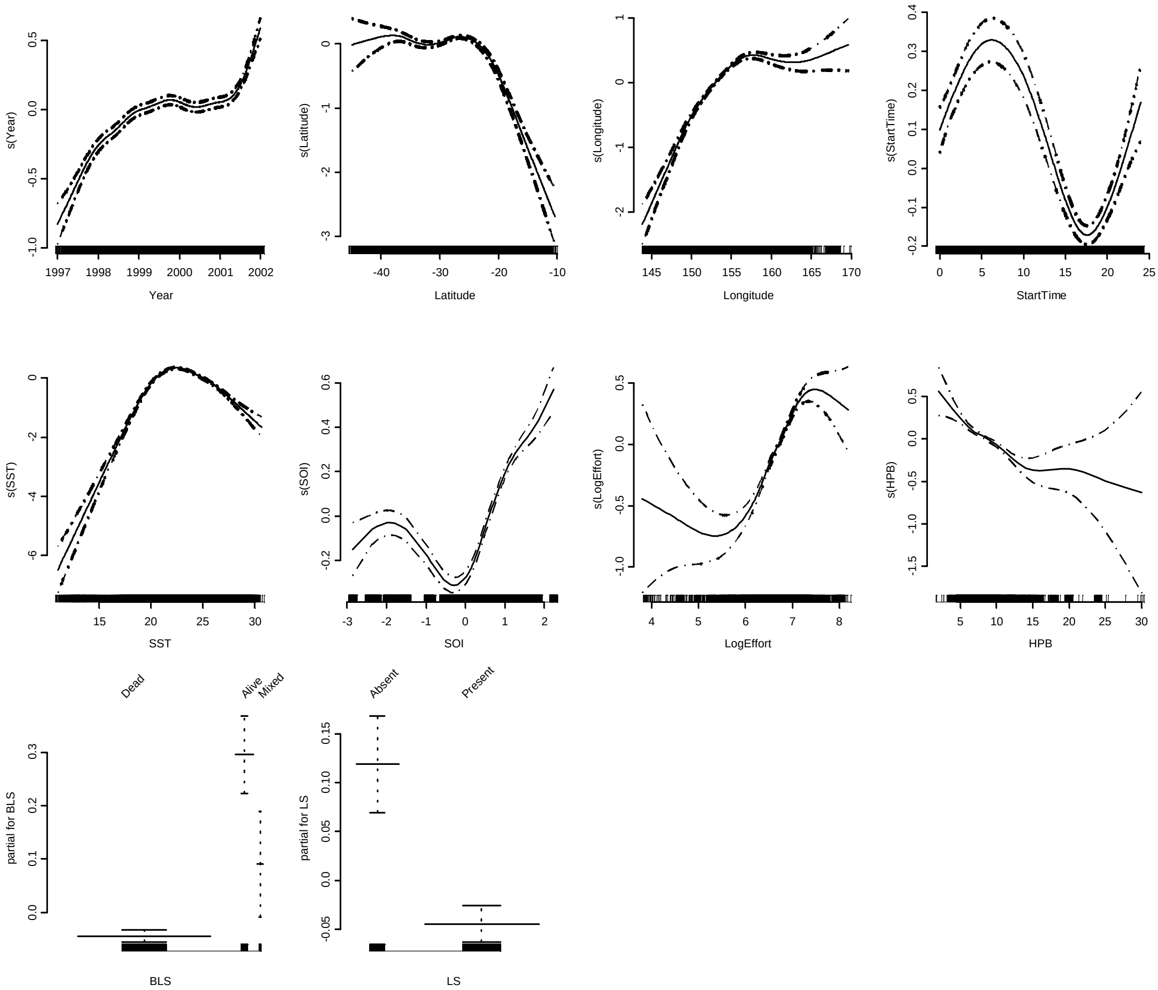


Figure 8.6a. GAM model for striped marlin presence/absence data in the Eastern Tuna and Billfish Longline Fishery between 1997 and 2001.

