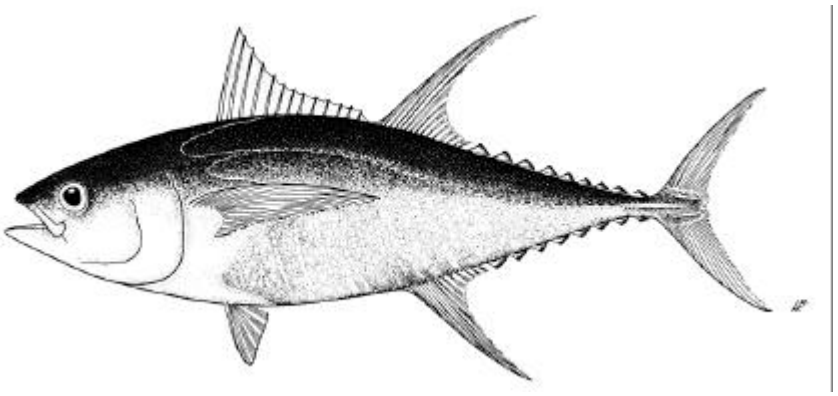
SCTB16 Working Paper

RG–2

Standardised analysis of yellowfin and bigeye cpue data from the Japanese longline fleet, 1952 to 2001



Adam Langley

Oceanic Fisheries Programme
Secretariat of the Pacific Community
Noumea, New Caledonia

June 2003

1 Introduction

Catch and effort data from the Japanese longline fleet has been a key input in the recent stock assessments of yellowfin and bigeye tuna in the western and central Pacific Ocean (Hampton 2002a & 2002b). The assessments have been undertaken using MULTIFAN-CL (MFCL) software (Fournier et al. 1998) and stratified the fishery into five regions (see Appendix 1).

The recent assessments have incorporated catch and effort data from the fishery standardised to account for changes in the depth distribution of the longline gear relative to the habitat preference of yellowfin and bigeye (Bigelow et al. 1999, 2002). The standardisation process derived estimates of effective effort for each species. For bigeye, the relative trend in effective effort is comparable to the annual trend in nominal fishing effort (Bigelow et al. 2002). However, the habitat standardisation predicts a considerable decline in the effective effort for yellowfin during the late 1970s due to the shift to deeper longline sets (Bigelow et al. 1999).

For the recent yellowfin and bigeye MFCL assessments, the catch and habitat standardised effort from the Japanese longline fishery was incorporated in the model assuming a constant catchability over the history of the fishery. The application of the habitat standardised effort series has a large influence on the assessment for yellowfin compared to the nominal effort series. Further development is being undertaken to improve the habitat standardisation models for both yellowfin and bigeye. In the interim, it was decided to derive alternative annual indices for both yellowfin and bigeye using the generalised linear modelling (GLM) approach. These indices will be incorporated in the respective MFCL assessments for comparison with the habitat standardisation approach.

This paper documents the results of a GLM approach to determine annual (and quarterly) indices for yellowfin and bigeye in the western and central Pacific Ocean.

2 Data set

The catch and effort data set was for the Japanese longline fleet from 1952 to 2001. The data were available in summary format aggregated by month and 5 degrees of latitude and longitude.

For 1975 onwards, the data were subdivided by 6 categories based on the number of hooks between floats (HBF) of the longline gear; 5–6 HBF, 7–9 HBF, 10–11 HBF, 12–15 HBF, 16–20 HBF, and greater than 20 HBF. No HBF data available for 1952 to 1974 and a value of 5 HBF was assumed for all records from this period. Data from 1952 to 1974 included all the fishing effort for the Japanese fleet, while data from 1975 to 2001 were a subset of the total longline effort with HBF recorded. For the latter period, the data set included at least 90% of the total fishing effort (number of hooks) from each year.

The variables in the data set included year, month, latitude bin, longitude bin, HBF category, the total number of hooks set, and the catch of yellowfin and bigeye tuna (in number of fish). For the earlier period (1952–1974), catch data were also available for the other associated species (ALB, SFA, MLS, SWO, MLZ, BLM, BLZ, SHA, SKJ, and “other species”). However, these catch data have not been incorporated in the more recent data that are aggregated by the HBF category. In future, it may be possible to include these catch data also.

The data set was subdivided into the five areas included in the current yellowfin and bigeye MFCL stock assessments (Appendix 1).

A small number of records with extreme outliers for nominal CPUE (number of fish/number of hooks) were excluded from the data set.

3 Data summary

Most of the Japanese catch and effort data was included within the more northern area of the WCPO fishery (MFCL areas 1–3) (Table 1). Annual trends in the total level of fishing effort by MFCL area are presented in Figure 1. For MFCL areas 1 to 3, there was a large increase in the number of records included in the data set in the mid 1970s. This did not correspond to a large increase in the level of fishing effort but is an artefact of the subdivision of the CPUE records by the HBF categories. This is also expressed as a reduction in the number of hooks per record and lower catches of yellowfin and bigeye per record (see Appendix 2). This effect was less pronounced for MFCL areas 4 and 5.

Table 1: Summary statistics for the Japanese longline CPUE data sets.

		MFCL area				
		1	2	3	4	5
Total number of records		28,373	23,194	30,150	4,772	6,269
Yellowfin	Catch (fish *1000)	2,276	22,801	19,905	4,062	2,469
	Zero records (%)	15.4	1.0	2.2	1.1	5.3
	Fish/100 hooks	0.14	1.36	0.93	1.16	0.59
Bigeye	Catch (fish *1000)	8,813	6,643	15,804	651	853
	Zero records (%)	7.3	2.3	0.9	5.3	6.3
	Fish/100 hooks	0.36	0.44	0.74	0.17	0.22

Most of the WCPO yellowfin catch by the Japanese fleet was taken in MFCL areas 2 and 3, while catches of bigeye were highest in areas 1 and 3. In MFCL area 3, annual catches of bigeye were comparable to the yellowfin catch. There was a strong peak in yellowfin catch in MFCL area 2 in the late 1970s and early 1980s (Figure 2).

For MFCL areas 2–4, the proportion of records with no yellowfin and/or no bigeye was low (Figure 2). In comparison, catch and effort records for MFCL area 1 had a relatively high proportion of null yellowfin catches, particularly in the early years of the fishery. The proportion of null bigeye records was also higher in this area, although generally less than 10%. The proportion of null catch records for both species in MFCL area 5 was also relatively high in some years (Figure 2).

The resolution of the aggregated data precludes a detailed examination of trends in the spatial distribution of fishing effort, although gross trends are apparent for some of the MFCL areas. For MFCL area 2, fishing effort has generally shifted eastwards since the mid 1970s, while fishing effort in MFCL area 3 moved westwards (Appendix 2). For area 5, fishing effort shifted south and eastwards. The changes in the distribution of fishing effort are probably related to the declaration of EEZs and subsequent shift of fishing effort into International Waters as well as the impact of various licensing arrangements with individual countries.

No strong changes in the seasonal distribution of fishing effort are apparent for the five MFCL areas (Appendix 2).

3.1 Gear configuration

Since the mid 1970s, there has been a steady increase in the number of hooks set between floats, particularly in MFCL areas 1–3 (Appendix 2). For each MFCL area, annual trends in the unstandardised catch rate of yellowfin and bigeye were examined with respect to HBF category. The proportion of the catch of bigeye in the combined bigeye and yellowfin catch was also examined. This analysis was restricted to the 1975–2001 years for which reliable data concerning the configuration of the HBF are available.

For MFCL area 1, catch rates of yellowfin were generally low, although there is a general indication that unstandardised catch rates increased with an increase in the number of hooks between floats (Figure 5). The trend is evident for bigeye catch rates although the actual magnitude of the effect was considerably greater than for yellowfin (Figure 4). There was no consistent change in the relative proportion of the two species in combined yellowfin and bigeye catch with the possible exception of a decline in the proportion of bigeye in the catch from category 5 HBF gear (Figure 3).

For the western equatorial area (MFCL area 2), there was no apparent difference in yellowfin or bigeye catch rates with respect to different configurations of HBFs (Figure 4 and Figure 5). From 1980 to 1990, there was an increase in the catch rate of bigeye from all set types that may relate to other changes in the fishing operation. This trend resulted in an increase in the relative proportion of bigeye in the catch that has persisted in subsequent years as catch rates for both bigeye and yellowfin have declined.

For the central equatorial area (MFCL area 3), there was a general increase in the catch rate of yellowfin with increased number of hooks between floats, with the exception of higher catch rates achieved by 5 HBF gear prior to 1985 (Figure 5). The converse was apparent for bigeye, with a decline in catch rates with a greater number of hooks between floats, although the magnitude of the effect was lower than for yellowfin (Figure 4). Consequently, there was a general decrease in the proportion of bigeye caught with increased HBFs that persisted throughout the time-series (Figure 3).

In MFCL areas 4 and 5, the catch rate of both yellowfin and bigeye increased with increased HBF, although the magnitude of the effect was greater for yellowfin (Figure 4 and Figure 5). Consequently, the increase in HBF tended to result in an increase in the proportion of bigeye in the catch although there was considerable variation between years (Figure 3).

Some of the observed trends in the catch rate of bigeye and yellowfin by HBF category may be attributable to differences in the gear configuation with respect to latitude and longitude and the differences in the spatial distribution of the two species (Figure 6, Figure 7, and Figure 8). For MFCL areas 4 and 5, there were a higher proportion of shallower sets (HBF category 1 and 2) in the southern latitudes and, conversely, a higher proportion of deeper sets (HBF category 3, 4, and 5) in subtropical waters.

Similarly, for MFCL region 3, there was a decline in deeper sets (HBF 5) with increasing latitude (Figure 6).

No strong seasonal trend in the distribution of HBFs was apparent with the exception of a shift to shallower sets during May–July in MFCL area 1.

No additional information is available concerning the configuration of the longline gear and/or setting procedure, for example the introduction of line shooters to the fleet.

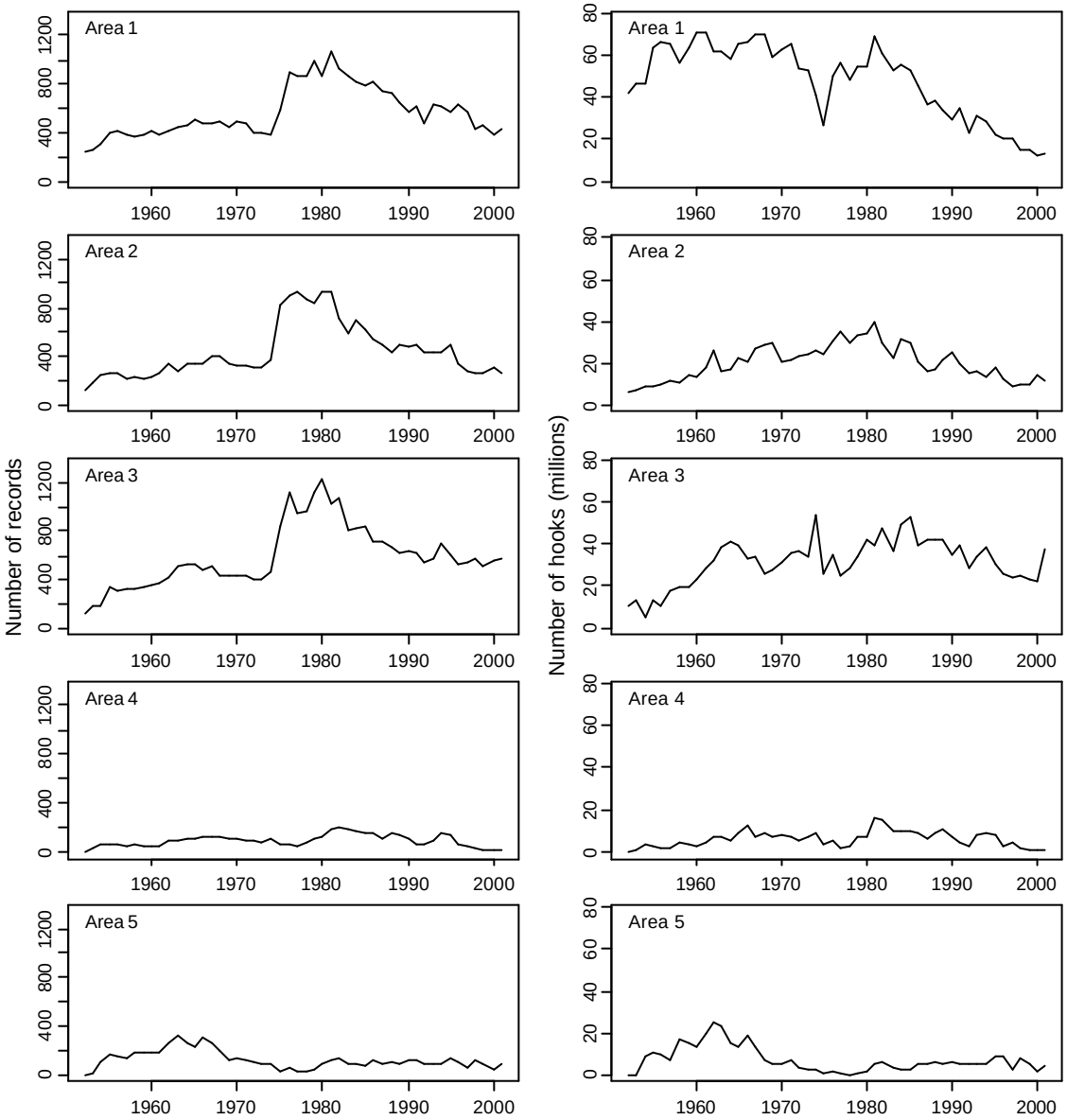


Figure 1: Annual number of CPUE records and total number of hooks set by MFCL area from 1952 to 2001.

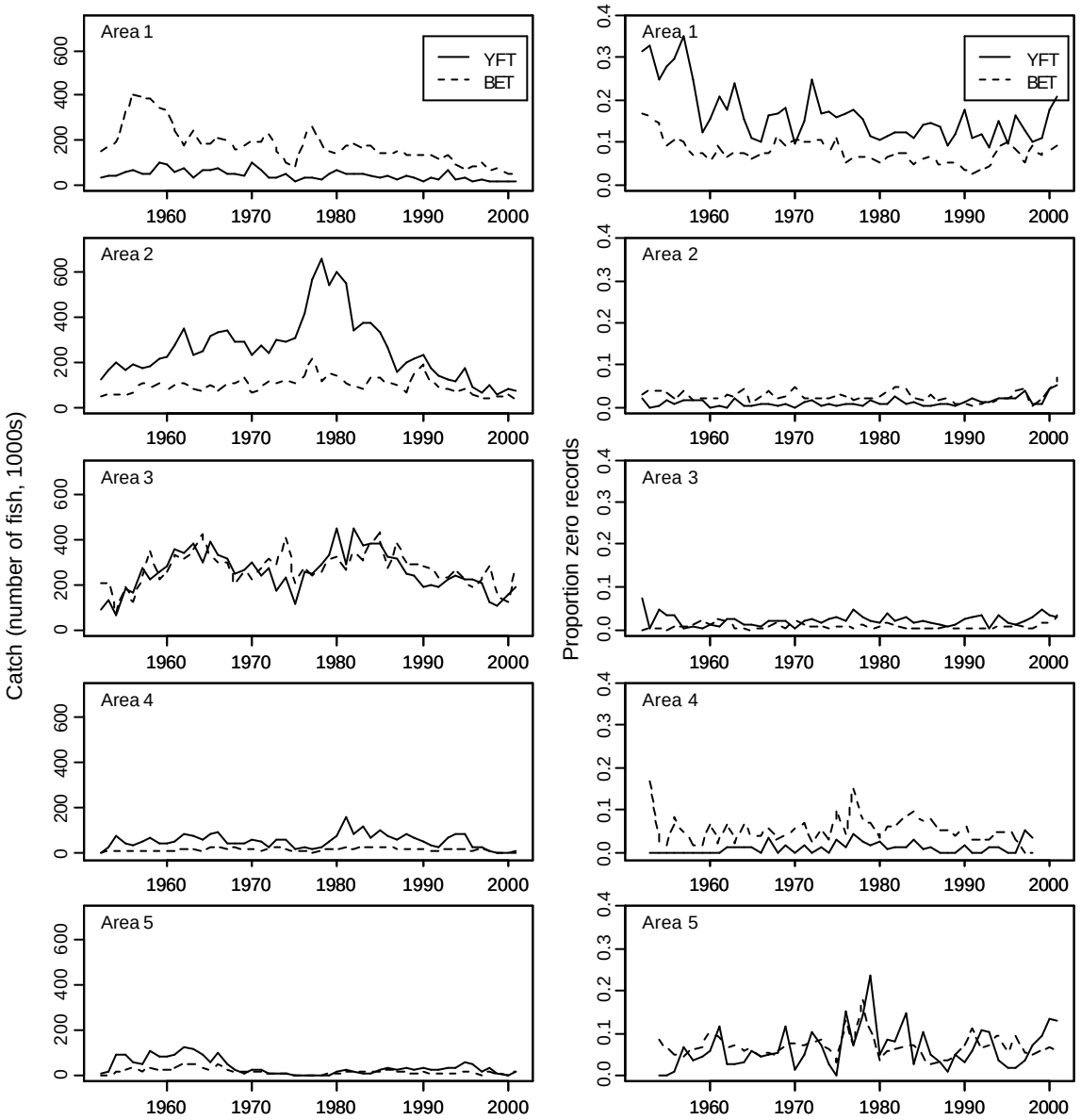


Figure 2: Annual trends in the catch (number of fish) of yellowfin and bigeye (left) and the proportion of records with no catch of each species for the five MFCL areas.