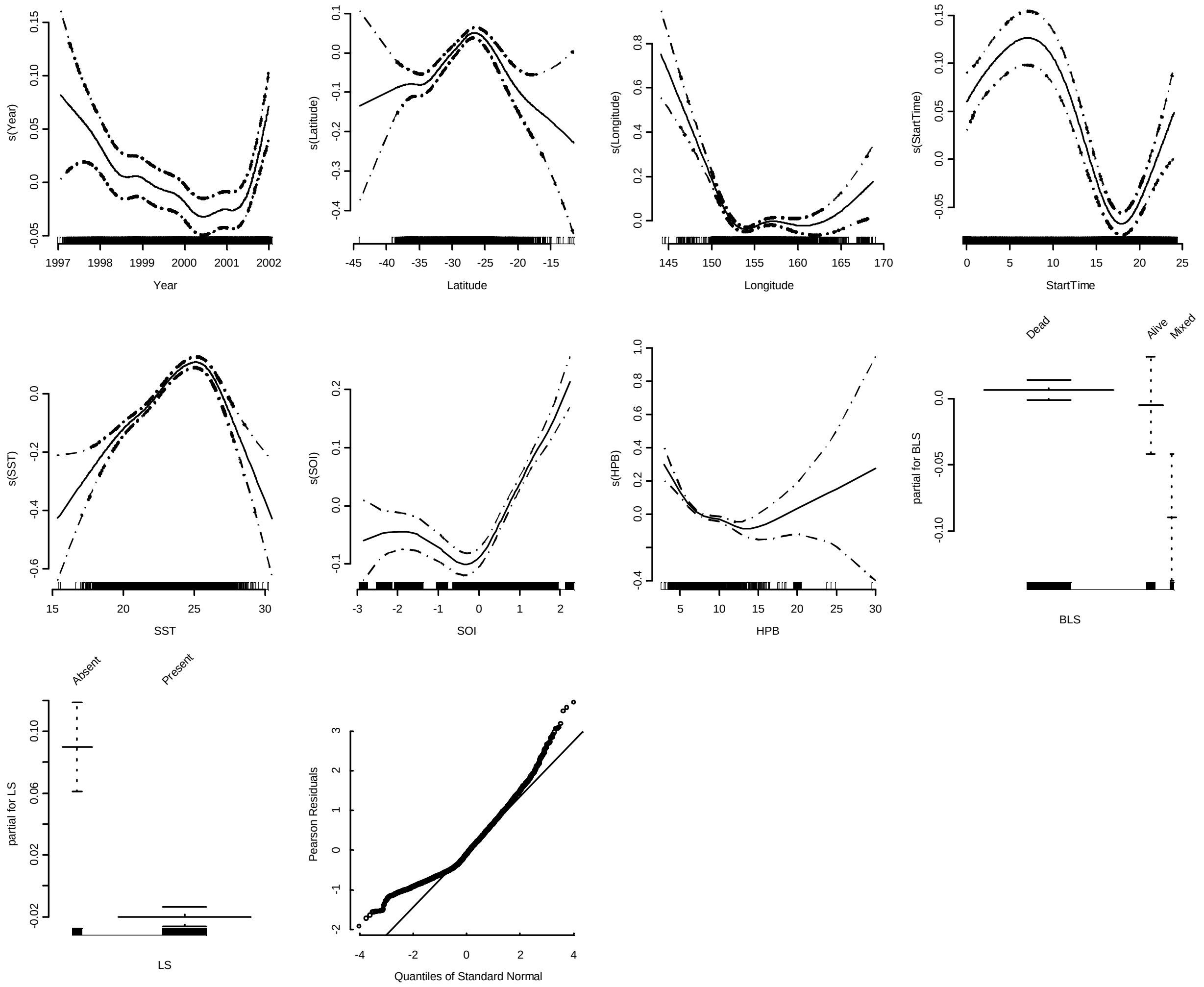


Figure 8.6b. GAM model for striped marlin presence-only data in the Eastern Tuna and Billfish Longline Fishery between 1997 and 2001.