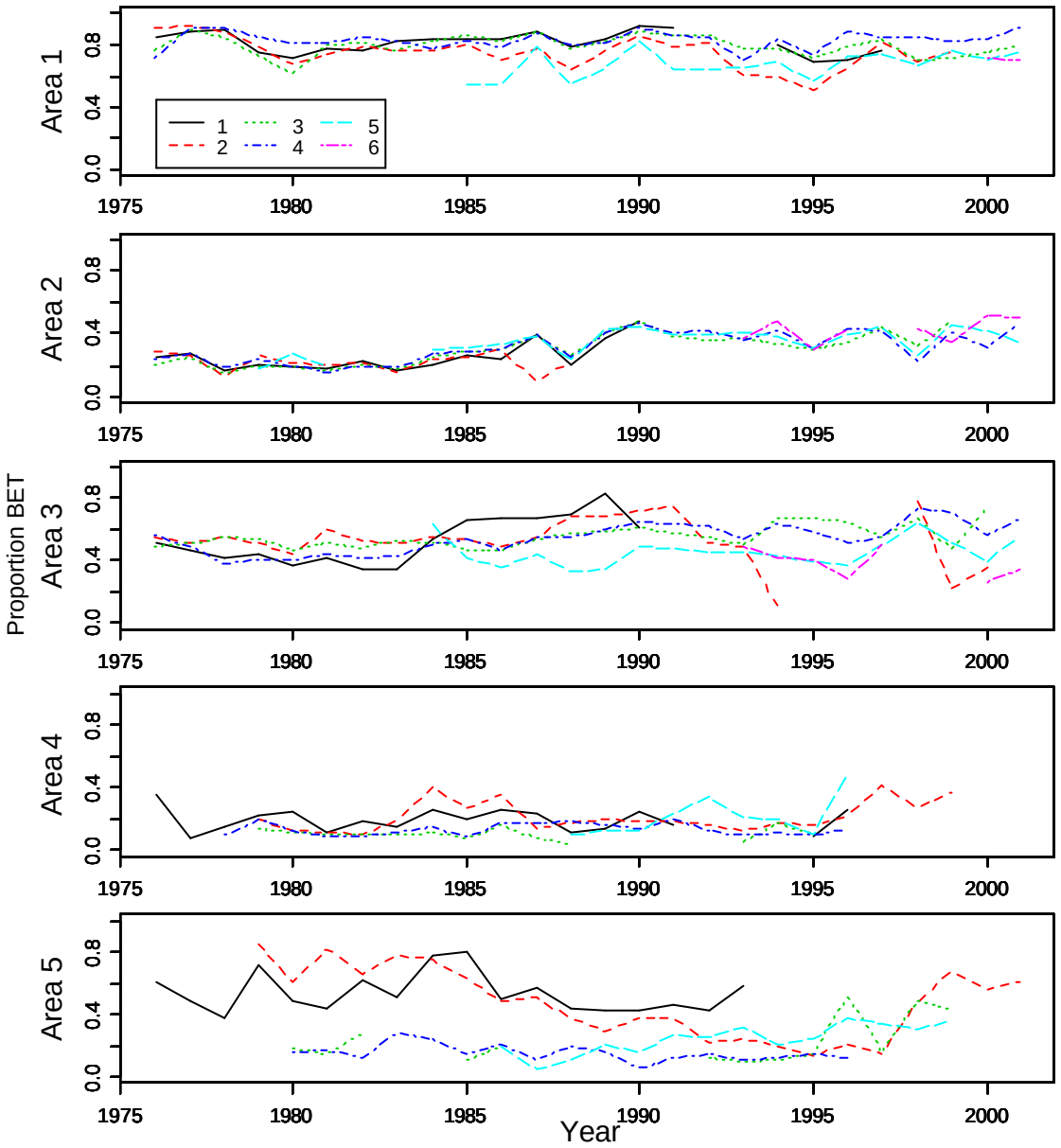


Figure 3: Annual proportion of bigeye in the combined bigeye and yellowfin catch (number of fish) by HPB category for each MFCL area.

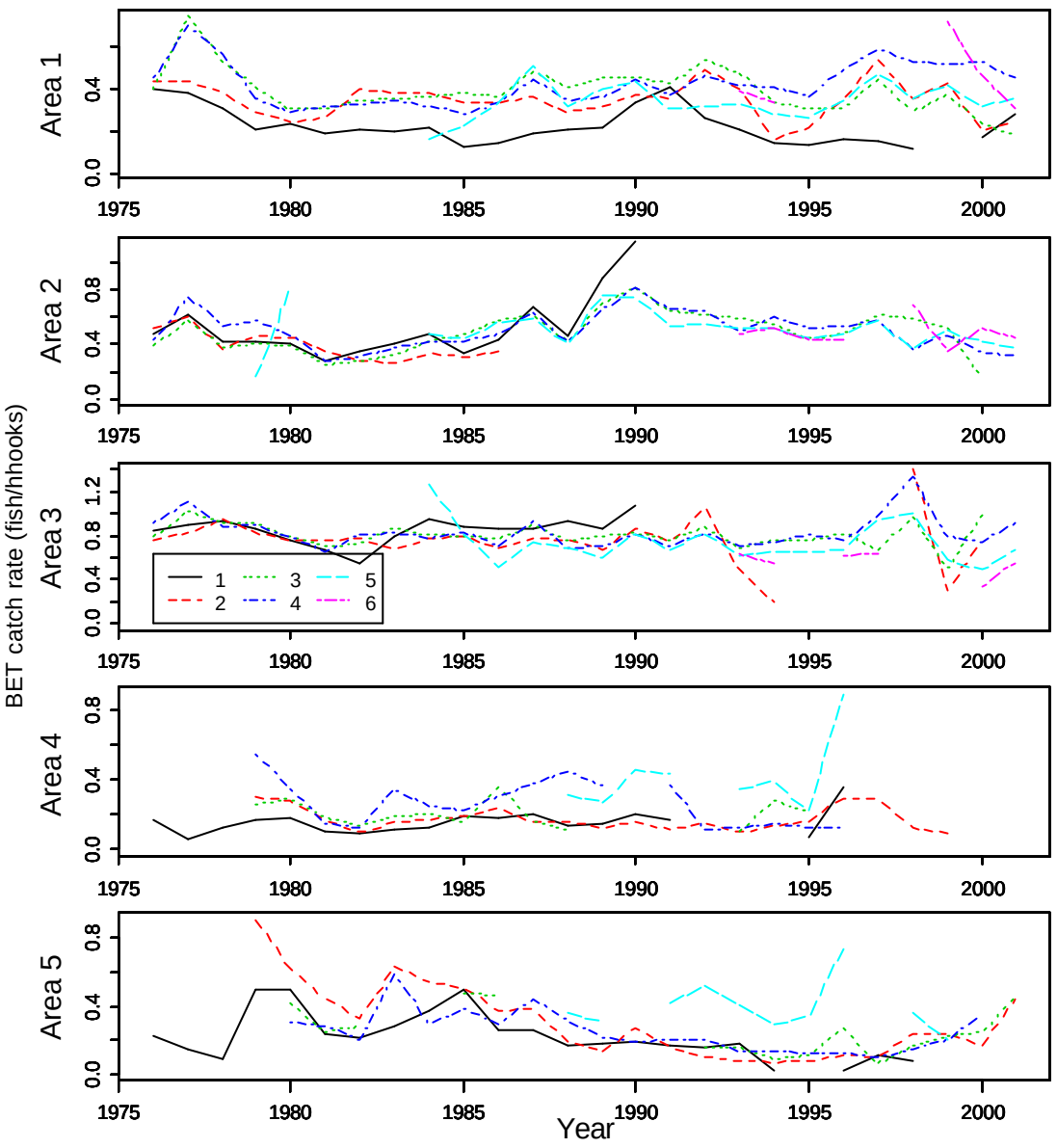


Figure 4: Annual catch rate of bigeye (number of fish per 100 hooks) by HPB category for each MFCL area from 1976 to 2001. Only area/month/HBF categories with at least 100,000 hooks are plotted.

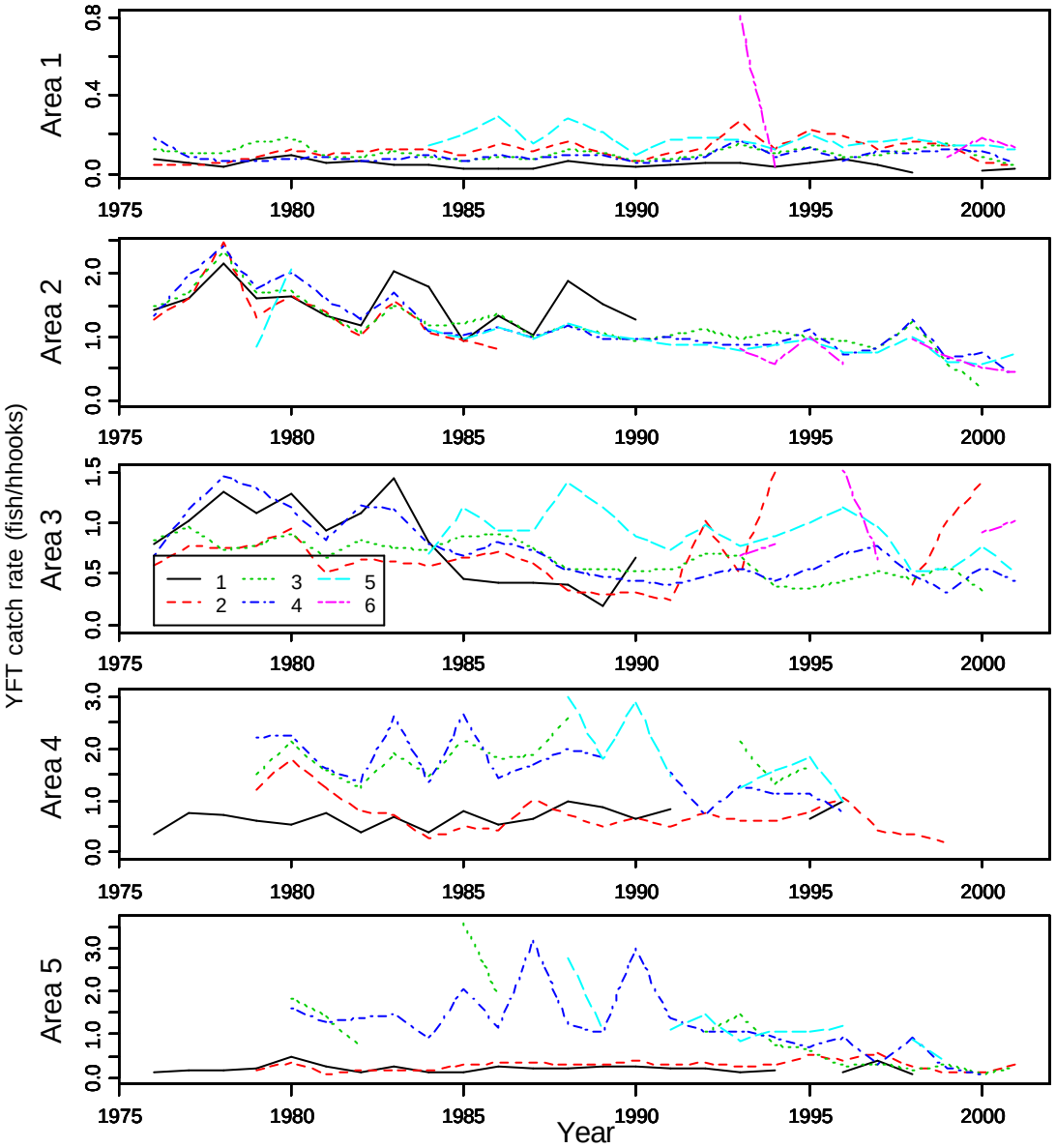


Figure 5: Annual catch rate of yellowfin (number of fish per 100 hooks) by HPB category for each MFCL area from 1976 to 2001. Only area/month/HBF categories with at least 100,000 hooks are plotted.

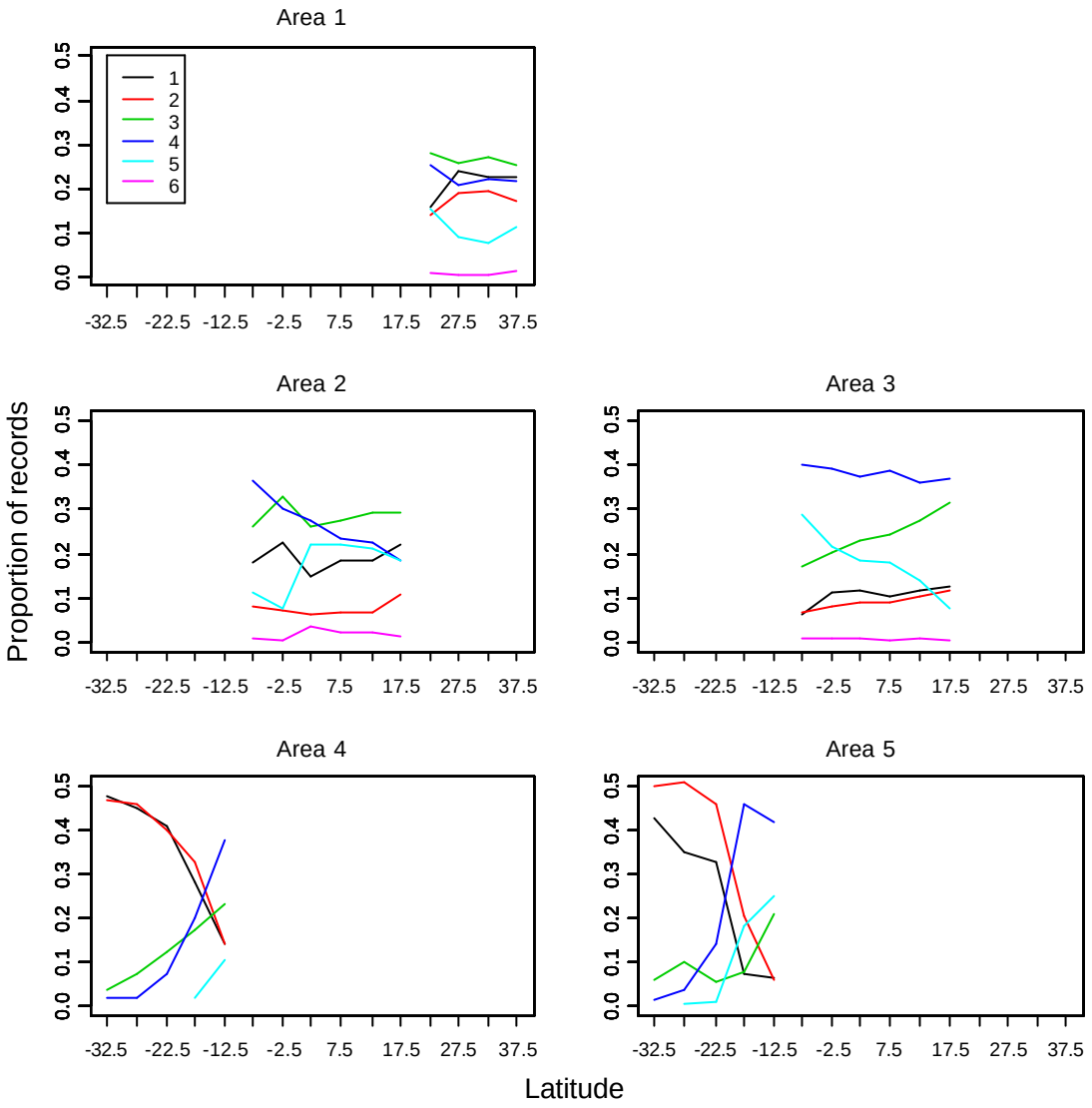


Figure 6: Proportion of CPUE records in each HBF category by latitude for the five MFCL areas. The data are aggregated for the 1976–2001 years.

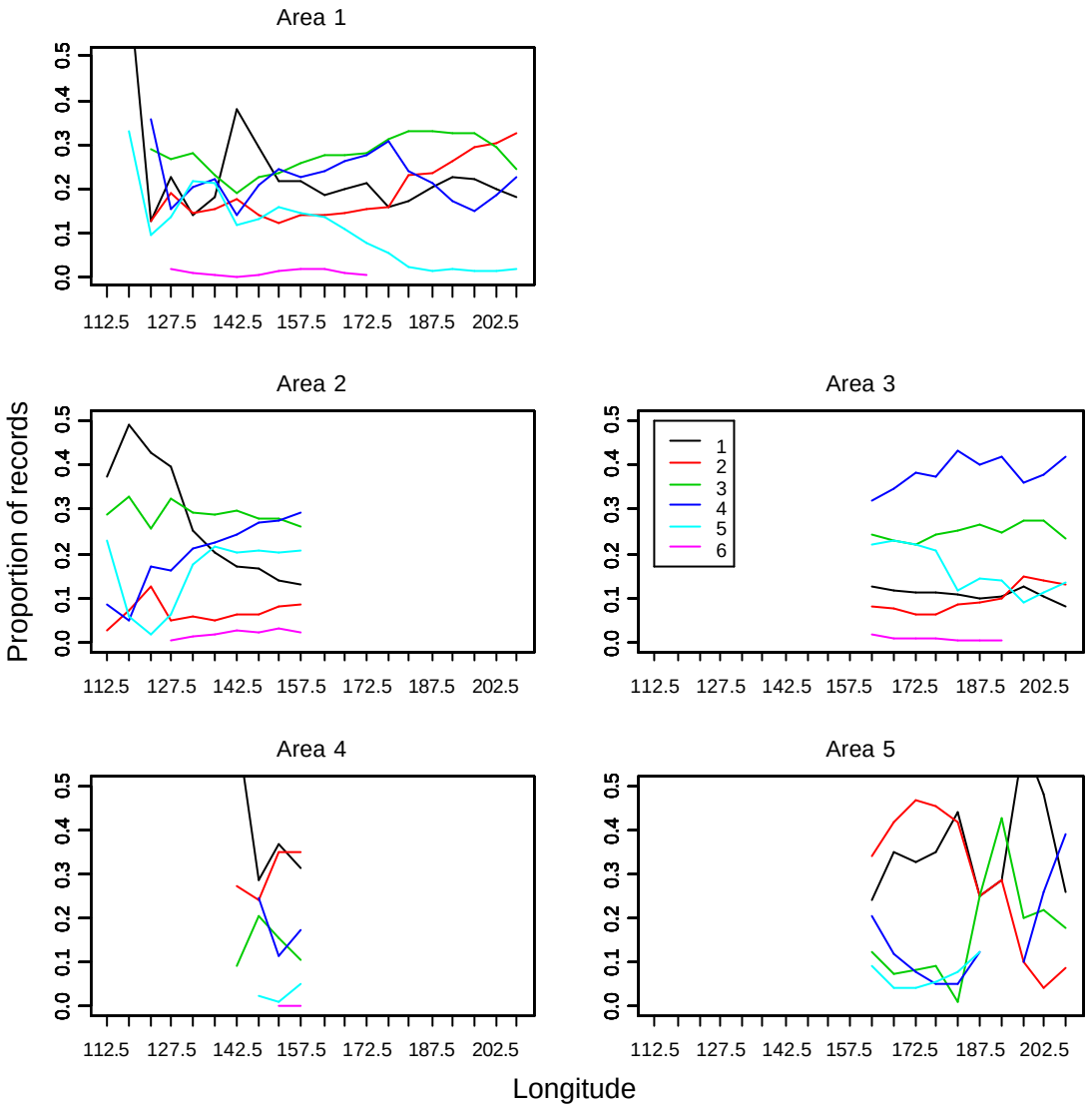


Figure 7: Proportion of CPUE records in each HBF category by longitude for the five MFCL areas. The data are aggregated for the 1976–2001 years.