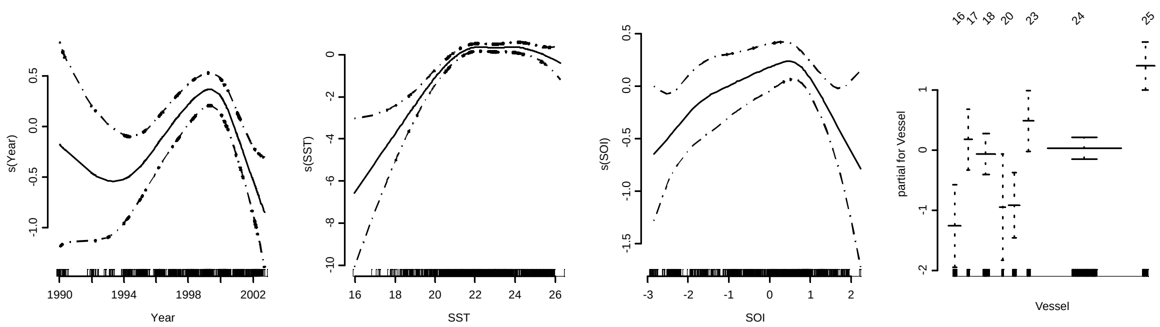


Figure 8.7a. GAM model for striped marlin presence/absence data in the charter boat fishery in region B.

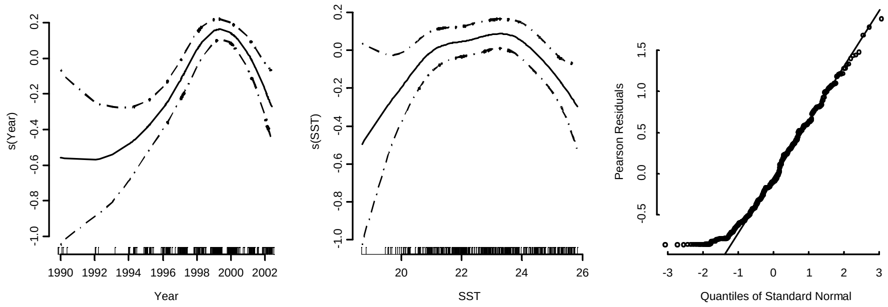


Figure 8.7b. GAM model for striped marlin presence-only data in the charter boat fishery in region B.

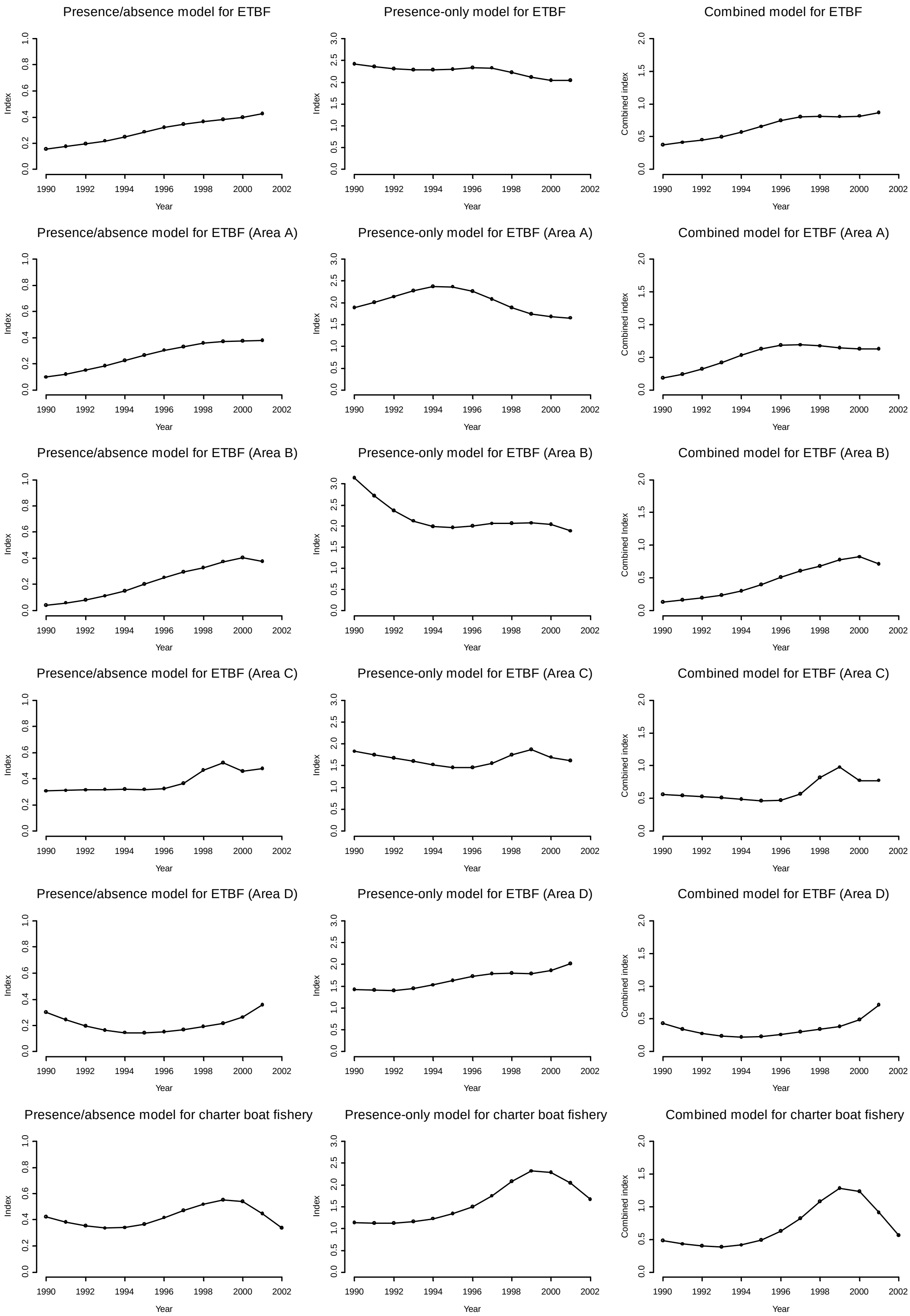


Figure 8.8. Indices of abundance calculated from GAM models for striped marlin absence/presence data and presence-only data, and combined indices in the Eastern Tuna and Billfish Longline Fishery (ETBF) and charter boat fishery.