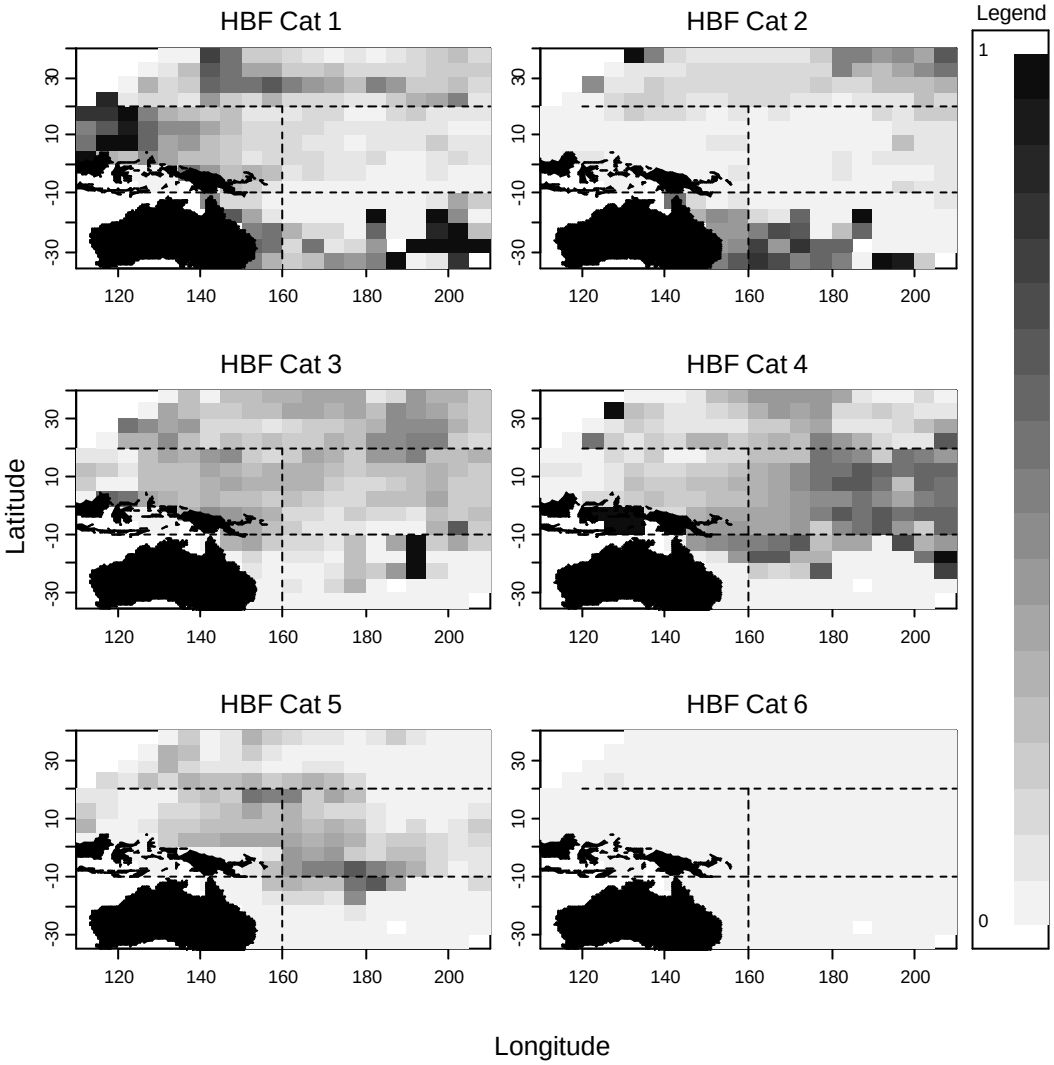


Figure 8: Proportion of total hooks set by each HBF category by five degree latitude and longitude bin for 1976 to 2001 years combined.

4 GLM standardised CPUE analysis

4.1 Methods

Standardised CPUE indices were derived for yellowfin and bigeye using a generalised linear modelling approach.

For each species, a separate CPUE analysis was undertaken for each MFCL area. Modelling the CPUE data separately for each MFCL area enables a different parameterisation for each of the significant explanatory variables included in the respective CPUE model. It also overcomes computational difficulties in dealing with a single large data set.

For each model, the dependent variable was the natural logarithm of the non-zero catch, expressed as the total number of fish caught (either yellowfin or bigeye) in the year/month/lat/long/HBF cell. Zero catch records were excluded from the analysis. These generally comprised a small proportion of the total records in each MFCL area.

A stepwise fitting procedure was applied to each of the five MFCL area data subsets. The potential explanatory variables included the categorical variables year, month, and HBF category. Latitude and longitude were included a third order polynomial functions. The effort variable (number of hooks) was initially included as a third order polynomial function. However, the parameterisation resulted in an unrealistic relationship between catch and effort and a poor fit to the low catch values. In the final model, the effort variable was incorporated as a linear function of the natural logarithm of the number of hooks. This imposed a linear relationship between the catch and the number of hooks set.

Initial exploratory analysis revealed a number of potentially significant interactions between the main variables, principally the interaction between month/latitude, month/longitude, HBF category/latitude, and HBF category/longitude. These interaction terms were included as potential explanatory variables in the stepwise fitting procedure.

The monthly Southern Oscillation Index (SOI) was included as a potential explanatory variable in all CPUE models (source: http://www.cpc.ncep.noaa.gov/data/indices/index.html). The SOI index was included for the corresponding month of fishing and lagged by three months.

Each record was weighted in the fitting procedure by the level of effort (number of hooks) in the year/month/lat/long/HBF cell. The stepwise fitting procedure included variables based on the AIC criteria. This process was used to identify the main explanatory variables. These were generally common between each of the five CPUE models although the parameterisation of these variables differed considerably between models.

For simplicity, it was decided to apply a generic model structure to each of the five MFCL area data sets. The parameterisation of each variable is plotted in the subsequent figures. Confidence intervals (+/- 2 standard error) were also determined.

To determine the relative catch rates between the five MFCL areas, the annual CPUE indices (model coefficients) were exponentiated and then scaled to the global mean catch rate for the specific MFCL area.

4.2 Yellowfin

The generic CPUE model for yellowfin has the formulation:

> Log(number of fish) ~ log(number hooks) + year + interaction(month, latitude) + interaction(month, longitude) + interaction(HBF, latitude) + interaction(HBF, longitude)

The CPUE models for the MFCL areas 2–5 explained 70–80% of the observed variation in the natural logarithm of the catch of yellowfin (number of fish) (Table 2 and Table 3). The explanatory power of the MFCL area 1 model was lower accounting for only 57% of the variation. The individual CPUE models represented a good fit to data, except for records with a small catch (less than 20 fish) (Figure 10). The relatively high proportion of small catches in the MFCL area 1 CPUE data set explains the lower explanatory power of the respective CPUE model (Figure 9).

Table 2: Summary of step-wise fits to each of the MFCL area yellowfin CPUE data sets. The r-squared value (%) is given for each iteration.

Iteration	MFCL area 1		MFCL area 2		MFCL area 3	
	Variable	R^2	Variable	R^2	Variable	R^2
1	Num_hooks	25.2	Num_hooks	64.2	Num_hooks	43.8
2	HPB*lat	43.7	HPB*lat	74.8	Month*lat	69.5
3	HPB*long	52.4	Year	77.8	HPB*long	75.7
4	Year	56.4	HPB*long	79.8	Year	78.4
5	Month*lat	58.3	Month*lat	80.5	HPB*lat	79.1
6			Month*long	80.8	Month*long	79.8

Iteration	MFCL area 4		MFCL area 5	
	Variable	R^2	Variable	R^2
1	Num_hooks	36.1	Num_hooks	39.7
2	Month*lat	58.9	Month*lat	68.2
3	Year	65.6	Month*long	72.2
4	Month*long	70.4	Year	77.1
5	HPB*lat	70.9	HPB*lat	77.6
6	HPB*long	71.1	HPB*long	78.0

Table 3: Proportion of the observed variation in the natural logarithm of yellowfin catch explained by each of the five generic MFCL area CPUE models.

MFCL region	Percent R^2
1	58.4
2	80.8
3	79.8
4	71.1
5	78.0

The predicted relationships between the number of hooks set and yellowfin catch are given in Figure 11. The slope of the relationship is steeper for MFCL areas 2 and 3 - consistent with the higher overall catch rate from these two areas.

For each of the CPUE models, there is a decline in the predicted catch of yellowfin with increasing latitude (Figure 12). There is also considerable seasonal trend in catch rates with respect to latitude. In the western equatorial area (MFCL area 2), catch rates are relatively constant throughout the year, while a stronger seasonal trend is apparent in the southeastern equatorial area of MFCL area 3 with higher catch rates in May–August. The seasonal trend in catch rates in the northern MFCL area 3 is reversed with highest catch rates during October–February (Figure 12).

The seasonal effect is greatest in the sub-tropical areas (12–25° S). For the northern area of MFCL 4 and 5, catch rates peak in May–August, while in the southern areas higher catch rates generally occur in the austral summer (October–February) (Figure 12). In the northern sub-tropical area of MFCL 1 catch rates peaked in April–June.

For all CPUE models, the predicted yellowfin catch declined with increasing longitude (Figure 14).

For some of the CPUE models, there was also a strong interaction effect between latitude, longitude, and the HBF category. To examine the relationship in more detail the CPUE models were refined to include an interaction term between the three variables. Sufficient data were available to estimate the coefficients for MFCL areas 1–3 only and coefficients were only derived for cells with at least 50 records. The resulting coefficients were expressed relative to the coefficient for the HBF 1 category. It is important to remember that HBF data were only available from 1975 onwards and the HBF category effects may be biased by the higher catch rates in the earlier years.

The interaction terms indicated that increasing the HBF had a large positive impact on yellowfin catch rates within MFCL area 1, in particularly in the central region (Figure 15). Further eastwards there was a slight negative impact on yellowfin catch rates with increasing HBF.

For MFCL area 2, the predicted effect of the HBF category was relatively low, especially compared to MFCL area 1 (Figure 16). Higher catch rates were achieved in the coastal areas with HBF 1 longline gear, while increased HBF yielded slightly higher yellowfin catch rates in the northeastern area of MFCL area 2.

The HBF effect was also relatively low from the MFCL area 3 CPUE model. Overall, the model predicted a decline in catch rates with increased HBF, with the exception of the northwestern sector of the region (Figure 14).

Overall, the effect of increasing HBF on yellowfin catch rates was variable between areas. The catch rates were depressed in the area influenced by the South Equatorial current (south of 5° N) (see Appendix 3). However, increased HBF was predicted to elevate catch rates considerably in an area at the junction of the Kuroshio current, the southern eddy of the North Pacific current, and the North Equatorial current (Appendix 3).

The year effects from the yellowfin CPUE models were comparable to the annual trends in unstandardised catch rates from the fishery (Figure 18). For MFCL area 2, the decline in CPUE indices was slightly lower than for the unstandardised data. Similarly, for MFCL area 3, the decline in unstandardised CPUE at the start of the time-series was moderated in the standardised CPUE analysis. For both MFCL areas 4 and 5, the year coefficients at the start of the time-series are high but the indices have very low precision (see Figure 11).

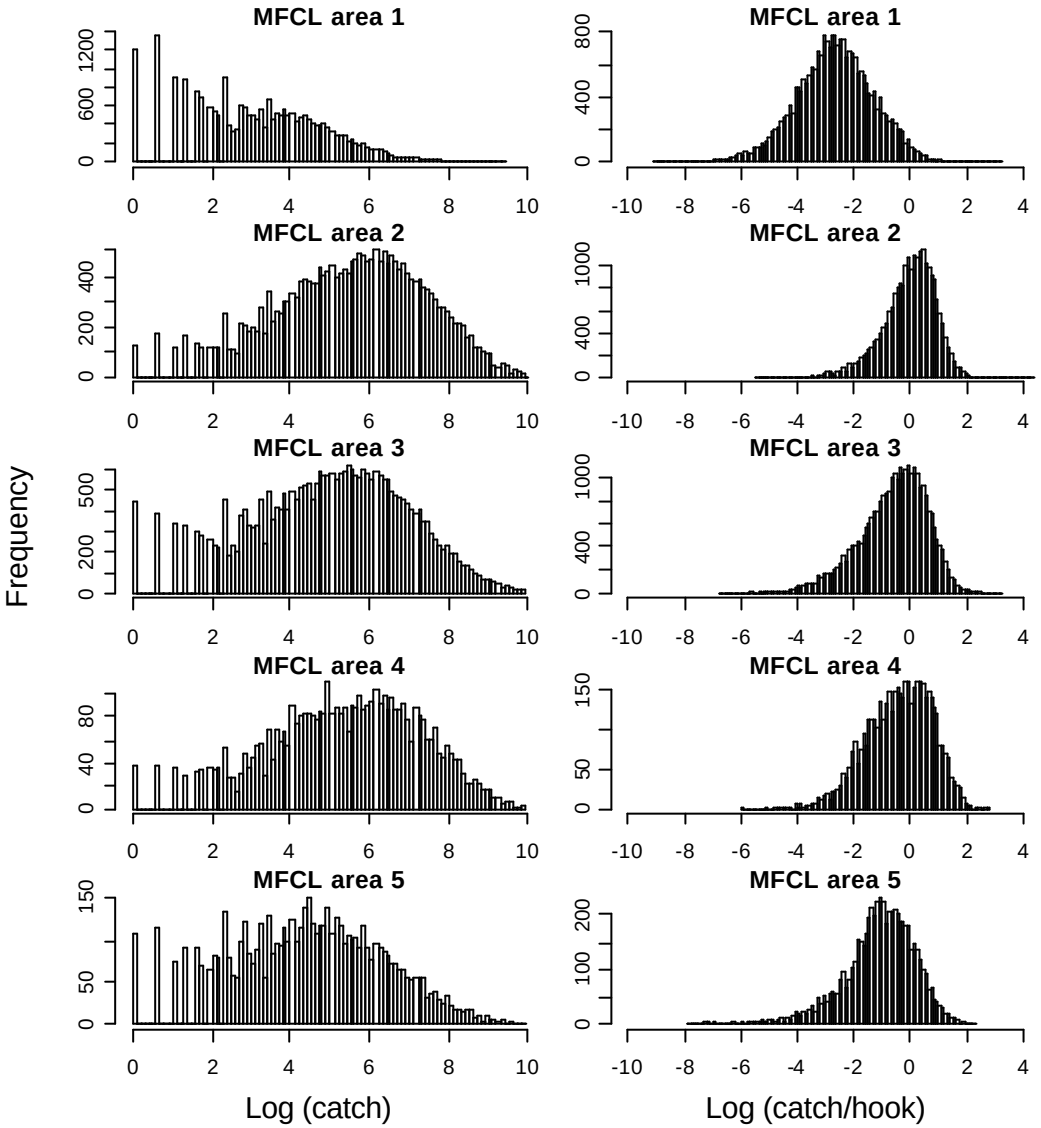


Figure 9: Histograms of the distribution of logarithm of yellowfin catch (number of fish) and catch rate (number of fish per 100 hooks) for each of the five MFCL area data sets.