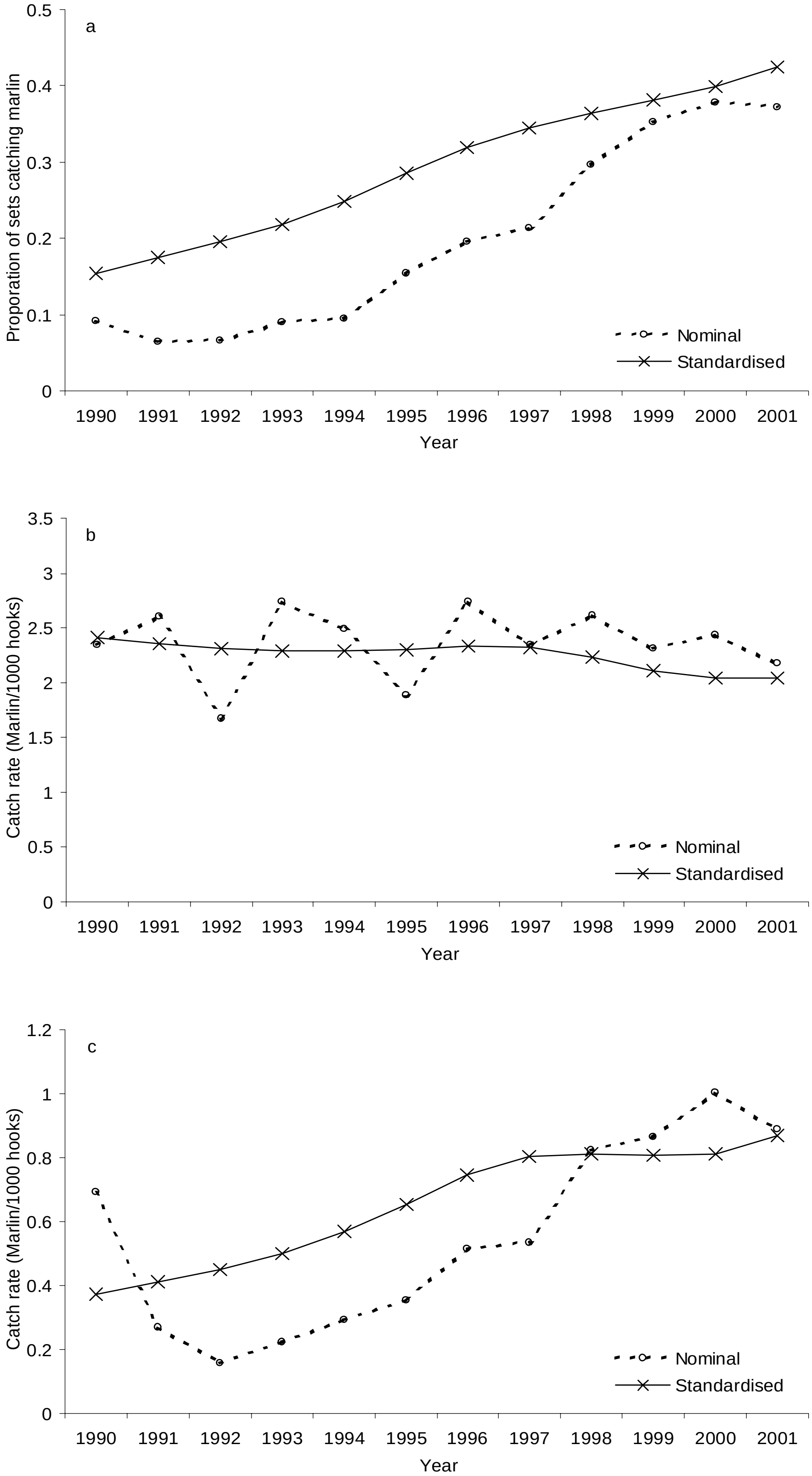


Figure 8.9. Nominal and standardised indices calculated for a) presence-only data, b) presence/absence data and c) combined data, for the entire ETBF longline fishery. Refer to methods for details of calculations.

The temporal pattern exhibited by all but one of the presence/absence models for the selected subregions (A-C) generally shows an increasing trend in catch probability (Figures 8.2a, 8.3a, 8.4a, 8.5a and 8.8), similar to the trend apparent for the entire fishery. There was little overall increase in region D, with catch probability actually declining until the mid-1990s, before increasing again after 1995 to a similar level.

The temporal trend in CPUE exhibited by the presence-only models varies between regions. In region A, catch rate increased between 1990 and 1994, but declined thereafter (Figures 8.2a, b and 8.8). In region B, the catch rate decline between 1990 and 2001, with most of this decline occurring in the first 4 years (Figures 8.3a, b and 8.8). In region C, values declined between 1990 and 1996 before increasing to a peak in 1999 and then declining again by 2001 (Figures 8.4a, b and 8.8). In region D, catch rates calculated from presence-only data have increased from between 1990 and 2001 (Figures 8.5a, b and 8.8).

8.3.3 Charter boat fishery

GAM analyses were carried out for the charter boat fishery (which lies in area B) between 1990 and 2001, using both presence/absence data and presence-only data. While five variables were considered in the models, not all were selected during the backward stepwise regression. In the presence/absence model the port variable was excluded while in the presence-only model the port, vessel and SOI variables were excluded (Table 8.3).

The temporal pattern for both presence/absence and-presence-only models depicts a peak in 1999 and a declining trend thereafter (Figures 8.7a, b and 8.8). The presence/absence, presence-only, and combined abundance index presented in Figure 8 was calculated using vessel ID 18, although models were also analysed for each of the other vessels, and found to produce similar trends. In these other indices the trend remained the same with only slight increases or decreases in the magnitude of the index. In relation to environmental factors, the models indicate that higher values occur between 20ºC-26ºC SST and with increasing SOI anomalies, although the data for positive SOI is limited (due to the short time period analysed during which few switches between El-Nino and La-Nina conditions were recorded).

8.4 Discussion

The trends in the standardised CPUE of striped marlin over the past 12 years have varied to some degree between regions, although in general, standardised CPUE were higher in the second half of the 1990's than the earlier years. In addition trends in standardised CPUE, as calculated for the charter fishery in region B and the ETBF fishery in region B, show some similarities. Given some of the limitations of both data-sets used in the analyses, and the fact that only main effects were considered, the models presented here to standardise CPUE for striped marlin taken in the ETBF longline sector, represent preliminary investigation of the abundance of striped marlin off the east coast of Australia in the past 12 years, laying the groundwork for future analyses. Potential explanations for why there are observed inter-regional differences, and between abundance trends calculated from data taken from the charter fishery and the ETBF fishery in region B, are discussed below. The implications of various limitations in the data used for the interpretation of such trends, is also discussed below.