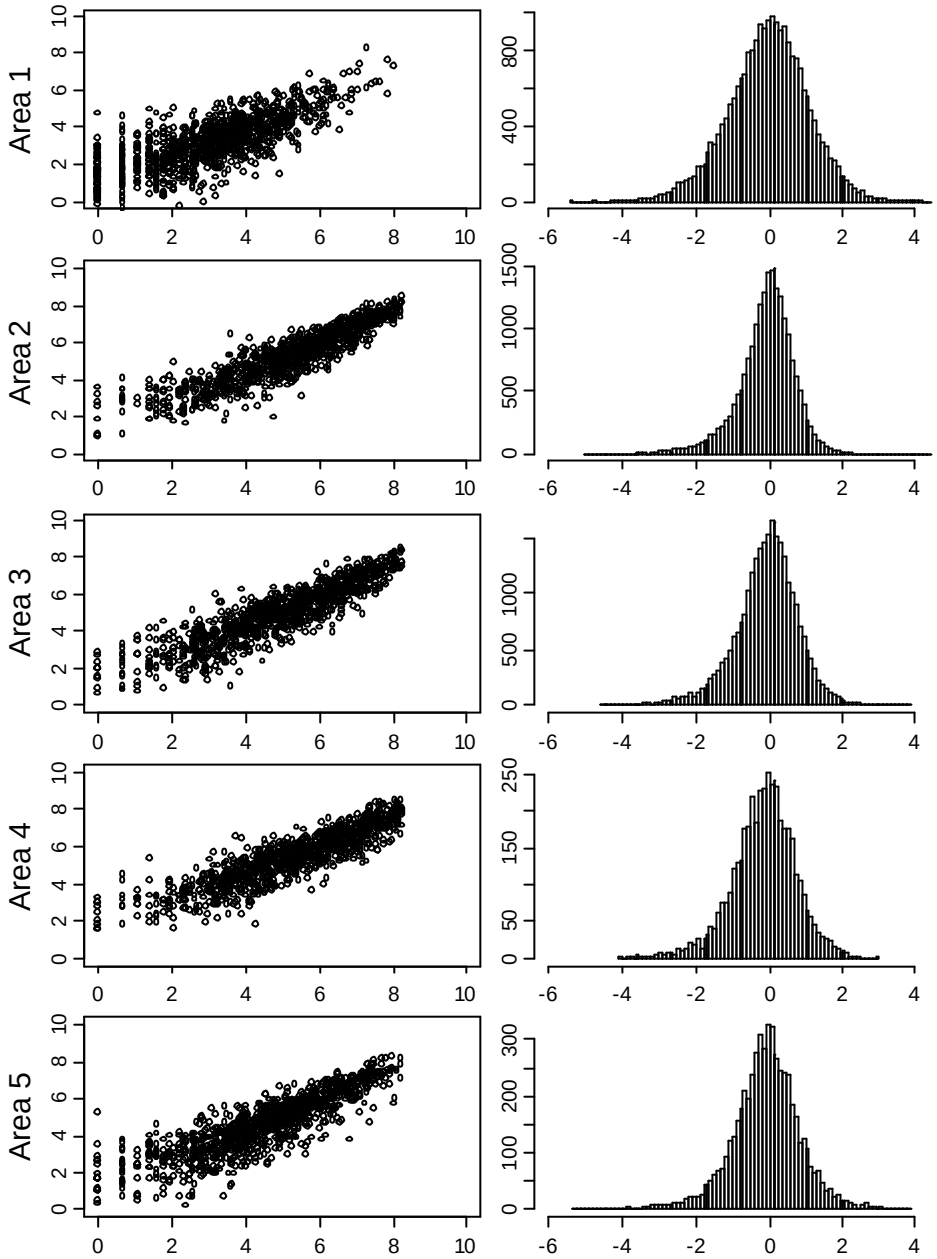


Figure 10: A comparison of a random sample of the observed (x-axis) and predicted (y-axis) values from each of the five MFCL area CPUE analyses (left) and the distribution of the residuals for each model.

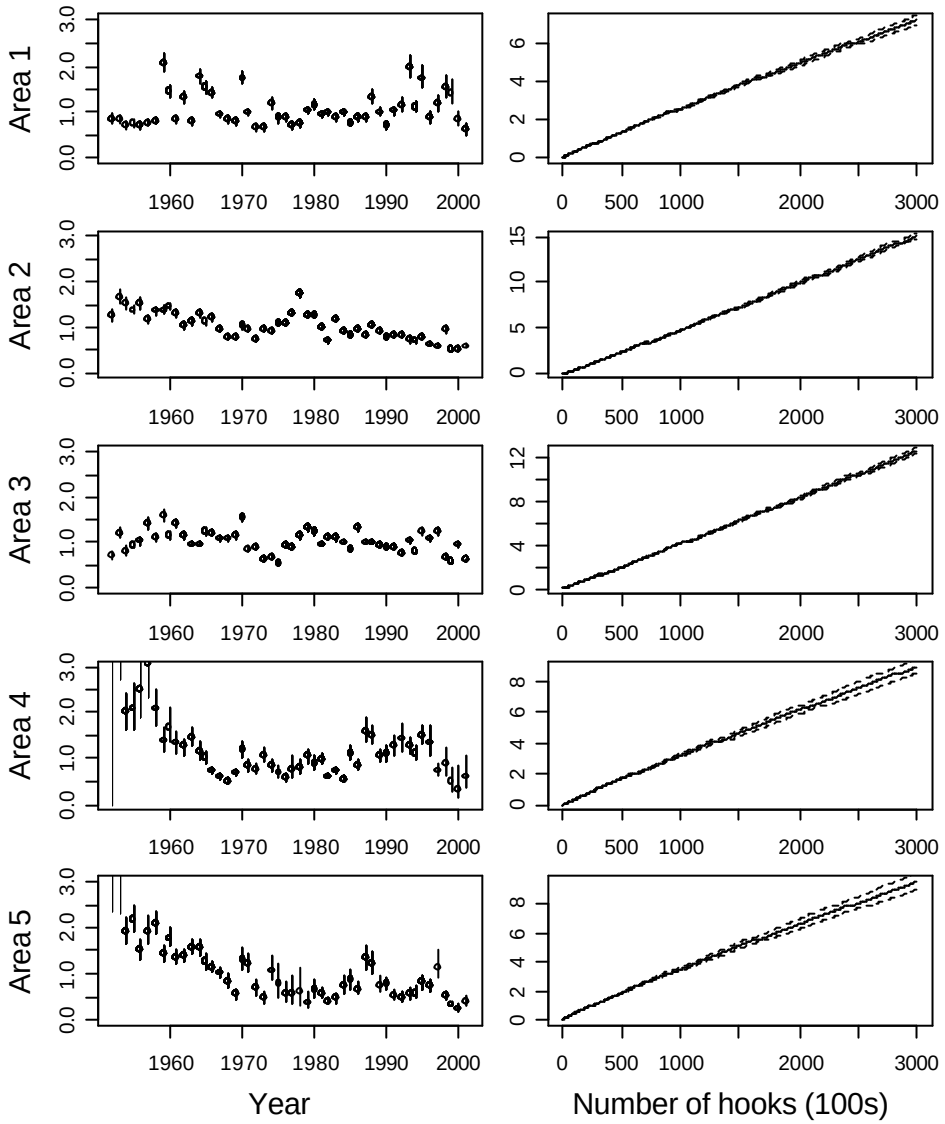


Figure 11: Predicted relationship between yellowfin catch and year (left) and number of hooks set (right) for each MFCL area.

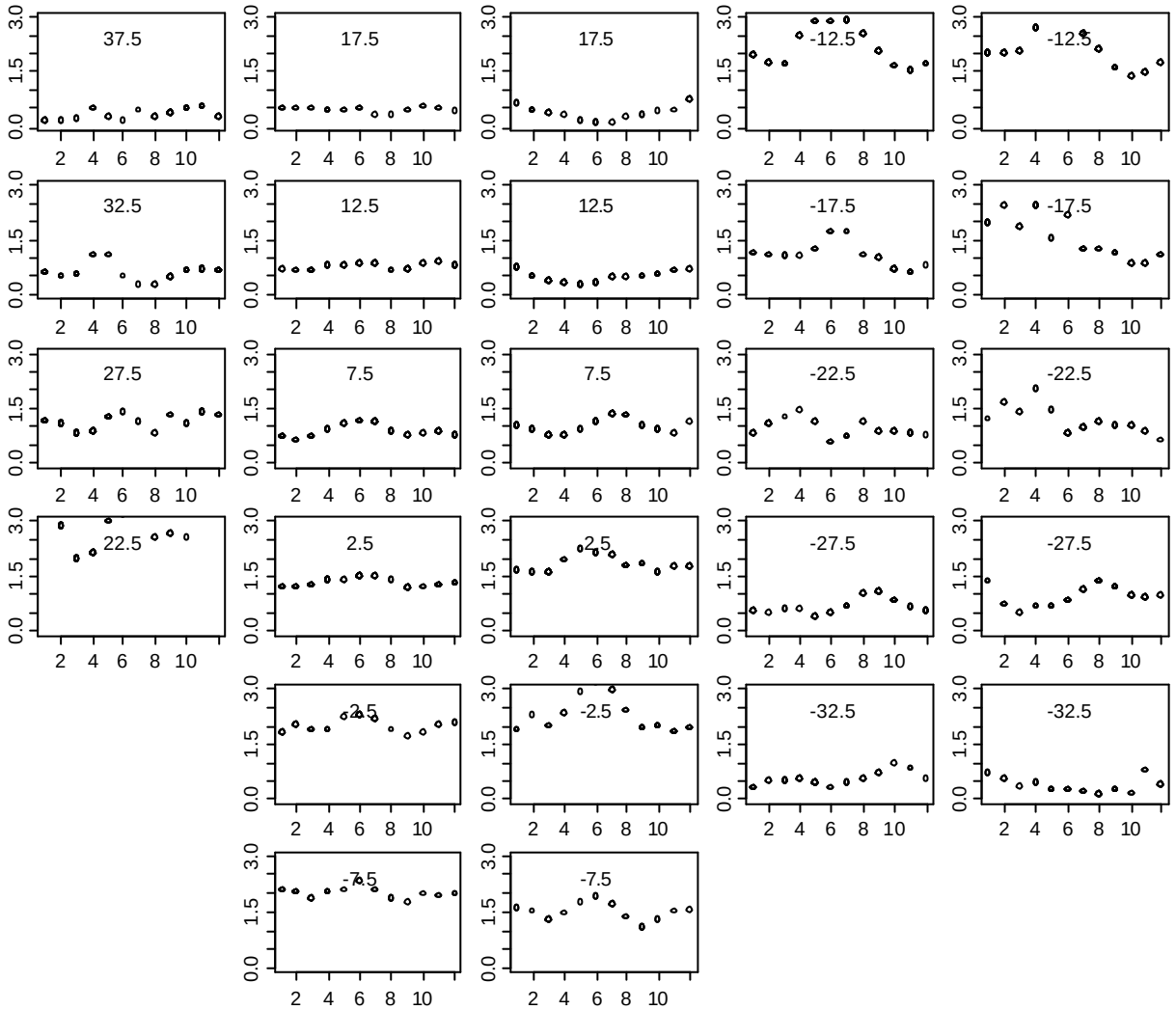


Figure 12: Predicted relationship between yellowfin catch and month by latitude bin (rows) for MFCL areas 1 to 5 (columns 1 to 5, left to right).

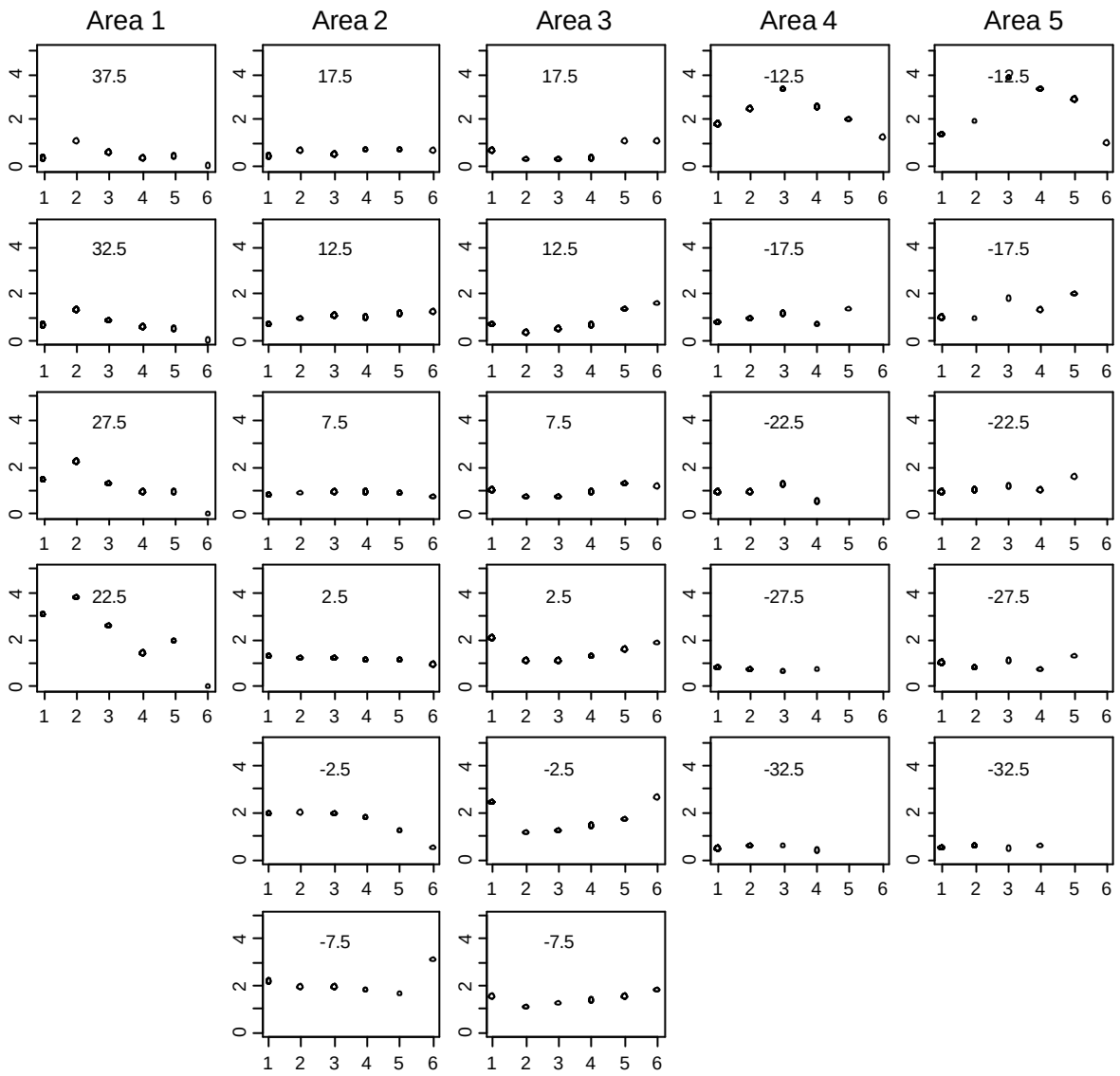


Figure 13: Predicted relationship between yellowfin catch and HBF category (1 to 6) by latitude bin (rows) for each MFCL area (1 to 5, left to right).

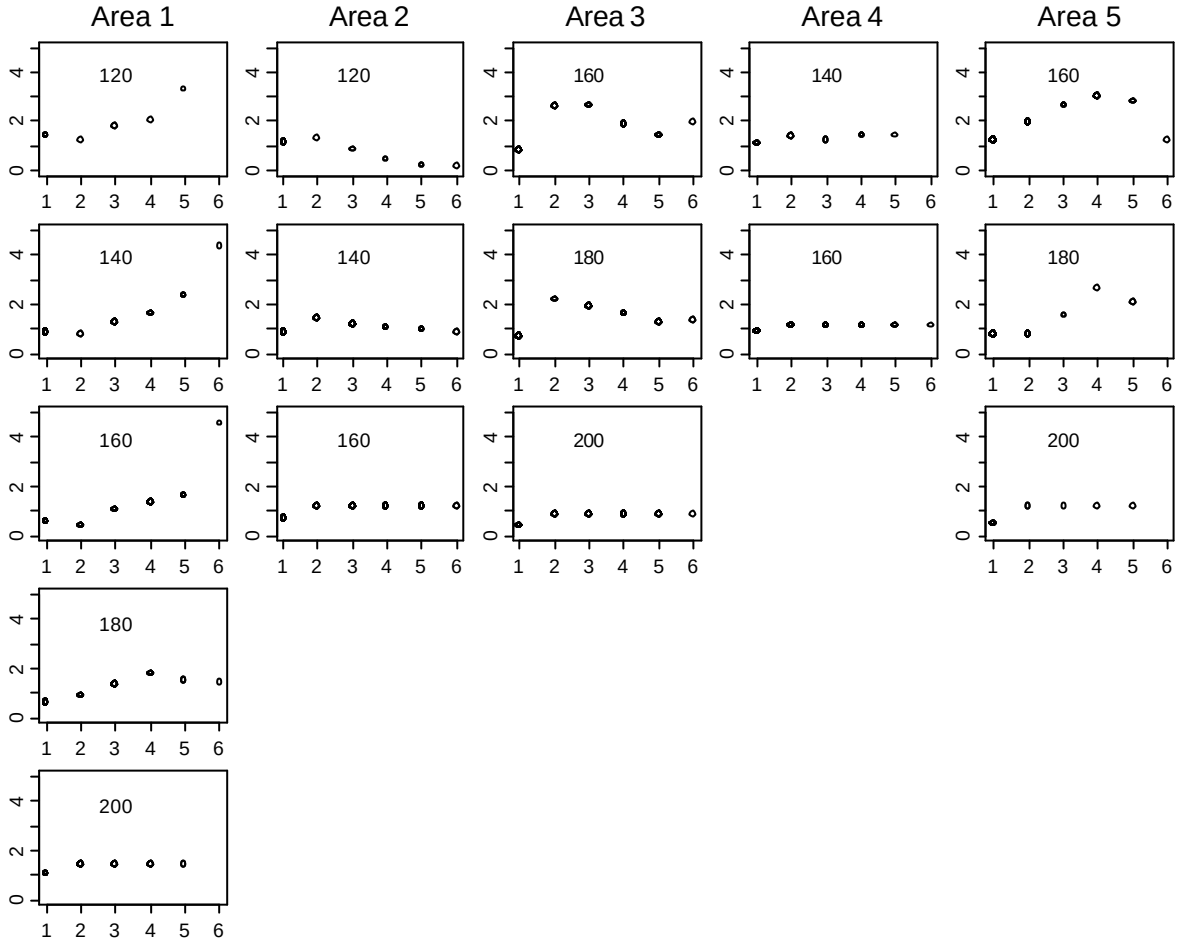


Figure 14: Predicted relationship between yellowfin catch and HBF category by longitude bin (rows) for each MFCL area (1 to 5, left to right). Longitudes have been aggregated to the nearest 20 degrees.

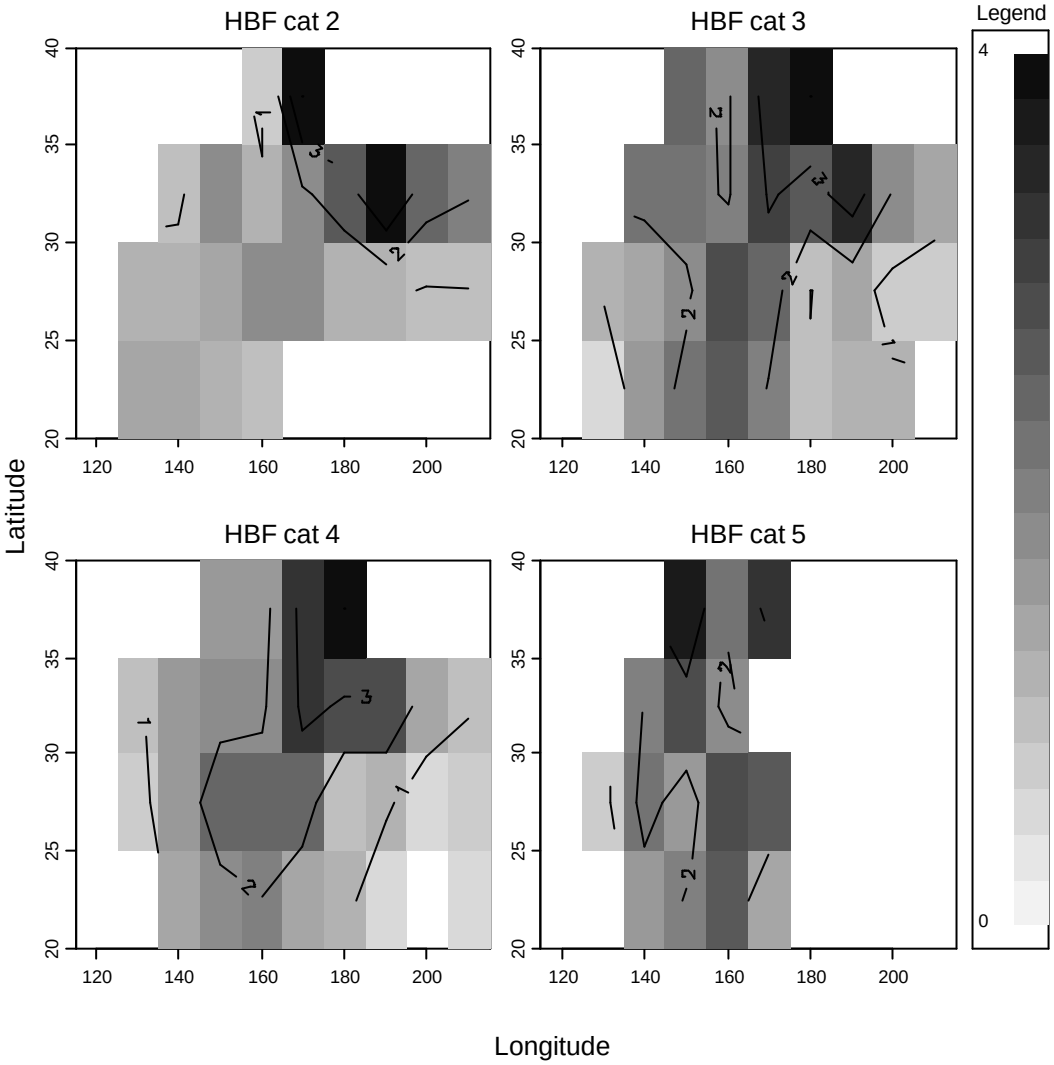


Figure 15: The relative effect of each HBF category on the catch rate of yellowfin by latitude and longitude bin for MFCL area 1. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and two and three times the HBF 1 effect.

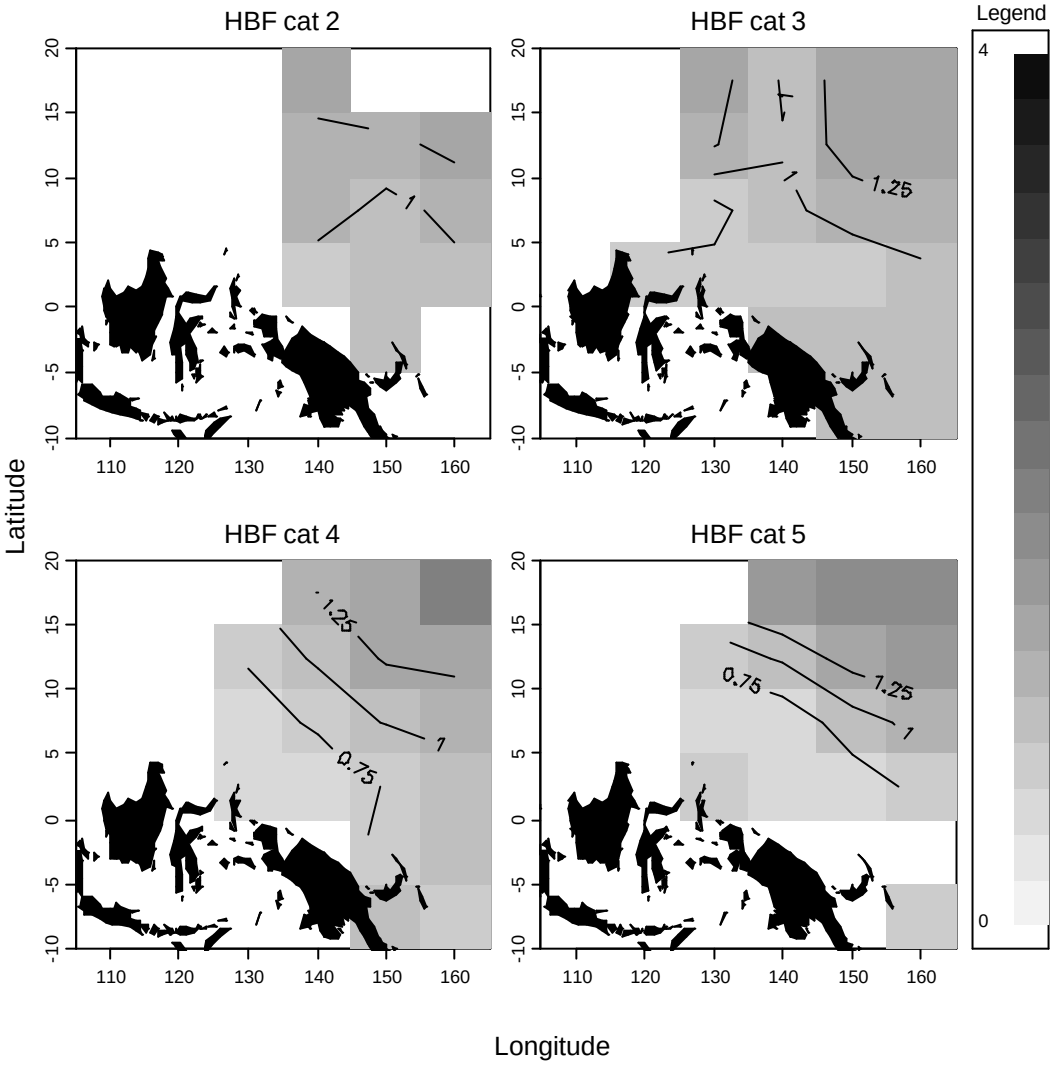


Figure 16: The relative effect of each HBF category on the catch rate of yellowfin by latitude and longitude bin for MFCL area 2. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and 75% and 125% of the HBF 1 effect.

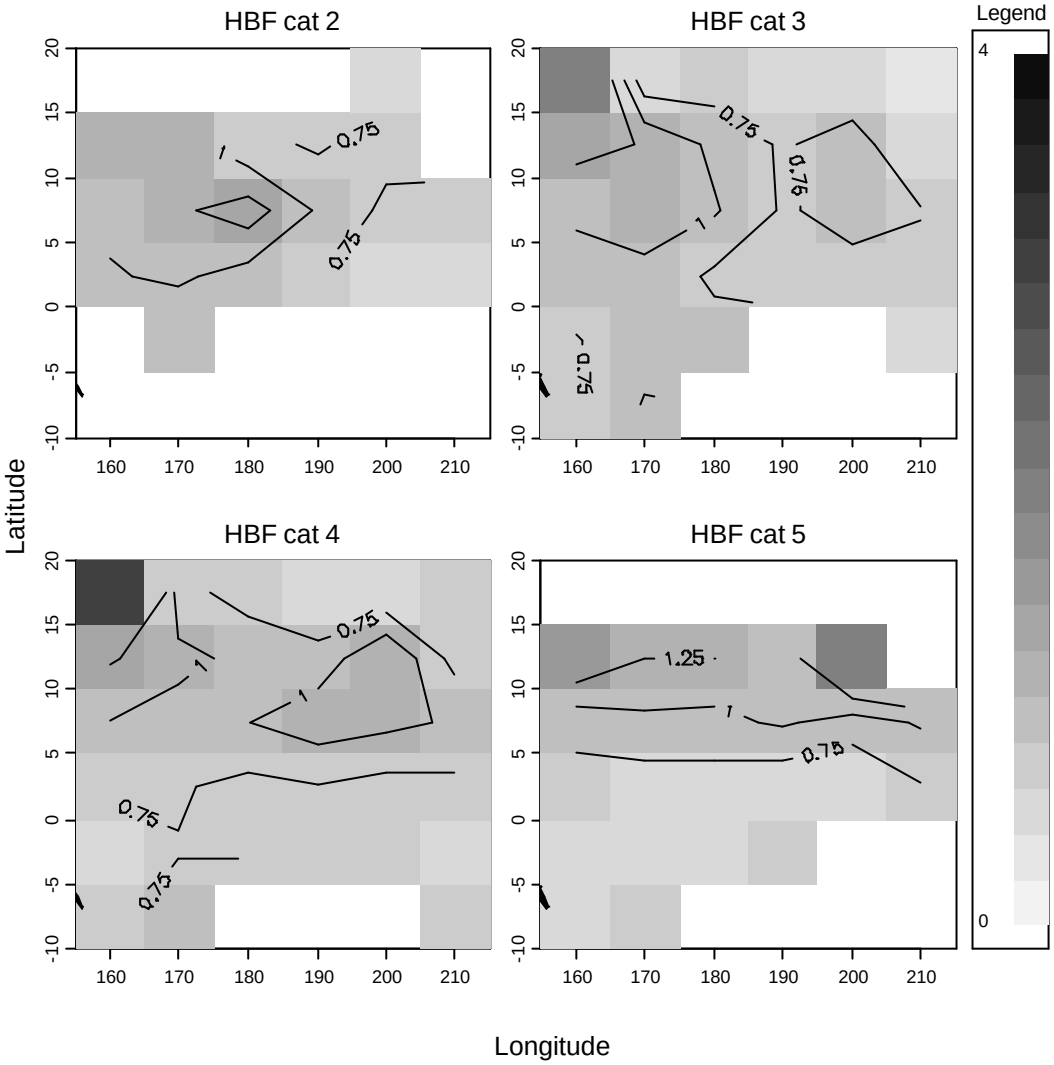


Figure 17: The relative effect of each HBF category on the catch rate of yellowfin by latitude and longitude bin for MFCL area 3. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and 75% and 125% of the HBF 1 effect.

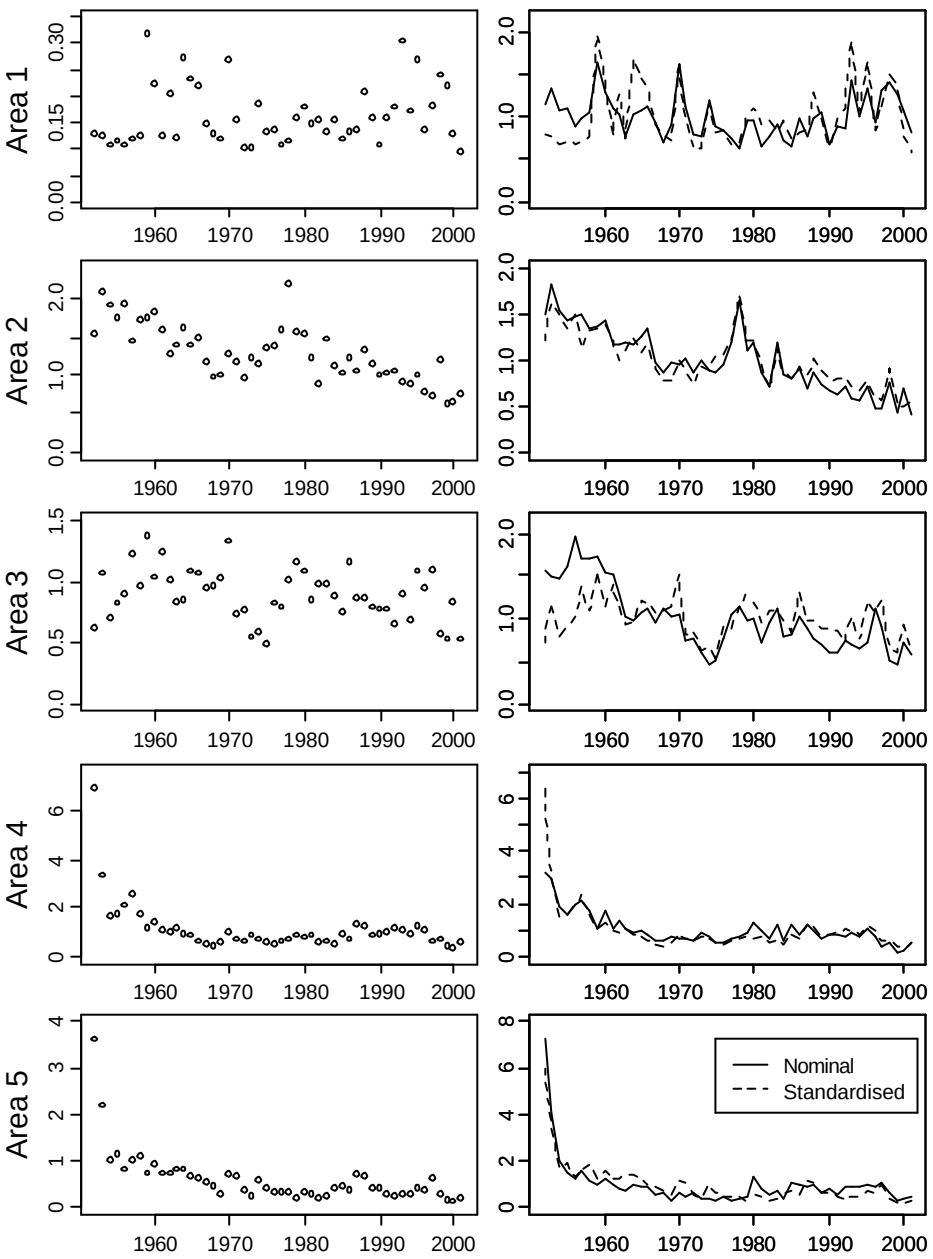


Figure 18: Annual CPUE indices by MFCL region for the WCPO yellowfin stock. Standardised indices (left) scaled by global mean catch rate (number of fish/hundred hooks) and a comparison of the standardised indices and nominal CPUE (number of fish/hundred hooks) for each area (right). For comparison, the two series are scaled to the mean of the series.

4.3 Bigeye

The generic CPUE model for bigeye has the formulation:

> Log(number of fish) ~ log(number hooks) + year + interaction(month, latitude) + interaction(month, longitude) + interaction(HBF, latitude) + interaction(HBF, longitude)

The five bigeye CPUE models explain at least 75% of the observed variation in the natural logrithm of the catch from the longline fishery, with the MFCL area 2 and 3 CPUE models accounting for over 84% of the variation (Table 4 and Table 5). The slightly lower explanatory power of the MFCL area 1, 4, and 5 models is attributable to the higher proportion of low catches (less than 20 fish per record) in these three data sets. The models do not fit the low values particularly well and the, consequently, the distribution of the residuals are negatively skewed (Figure 20).

Table 4: Summary of step-wise fits to each of the MFCL area bigeye CPUE data sets. The r-squared value (%) is given for each iteration.

Iteration	MFCL area 1		MFCL area 2		MFCL area 3	
	Variable	R^2	Variable	R^2	Variable	R^2
1	Num_hooks	50.7	Num_hooks	71.0	Num_hooks	83.1
2	Month*lat	65.0	HPB*lat	77.7	HPB*lat	85.9
3	Year	68.0	Year	81.7	Year	87.7
4	HPB*long	79.1	HPB*long	83.6	HPB*long	89.3
5	HPB*lat	79.5	Month*long	84.0	Month*long	89.5
6	Month*long	81.9				

Iteration	MFCL area 4		MFCL area 5	
	Variable	R^2	Variable	R^2
1	Num_hooks	54.8	Num_hooks	61.6
2	Month*lat	67.6	Month*lat	68.9
3	Year	71.4	Year	72.5
4	HPB*long	73.7	Month*long	74.6
5	HPB*lat	74.9	HPB*lat	76.1
6	Month*long	75.1	HPB*long	76.7

Table 5: Proportion of the observed variation in the natural logarithm of bigeye catch explained by each of the five generic MFCL area CPUE models.

MFCL region	Percent R^2
1	81.9
2	84.0
3	89.5
4	75.1
5	76.7

The relationship between bigeye catch and fishing effort (number of hooks) was comparable between the five MFCL areas (Figure 21). This is consistent with the lower variation in catch rates between areas compared to yellowfin tuna (see Table 1).

Bigeye catch rates were relatively consistent throughout the equatorial areas (MFCL areas 2 and 3) with respect to both latitude and month (Figure 22). However, in the sub-tropical areas there was a strong seasonal trend in catch rates. In the southern areas (MFCL areas 4 and 5), predicted catch rates were highest in the austral winter (May–August) and low during summer. Conversely, north of the equator catch rates were predicted to be highest during September–February and low from April to June (Figure 22).