8.4.1 Regional variability

There are a number of possible explanations for the apparent inter-regional variability in temporal trends for standardised catch rates of striped marlin. The following represents a discussion of some of these:

- **Regional population structuring or very low levels of viscosity/mixing** – whereby abundance will vary based on initial regional abundance and then differing levels of fishing effort over time in each region (assuming all other factors are accounted for: see 3rd dot point). Of all the potential explanations presented here, this is the least likely. CPUE analyses of Japanese longline data (Chapter 5; Squire and Suzuki, 1990; Ward, 1996), and a substantial body of tag-recapture evidence (Appendix I), suggest that striped marlin distribution off eastern Australia shifts seasonally, and that there is a common region of mixing and spawning in the south Coral Sea and extending east of these waters. There is some evidence that the southwest Pacific might contain a sub-population of striped marlin relative to the rest of the Pacific (e.g. Graves and McDowell, 1994), but it is highly unlikely, based on current evidence, that there is further population structuring within this southwest Pacific region. Hence, marlin caught in each of the subregions A-D are most likely from the same stock, and are likely to mix on a seasonal basis.

- **The "age" of the fishery in each region**– i.e. the length of time each region has been fished to a significant level. The Australian east coast longline fishery originated in NSW, growing rapidly in the mid 1980s, before many vessels left in 1988. A second growth period occurred through the 1990s, with the fishery expanding into northern Queensland waters. The expansion then moved eastwards offshore from southern QLD from the mid 1990s as the swordfish fishery developed (Caton, 2002). With respect to the regions analysed in this study, the expansion represented a movement from region B (most southern region) to A and then increased fishing effort in offshore regions D and C in the mid-late 1990s. It is recognised that fisheries can be "fished down" on smaller regional scales. Whether this might occur with striped marlin is difficult to determine. Certainly the species is migratory, and appears to mix in the southern Coral Sea region. However, if adults exhibited some level of regional fidelity on a seasonal basis, then it might be possible that different regions show different abundance trends determined by the differences in the level of fishing pressure in each region. There is limited evidence from tag-recapture data for seasonal and regional site fidelity in striped marlin (see Chapter 2 and Appendix I), perhaps not enough to determine whether these are chance recaptures or evidence of site fidelity on a larger scale. Furthermore, although offshore regions (C and D) were only subjected to significant domestic fishing pressure later than were the coastal regions (A and B), a Japanese longline fishery (which readily took and even targeted striped marlin in the north-eastern offshore regions), had existed for decades prior to the domestic fleets expansion (Ward, 1996). So the possibility of differences in abundance trends being due to the fleets expanding into "unfished" regions seems less likely. Further investigation of the effect of Japanese longline catches and fishing effort upon regional catch rates of striped marlin is required in future analyses of abundance trends (This issue is briefly considered in the preceding chapter which analyses fisheries interactions).

- **Unaccounted for factors associated with fishing knowledge and targeting** – This is related to the previous point and refers to the fact that when a fishery expands into a new region, the fishers' knowledge of the region will take some time to develop, and an increase in fishing efficiency might be expected as this occurs, along with other increases in efficiency that result from technological advances associated with finding and catching fish (Hilborn and Walters, 1990). Increasing fishing efficiency or targeting efficiency might mask real trends in abundance and create an appearance of increasing abundance when this may not in fact be occurring (Hilborn and Walters, 1990). Such factors are difficult to account for in models (as the required data seldom exists) and are not considered in the current models. If such an effect was occurring, then it is possible that any decline in abundance might be masked. Part of the problem in assessing abundance of striped marlin using domestic longline data is the fact that this species was not traditionally a target species. However, given that in recent years, boats operating in discrete time area strata have taken this species as the dominant catch species (by weight and value), there is reasonable evidence for targeting occurring (see analyses in chapter 5) at least in some times and regions. The models did include hooks per basket as a measure of fishing depth. However, the fact that shallow sets are used to target yellowfin tuna also means that separating out targeting effects for this species is very difficult.