The CPUE models predicted a general increase in bigeye catch rates with increasing longitude (eastwards) (Figure 23).

The CPUE models reveal relatively complex interactions between latitude, longitude, and HBF category (Figure 23 and Figure 24). As for the yellowfin CPUE models, a second order interaction term between these three variables was fitted for the MFCL area 1–3 models. The coefficients from the interaction term were then plotted relative to the corresponding coefficient for the HBF 1 category.

For MFCL area 1, bigeye catch rates are predicted to increase in the central region with increased HBF (Figure 25). In MFCL area 2, an increase in HBF is predicted to depress catch rates in the northeastern sector of the region, while increasing catch rates in the more coastal area (Figure 26). For MFCL area 3, an increase in HBF category is predicted to increase the catch rate of bigeye south of the equator and in the northwest of the area (Figure 27). For all HBF categories, catch rates in the remainder of the area were comparable to the catch rate of HBF 1 gear.

Overall, bigeye catch rates increased with increasing HBF, although this effect was most evident in the northern area of the WCPO at the interface of the Kuroshio and North Pacific currents (see Appendix 3. Catch rates were also increased along the southern equatorial area, the area influenced by the Southern Equatorial current.

For all MFCL areas, the standardised annual indices are similar to the trends in unstandardised CPUE, with the exception of MFCL area 4 that reveals a decline in standardised CPUE indices while the nominal indices have no apparent trend (Figure 28). This may relate to the apparent shift in the latitudinal and seasonal distribution of fishing effort as well as a change in the configuration of the gear (see Appendix 2) Nevertheless, there is a relatively high variance associated with some of the earlier indices in the time-series (pre 1960) and, to a lesser extent, the more recent indices (see Figure 21). Some of the annual indices for the MFCL area 5 analysis are also poorly determined, in particular the indices from the late 1970s and early 1980s.

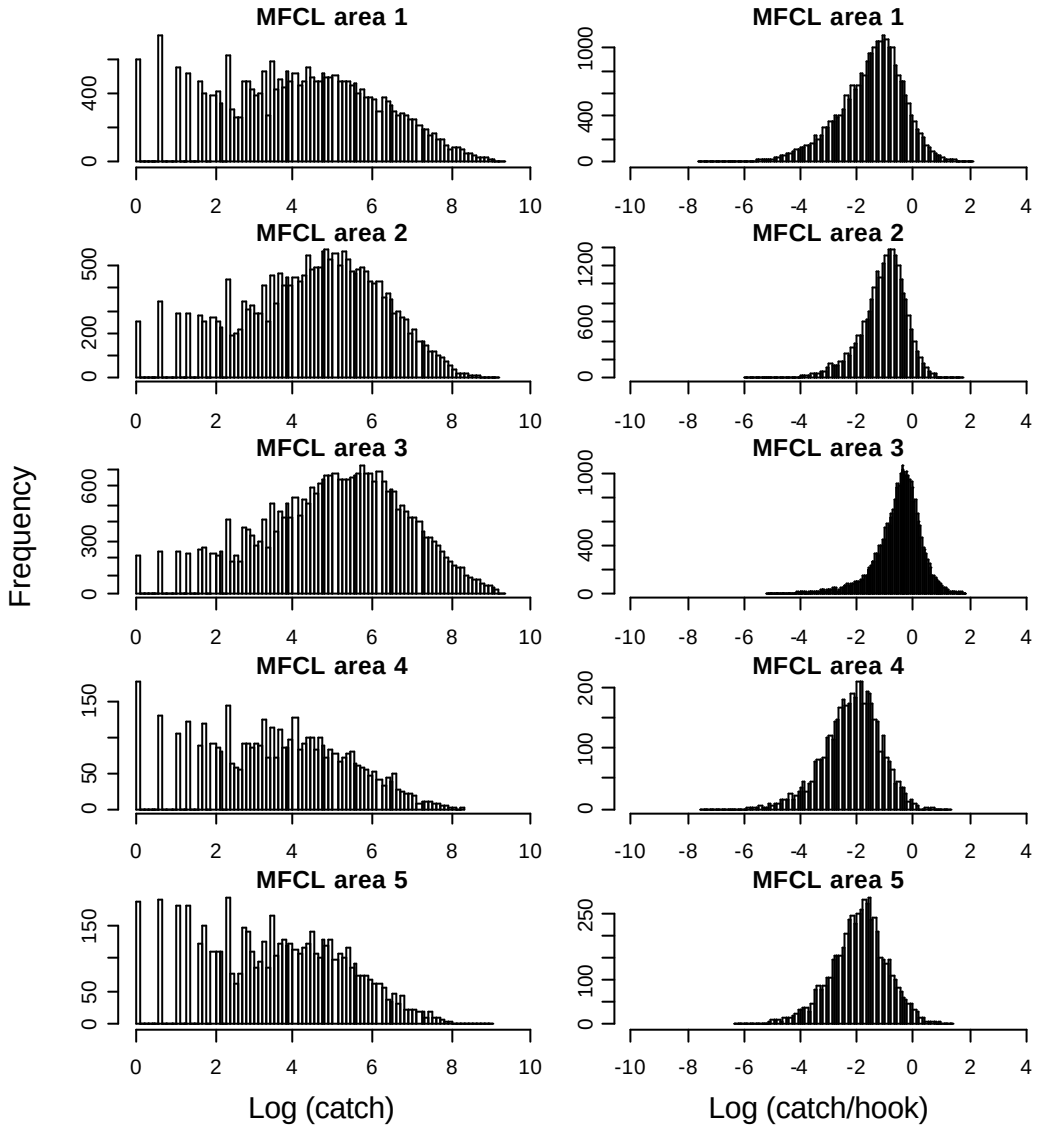


Figure 19: Histograms of the distribution of logarithm of bigeye catch (number of fish) and catch rate (number of fish per 100 hooks) for each of the five MFCL area data sets.

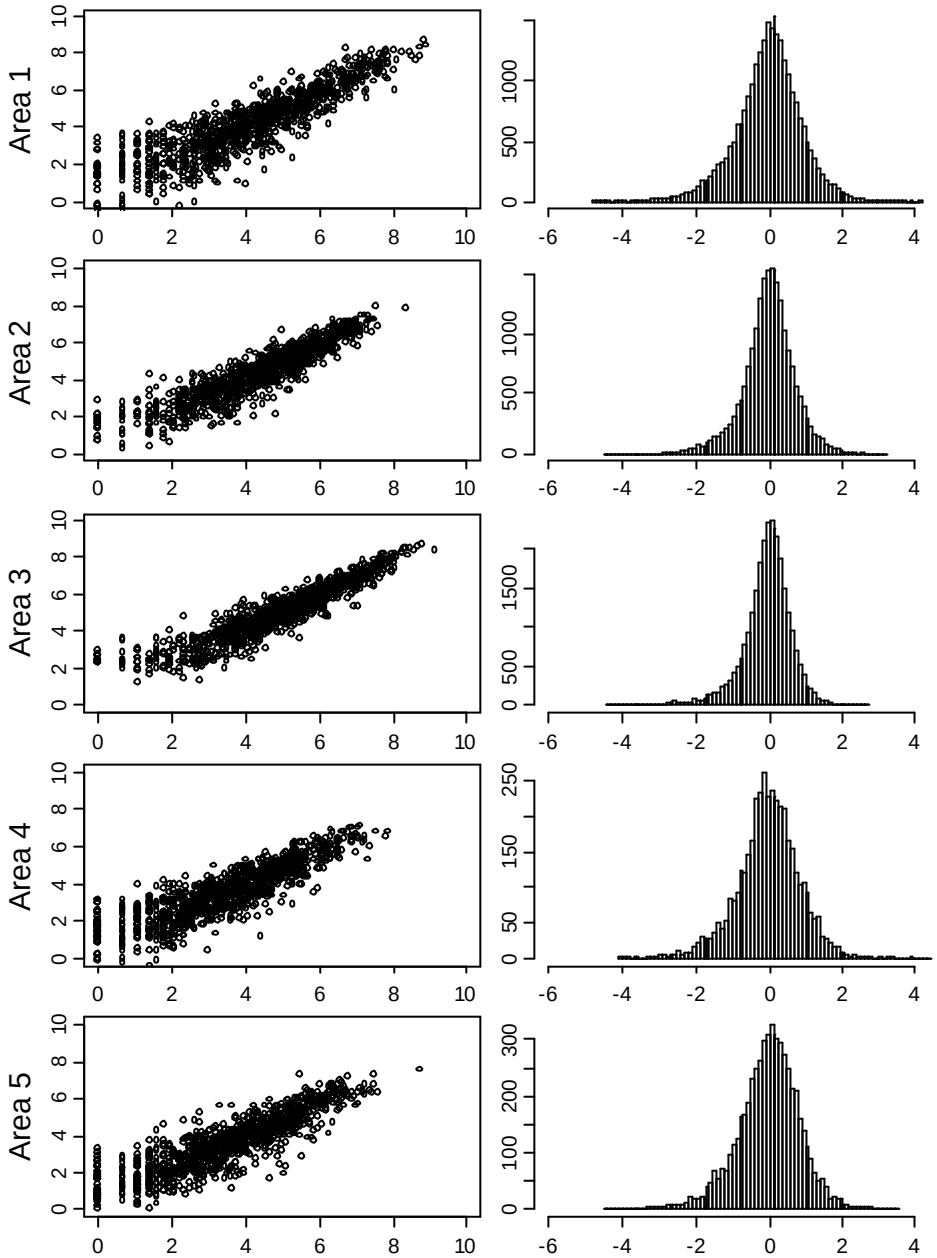


Figure 20: A comparison of a random sample of the observed (x-axis) and predicted (y-axis) values from each of the five bigeye MFCL area CPUE analyses (left) and the distribution of the residuals for each model.

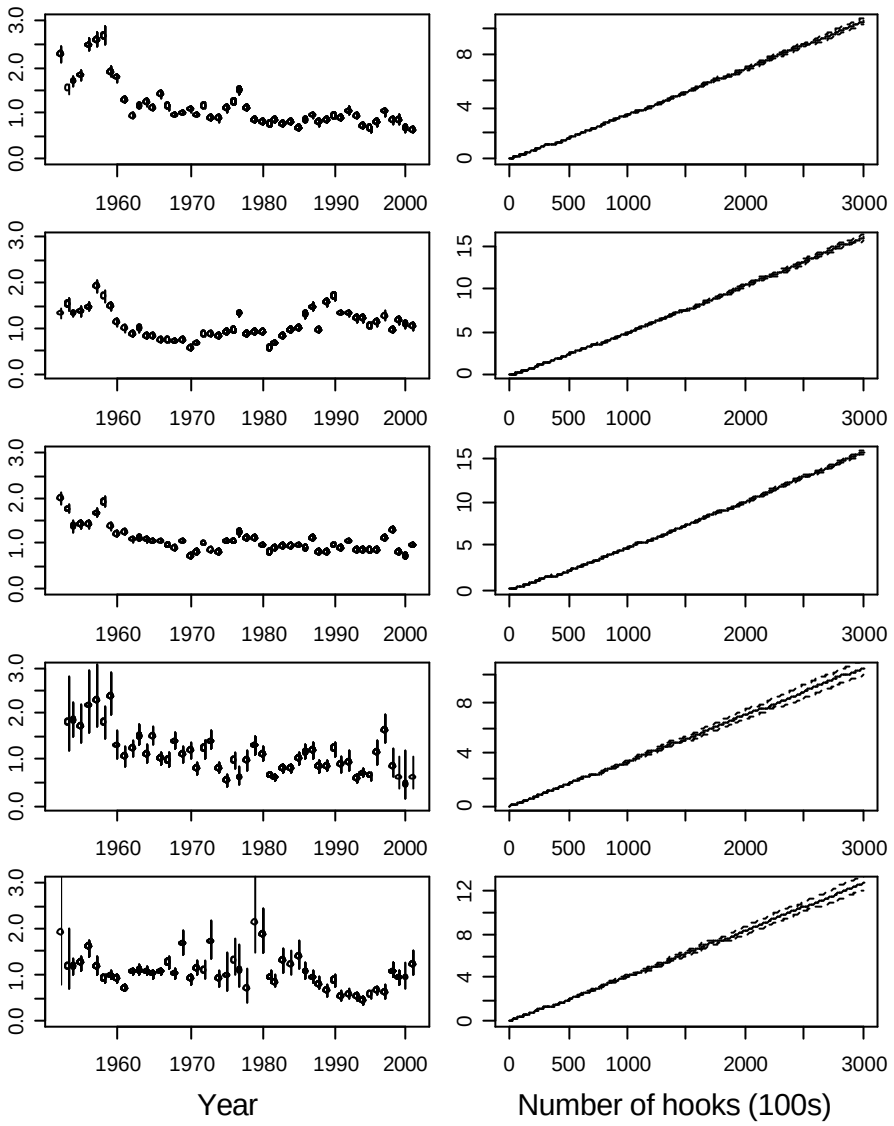


Figure 21: Predicted relationship between bigeye catch and year (left) and number of hooks set (right) for each MFCL area.

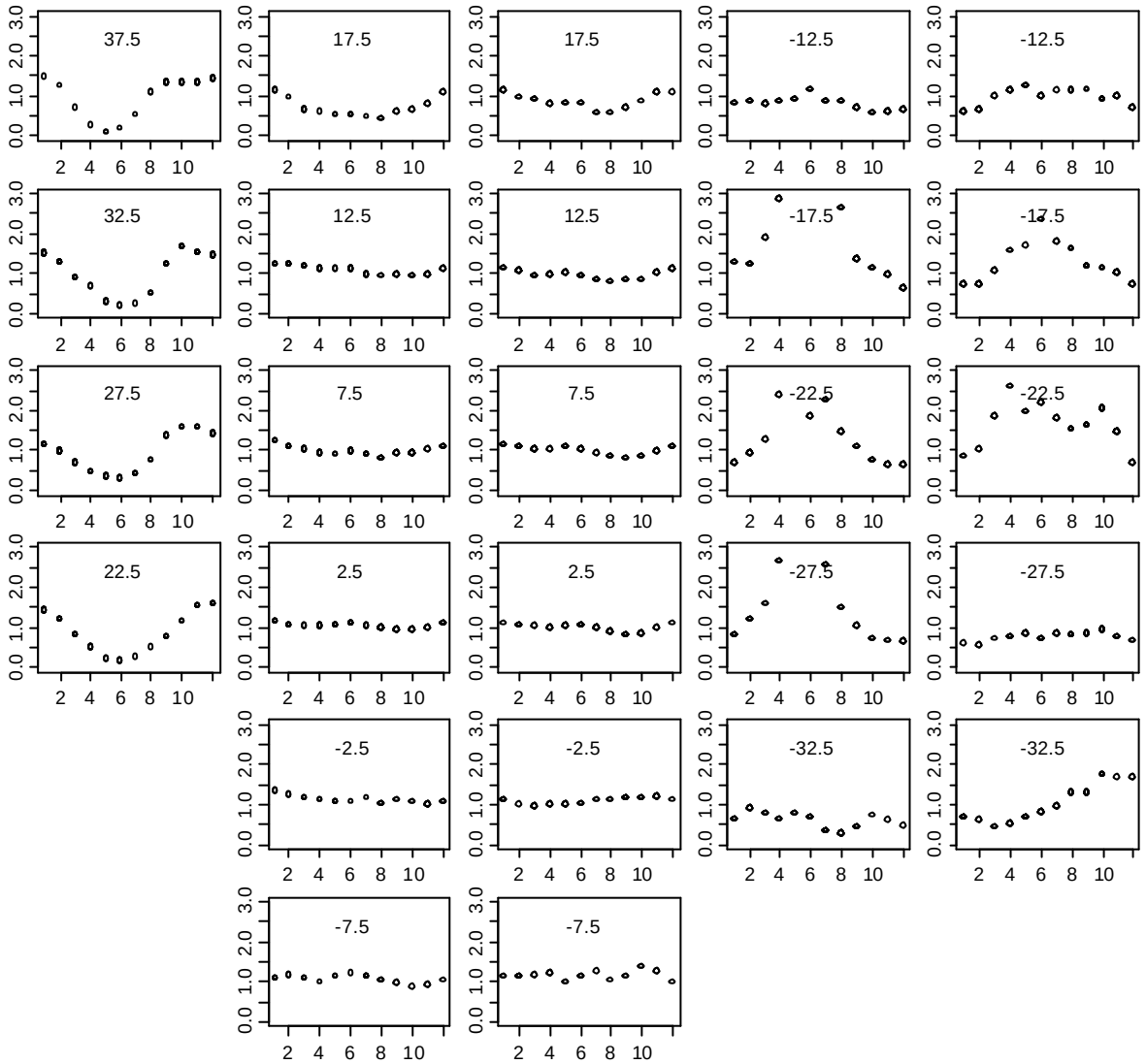


Figure 22: Predicted relationship between bigeye catch and month by latitude bin (rows) for each MFCL area (1 to 5, left to right).

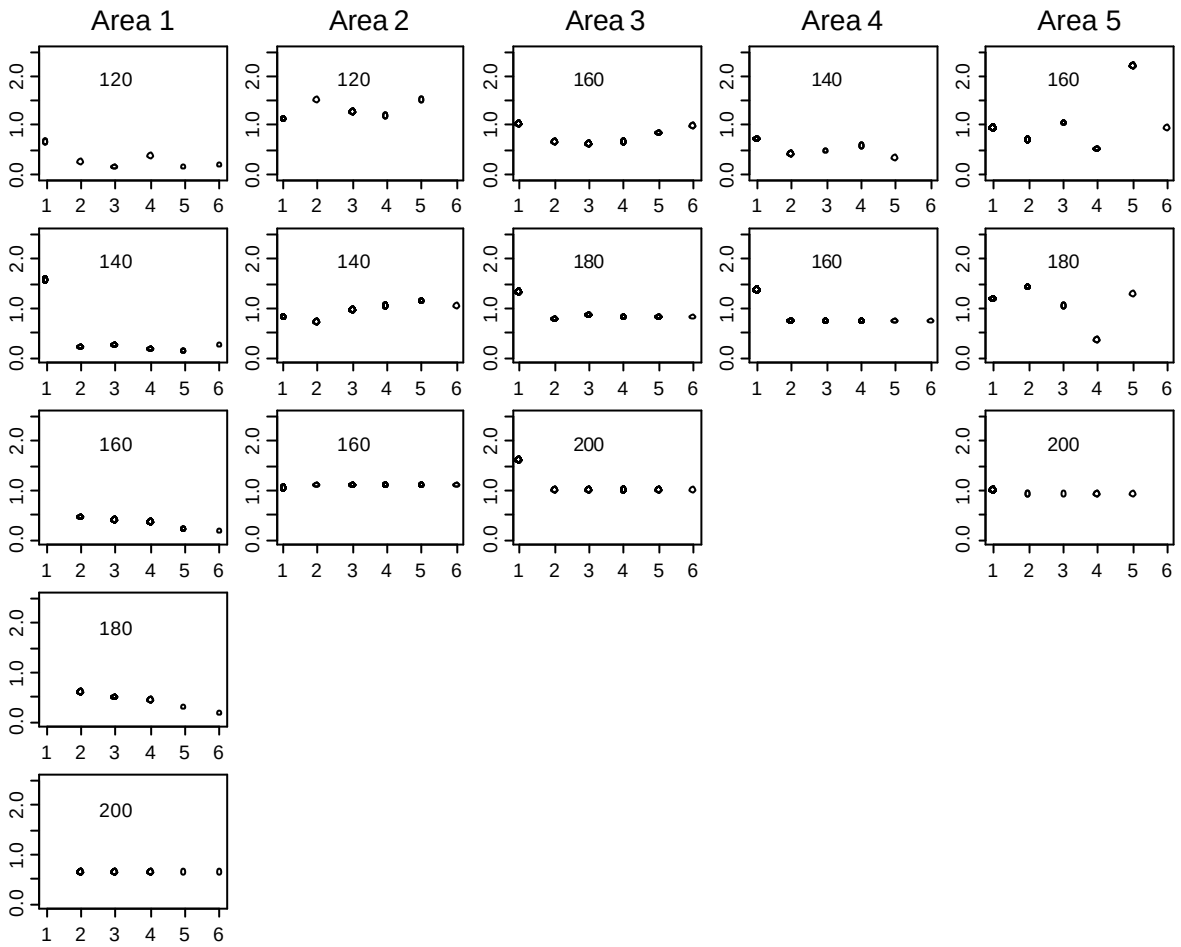


Figure 23: Predicted relationship between bigeye catch and HBF category by longitude bin (rows) for each MFCL area (1 to 5, left to right). Longitudes have been aggregated to the nearest 20 degrees.

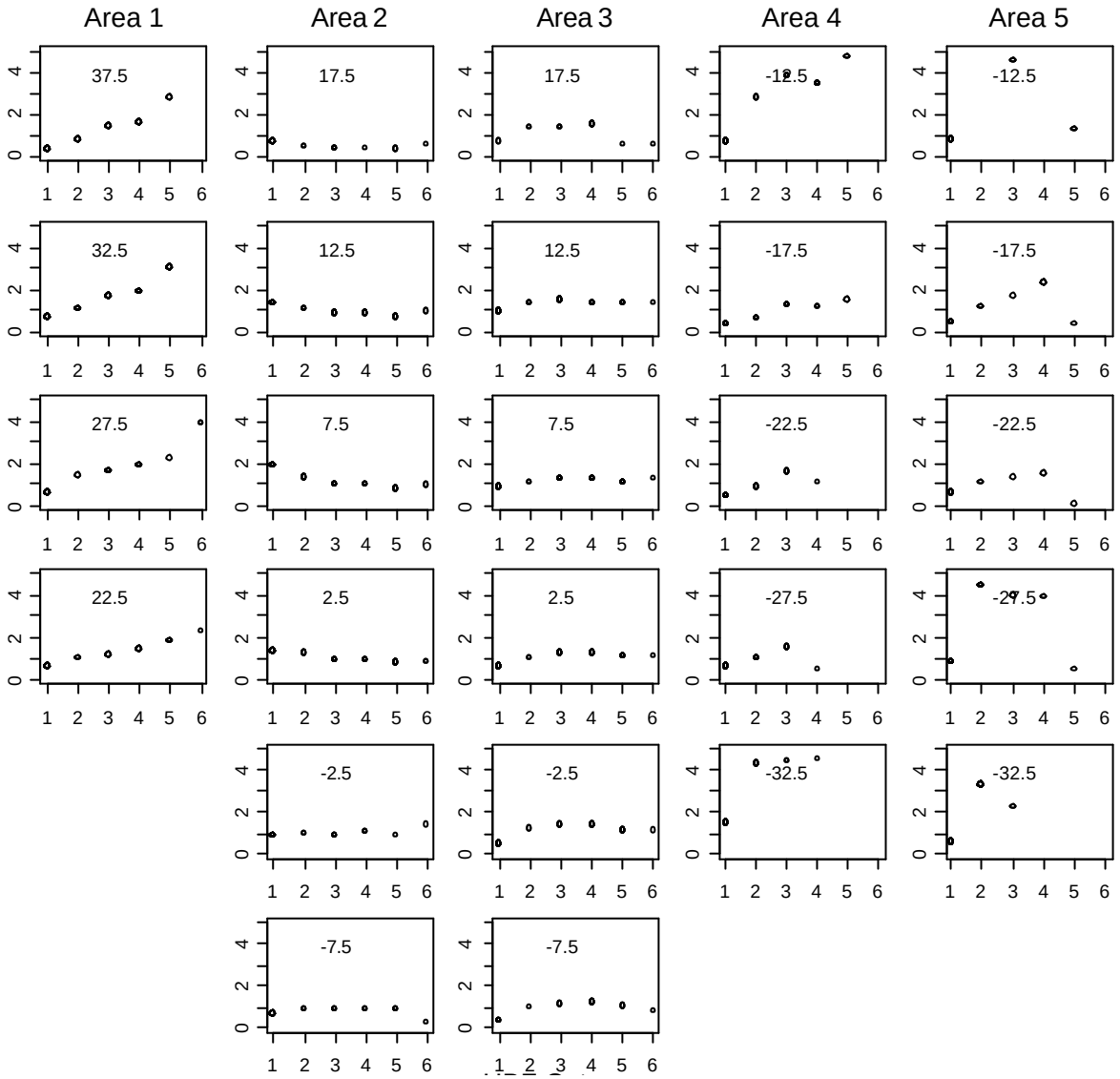


Figure 24: Predicted relationship between bigeye catch and HBF category by latitude bin (rows) for each MFCL area (1 to 5, left to right).

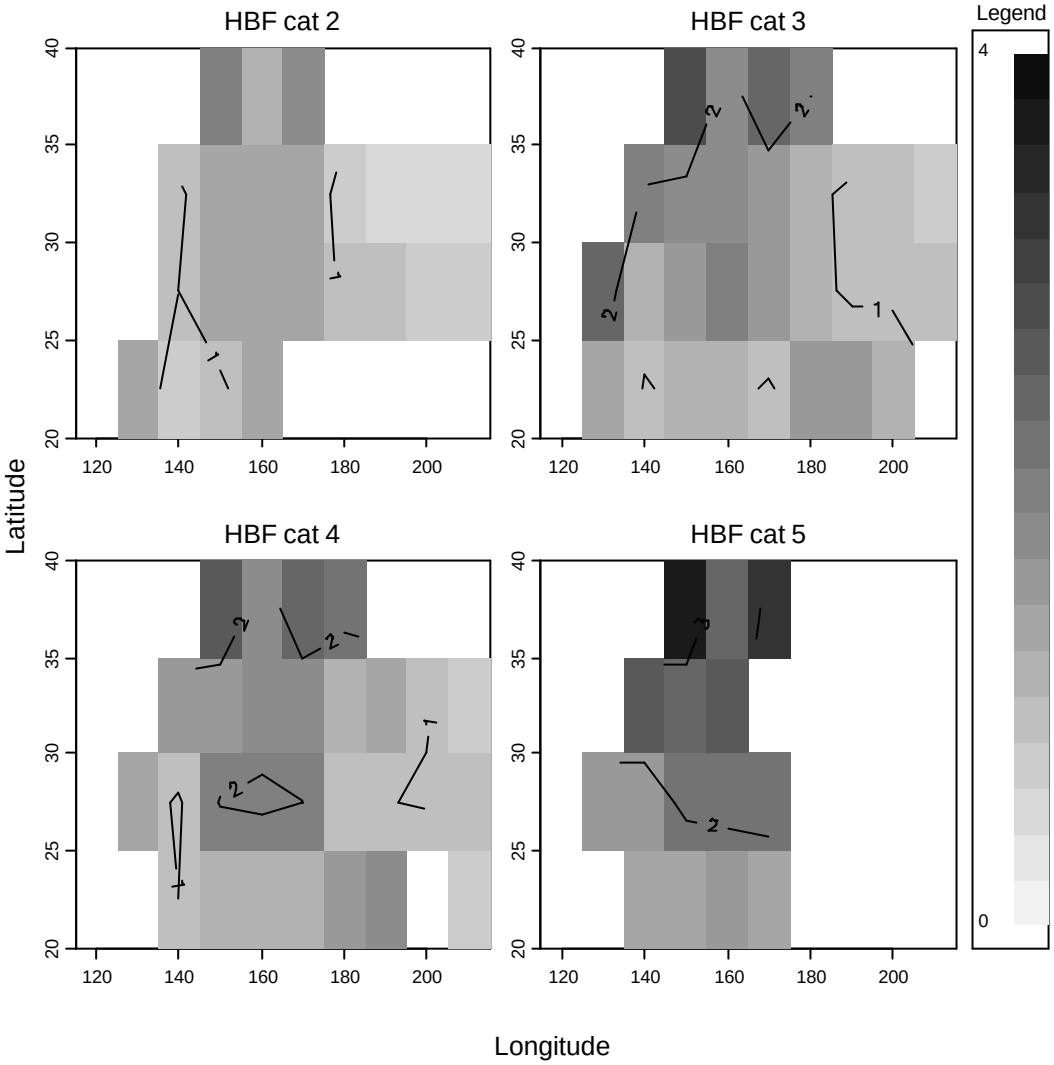


Figure 25: The relative effect of each HBF category on the catch rate of bigeye by latitude and longitude bin for MFCL area 1. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and two and three times the HBF 1 effect.

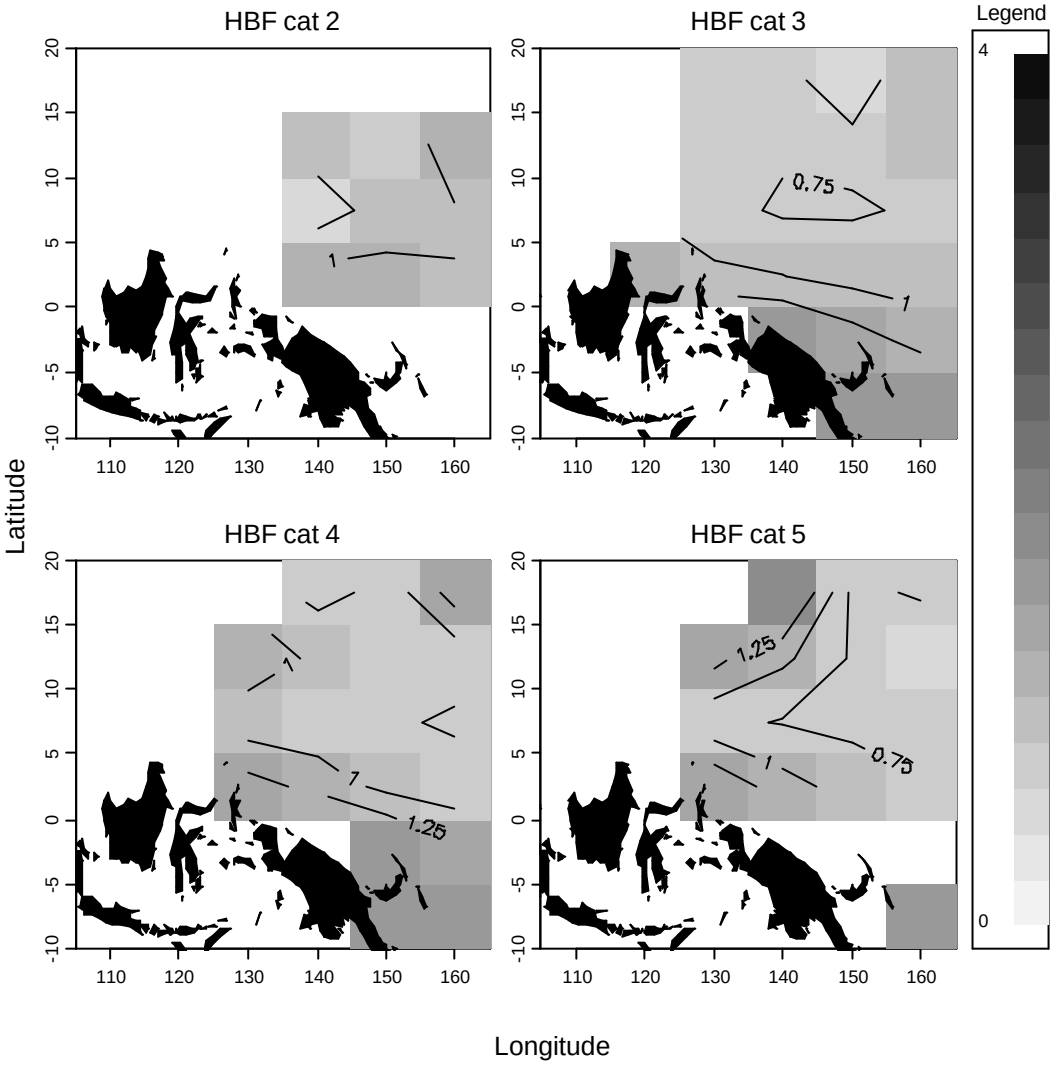


Figure 26: The relative effect of each HBF category on the catch rate of bigeye by latitude and longitude bin for MFCL area 2. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and 75% and 125% of the HBF 1 effect.

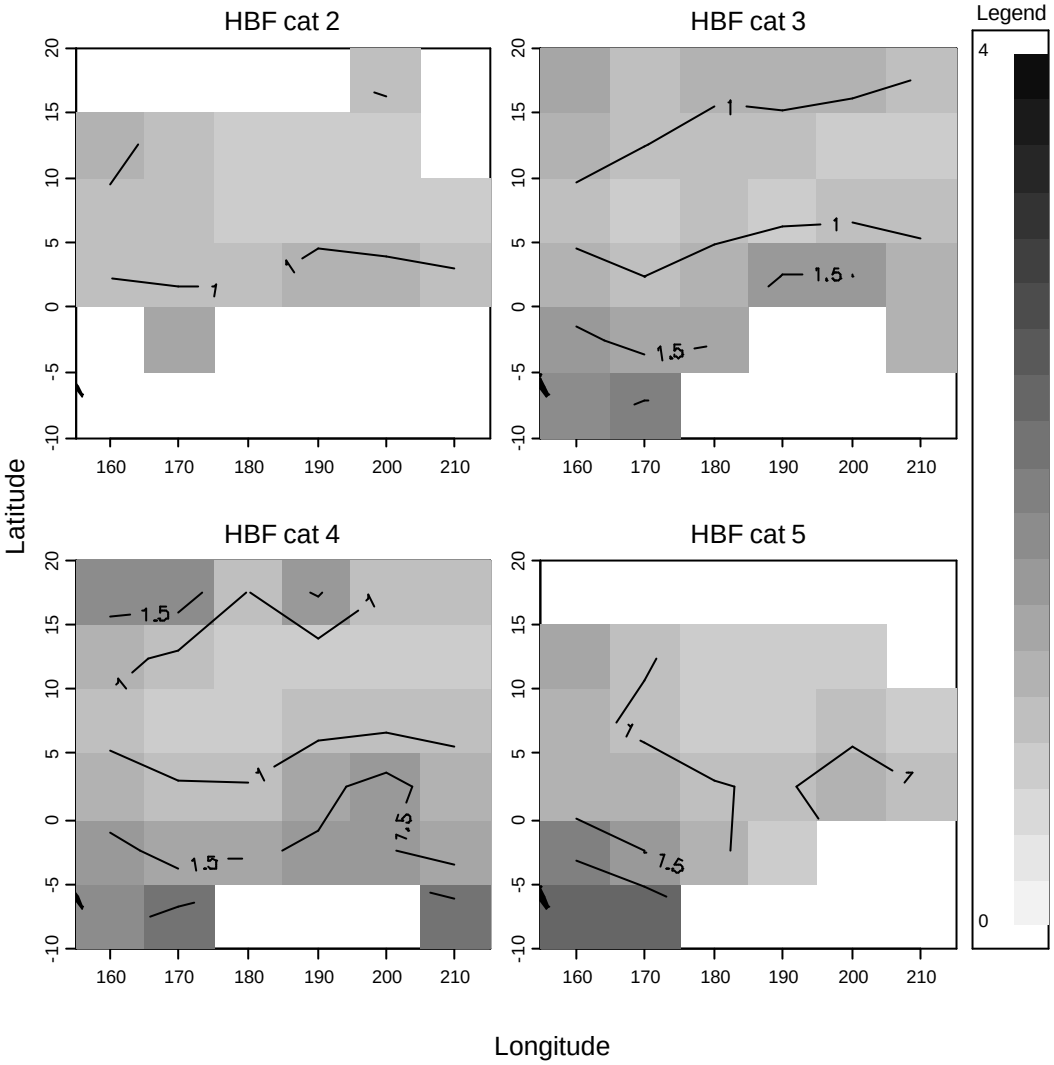


Figure 27: The relative effect of each HBF category on the catch rate of bigeye by latitude and longitude bin for MFCL area 3. The effects are calculated as a proportion of the coefficient for the corresponding HBF category 1. Only lat/long cells with at least 50 records are presented. Contour lines are plotted at unity and 150% and 200% of the HBF 1 effect.