- **Unaccounted for environmental factors which results in differing abundance patterns between regions -** The models used in the current analyses considered two main environmental variables, sea surface temperature and the southern oscillation index, factors which have been linked to marlin abundance in the past (Howard and Ueyanagi, 1965; Domeier et al, 2003; Squire, 1985). However, it is possible, and indeed likely, that other environmental factors not considered in these models might have affected the abundance or catchability of striped marlin, and that these factors would vary between regions. For example, striped marlin are predominantly an epipelagic species, inhabiting the surface layer above the thermocline. As such, the depth of the thermocline is likely to influence apparent abundance, as it affects the "volume" of the suitable striped marlin habitat. Hence for a given number of marlin in a given unit area (e.g. 100 nm^2), the depth of the thermocline affects the "density" of the fish in the area, the susceptibility to gear set at a certain depth, and therefore the catch rates taken in the area. There are likely to be other environmental factors that might be related to abundance which could not be taken into account within the models (e.g. prey abundance). The fact that two of the regions are coastal, and the other two regions are offshore, suggest that different environmental factors could be at play in the different regions. The northerly offshore regions are areas of more consistent abundance (but still seasonal) whereas abundance in the more southerly coastal regions appears to be in large part reliant on seasonal southerly movements of the warm East Australian Current.

- **Unaccounted for factors in the species biology and regional ecology**. Not only do the different regions considered vary in oceanographic and environmental factors likely to influence abundance, but longline and tagging based data suggest there are likely to be regional (and seasonal) differences in size and age composition for this species (see Chapters 2 and 5). This is also a factor which was not considered in the model but which could have important implications for regional differences in abundance trends. According to tag-release (Chapter 6; Appendix I) and size-monitoring data (Chapter 5) for striped marlin, a higher proportion of marlin which seasonally migrate into region B, the most southerly region considered, are larger marlin, i.e. more mature marlin. If these marlin exhibit seasonal site fidelity (there is only limited evidence for this in tag data), are sourced from a single region (e.g. Coral Sea) and take a number of years to mature to a point where they can endure the colder southerly waters, then such a region might be more susceptible to “fishing down” of a seasonally returning population, than might a region frequented by a wider size range. This effect might be particularly apparent after a couple of seasons of low spawning success or recruitment.

Another trend in the regional data series that should be noted is the contrasting temporal trends in presence/absence models and the presence-only models especially for regions A and B. It is important to consider exactly what such trends might imply about abundance within these regions. The presence/absence index indicates increasing catch probability through the 1990s, but declining “presence-only” catch rates. Such a situation might occur if the ability to catch marlin in a region increases constantly (but this ability is not accounted for in the model) but the abundance is decreasing. It can also occur if there is a shift in effort, for example from being evenly distributed throughout a region, to being concentrated on known “hotspots” (localised areas of high abundance).

8.4.2 Comparison of charter fishery and ETBF fishery in region B

The charter boat fishery analyses indicates that in region B, there was a considerable increase in abundance of striped marlin in the region during the mid to late 1990s. It is uncertain whether this was due to increased abundance in the southwest Pacific overall, or to environmental/oceanographic phenomena that enhanced the seasonal migration from the north into region B. Certainly gamefishing club annual reports have reported increased catches of striped marlin during the 1990s (Chapter 6). There is also the possibility that the withdrawal of the Japanese longline fleet from fishing in the EAFZ may also be a factor (See chapter 7). In addition there may be unaccounted for factors related to a switch in species targeting (perhaps due to differences in perceived abundance between seasons), or increased efficiencies in targeting (e.g. due to the use of switchbaiting) that could bring uncertainty into the interpretation of standardised catch rates based on data from this fishery. It is important to note however that there are some similar features in the two abundance time series for region B. The longline presence-only catch rate shows a decline in the early 1990s at a time when the charter presence-only catch rate is low. As charter catch rates increases in the mid to late 1990s, the longline catch rate increases slightly also. Both catch rates then indicate a decline in abundance after 1999. This decline in the longline presence-only catch rate is not reflected in the combined abundance index predominately because the proportion of operations catching striped marlin continually increased through this period. However the decline in the presence-only catch rate and concerns regarding size based vulnerabilities to fishing pressure in this region, suggest that at the very least, abundance should be monitored closely in the next several seasons in this region. More rigorous analyses that considers some of the factors mentioned above should be undertaken in the near future.

8.4.3 Environmental and fishing method related factors

The analyses presented here have also provided some information on the relationship between striped marlin catch rates and different environmental and fishing method related factors.

Environmental factors: The models confirm previous studies (Udo, 1957; Squire, 1985; Ortega-Garcia et al. 2003) of striped marlin which suggest that abundance is highest in waters between 20-28ºC (peaking between 23-25ºC). The models also indicate that catch rates increase as the southern oscillation index (SOI) anomaly becomes increasingly positive, in other words, catch rates are higher in La Nina periods. However, it should be noted that the relatively short time period analysed contained only two strong switches between La Nina and El Nino periods, so an extended time period analyses is required to confirm this observation.

Fishing method factors: Catch probability and catch rates were found to be highest for longlines “soaked” during the day (i.e. operation start times in the morning), and lowest for operations started at night. This is most likely related to the fact that nighttime sets are geared to target swordfish (and bigeye tuna), and supports research that indicates that striped marlin are predominantly day feeders (Fritsches, 2003).

Given that striped marlin are predominantly a surface layer inhabiting species, the depth of hook setting (represented by hooks per basket number in the current models) has been found in the past to effect catch rates for this species (e.g. Boggs, 1992). Although there is considerable uncertainty in the relationship at the extremes of the HPB range, the models indicate catch rates decline as the number of hooks per basket (and therefore depth of fishing) increases, at least in the range of 5-15 hooks per basket.

The restricted time period models (Fig 8.6a,b) also indicate that the catch probability for striped marlin is higher in operations using live bait. The use of live bait is particularly prevalent in more southern latitudes, however regional analyses of live bait trends was not attempted here. Presence-only catch rates suggest lower catch rates for operations using live bait, although this relationship was not significant. This relationship may be confounded with other factors and requires further investigation.

8.4.4 Considerations of limitations in the data and analyses

The GAM analyses indicate that fishery and environmental conditions influence the presence/absence and the presence-only data in similar manner although the temporal pattern differs. The inclusion of both these data types into a single model requires careful consideration. The inability of the GAM analyses in this study to reduce the number of terms in the presence/absence and the presence-only model may be a result of the small effect of the degrees of freedom. Given that there are definite differences in the amount of variability explained by each model term, suggests that further analyses involving modified scale weighting factors should be investigated. In addition, the influence of the interactions between model terms requires further detailed analysis.

The analyses presented in this paper should be treated as preliminary, and further exploration of the data should be carried out to investigate some of the problems highlighted above. While GAM analysis provides functional forms of the model terms, subsequent GLM analyses using polynomial approximations could be undertaken. There is also the need to undertake further analyses to provide the level of uncertainty associated with the combined abundance indices. The apparent trends in the combined index may not be significant if there is large uncertainties associated with the estimates. Furthermore the implication of using mean values for each variable, as done for the charter boat index, needs to be investigated. Alternatively it may be possible to estimate these indices and their associated uncertainty by resampling the data.

8.4.5 Summary

Overall the preliminary analysis of longline catch rate data suggests that there may have been either:

1. An increase in the abundance of striped marlin off the east coast of Australia in the second half of the 1990s;

2. An increase in the catchability (possibly relating to targeting or increased catching efficiency).

Increasing abundance is supported somewhat by the analyses of charter boat catch and effort data. It can occur as a result of good recruitments or shifts in abundance and distribution within the southwest Pacific due to environmental and oceanographic factors not accounted for within the model. However, this conclusion should be treated with some caution, given that these trends appear to be driven by increasing probability of catching marlin in the face of decreasing catch rates in those sets that do catch marlin (at least for coastal areas). In particular, in coastal regions A and B however, catch rates for operations taking at least one marlin appear to have declined since the early or mid 1990s. Increasing catch probability could occur as a result of a shift in the fishing distribution to areas more frequented by marlin, or other changes relating to increased targeting or fishing efficiency. These declines in southeast coastal waters (areas A and B) over past decade may warrant closer monitoring and analyses.

It is important to note that this represents a preliminary analyses of striped marlin abundance. The analyses considered only main effects and did not carry out an investigation of variability in the combined index. Given that the fishery has shifted and expanded to some degree over the past decade, interactions factors such as “time-area” should be included, with the hope of clearing up some of the uncertainties in the trends. Ideally, some measure of size classes being fished in different time-areas should also be included in the models. Future analyses should also aim to improve this model by including Japanese data and interaction effects, and looking at possible localised depletion effects.