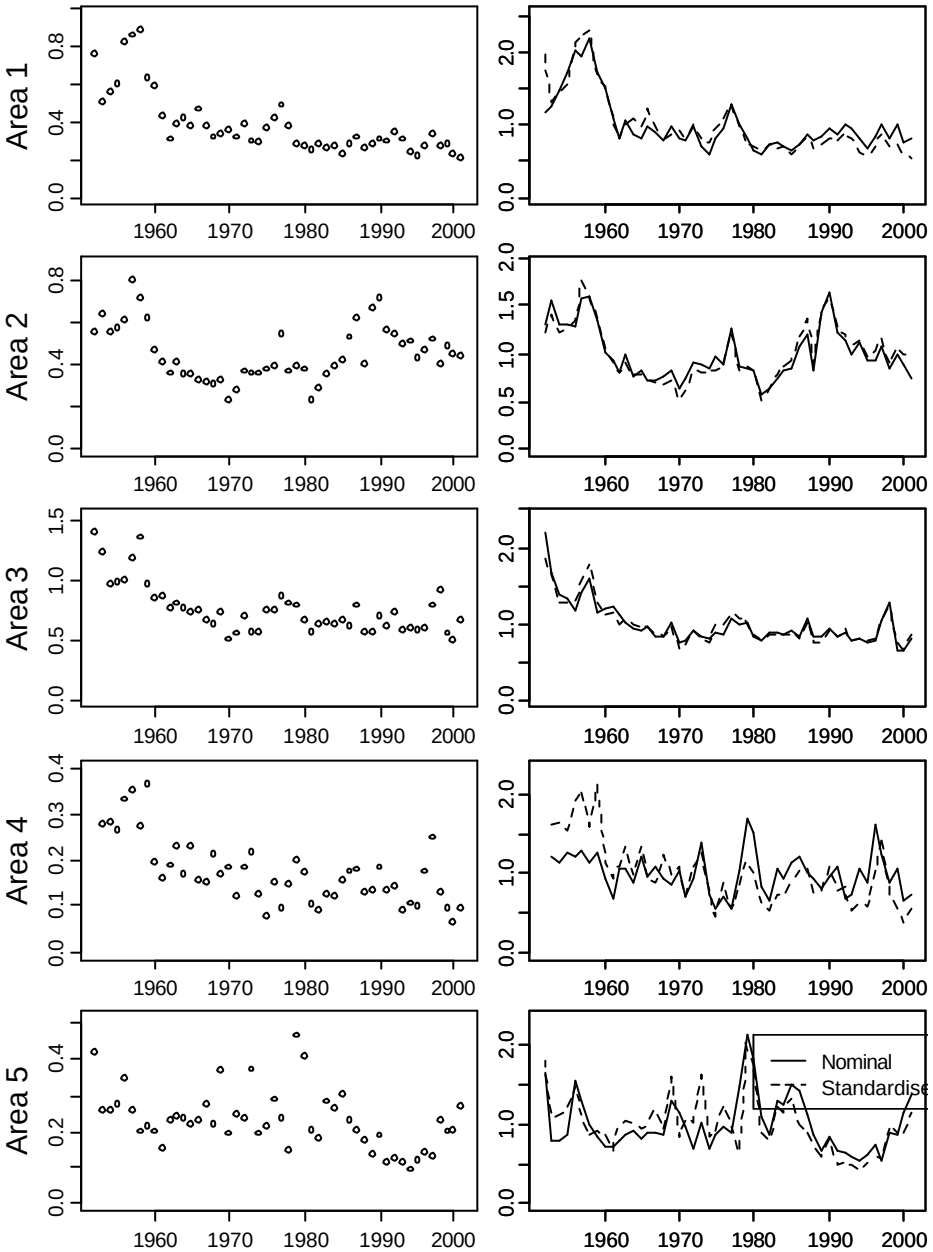


Figure 28: Annual CPUE indices by MFCL region for the WCPO bigeye fishery. Standardised indices (left) scaled by global mean catch rate (number of fish/hundred hooks) and a comparison of the standardised indices and nominal CPUE (number of fish/hundred hooks) for each area (right). For comparison, the two series are scaled to the mean of the series.

5 DISCUSSION

Overall, the GLMs for both yellowfin and bigeye represent a reasonable fit to the CPUE data sets from each of the five MFCL areas. The models have difficulty predicting the records with small catch. However, for most data sets these records represent a small proportion of the total records and a small component of the total effort. Nevertheless, they do account for a significant proportion of records from the yellowfin MFCL area 1 data set and the bigeye MFCL area 4 and 5 data sets. There are also a relatively high proportion of zero yellowfin catch records from MFCL area 1 that are excluded from the analysis.

The level of resolution of the data prevents a detailed exploration of the low catch records. These records generally have a low level of fishing effort and potentially represent exploratory fishing. Alternatively, the records may represent fishing activity principally targeting other species. However, catch data for other associated species were not available for the more recent data precluding the inclusion of such variables in the analysis.

For both yellowfin and bigeye, the annual trends in the standardised CPUE indices for each MFCL area are generally comparable to the trends in nominal CPUE. However, for yellowfin the GLM standardised indices differ considerably from the habitat standardised CPUE indices for the species. The GLM models include the HBF category variable and, thereby, potentially account for the shift in the operation of the fishery.

There is considerable spatial complexity in the predicted effect of increasing the HBF on the resulting catch of yellowfin. In general, catch rates of yellowfin are predicted to be lower for the deepest gear (higher HBF). However, this trend varies between areas and in some locations catch rates of yellowfin are actually elevated by increasing HBF. This may be potentially an artefact of the unbalanced data set with lower HBF dominating in the early period of the history when catch rates were highest. However, the effect may be a real observation and explainable by localised oceanographic conditions.

Conversely, for bigeye tuna GLM models there is a general increase in predicted catch rates with increasing HBF. This is consistent with the assumed change in targeting behaviour related to the increased depth of gear. However, this general observation does not pertain throughout the fishery and there are some areas where predicted catch rates of bigeye are depressed with higher HBF.

These observations need to be compared with the results of the habitat standardisation and any discrepancies between the two modelling approaches need to be more thoroughly investigated. This will potentially increase the understanding of the interaction between the longline fishery, the local oceanographic conditions, and the habitat preference of the two species and, thereby, enable a more robust index of relative abundance to be derived from the longline catch and effort data.

6 References

Bigelow, K. A., J. Hampton, and N. Miyabe. 1999. Effective longline effort within the yellowfin habitat and standardized CPUE. WP YFT-3, SCTB 12, Papeete, French Polynesia, 16 –23 June 1999.

Bigelow, K. A., J. Hampton, and N. Miyabe. 2002. Application of a habitat based model to estimate effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). *Fish. Oceanogr.* **11**: 143-155.

Fournier, D.A., Hampton, J., and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. *Can. J. Fish. Aquat. Sci.* **55**: 2105–2116.

Hampton, J. 2002a. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. SCTB15 Working Paper YFT 1.

Hampton, J. 2002b. Stock assessment of bigeye tuna in the western and central Pacific Ocean. SCTB15 Working Paper BET 1.

Appendix 1. MFCL areas for WCPO yellowfin and bigeye stock assessment.

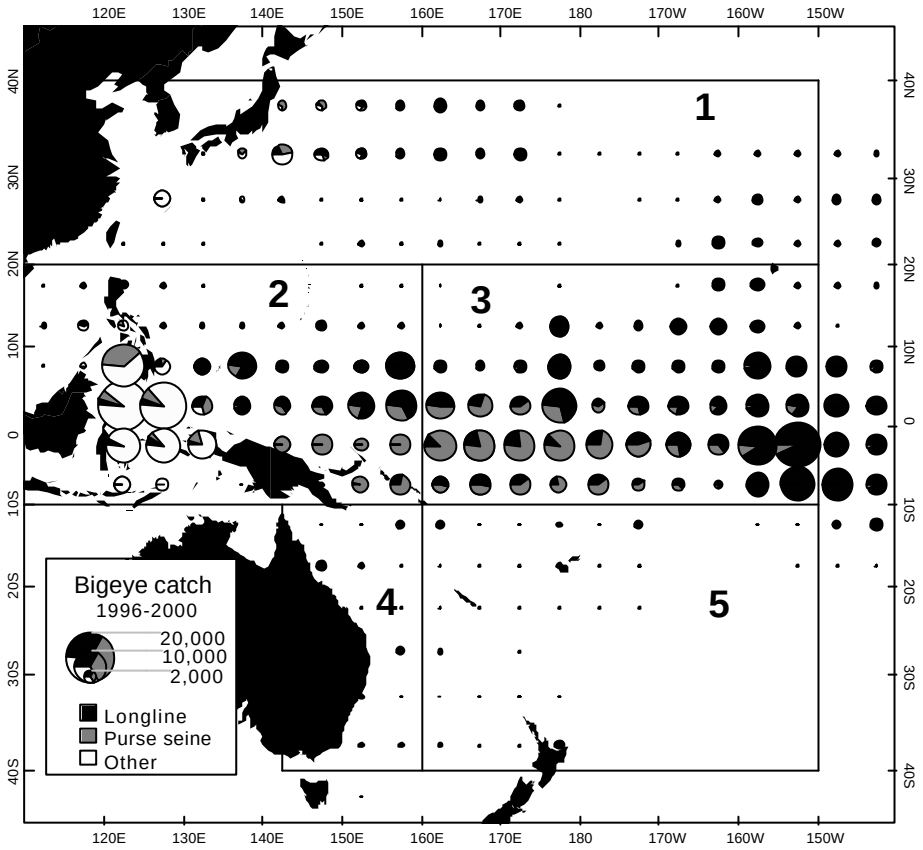


Figure A1. Distribution of bigeye tuna catch, 1996–2000. The numbered areas indicate the spatial stratification used in the MULTIFAN-CL model.

Appendix 2. Annual trends in the main variables included in the CPUE data set.

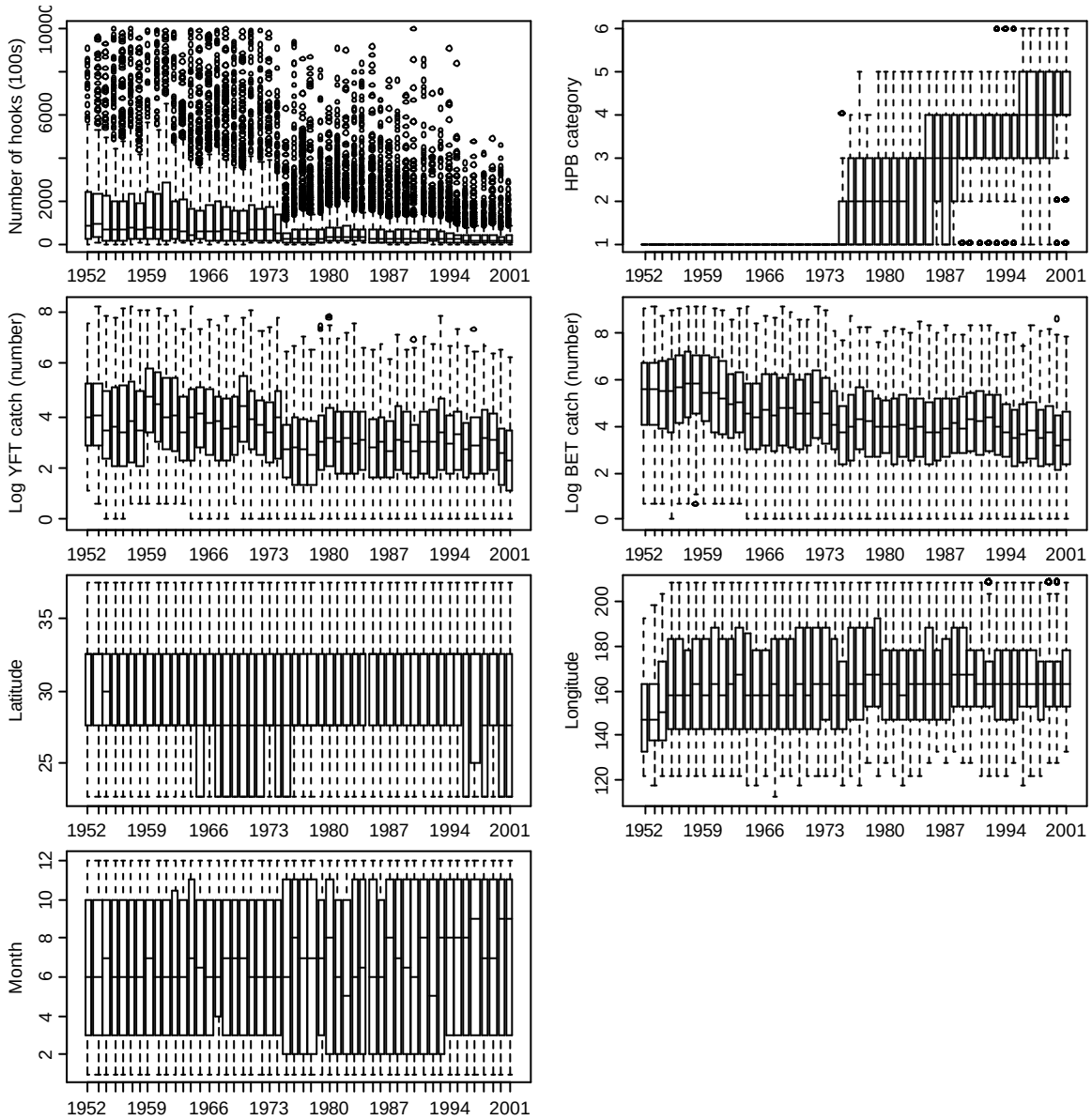


Figure B1: Boxplots of the main variables included in the MFCL area 1 data set by year.

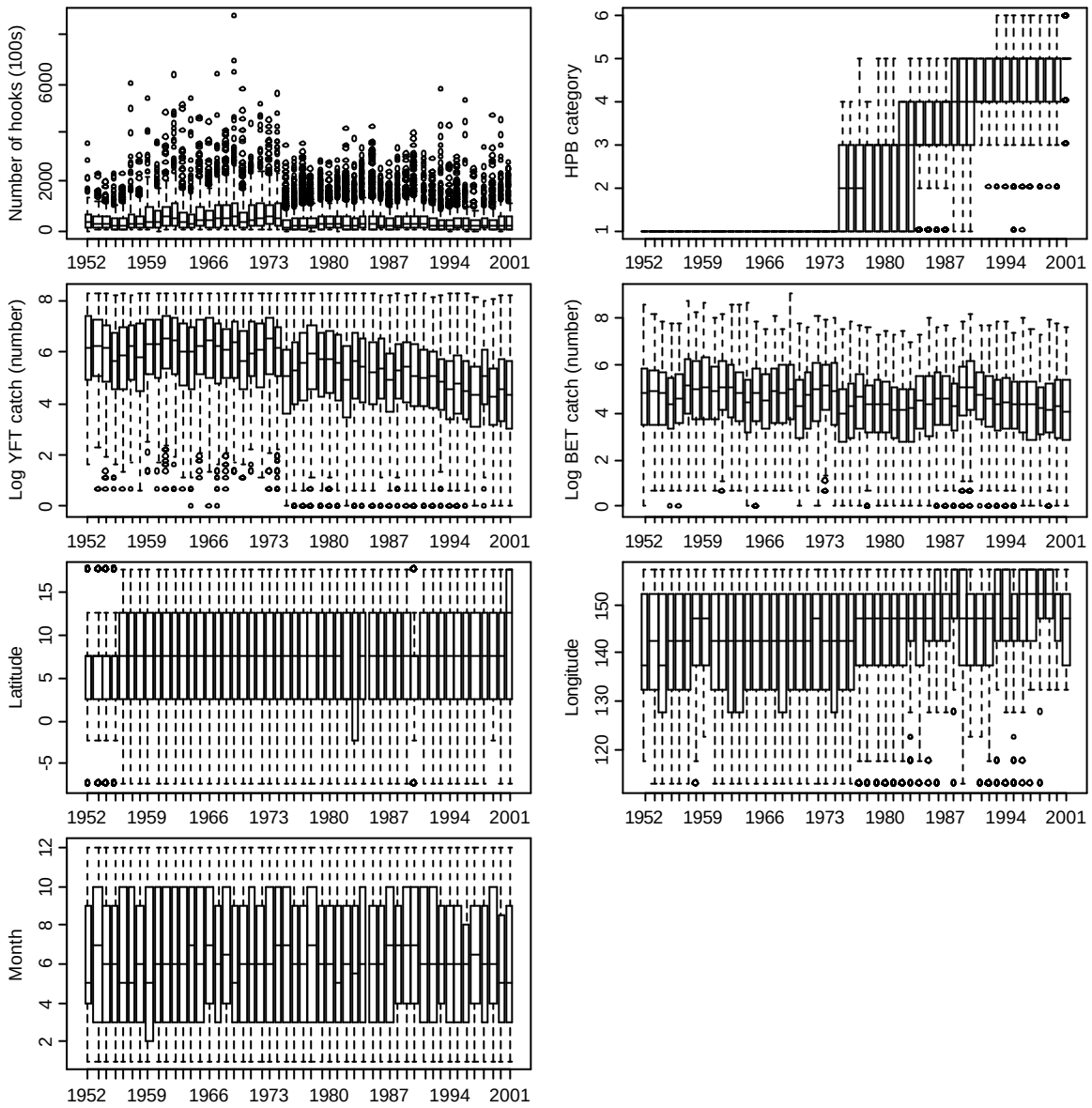


Figure B2: Boxplots of the main variables included in the MFCL area 2 data set by year.

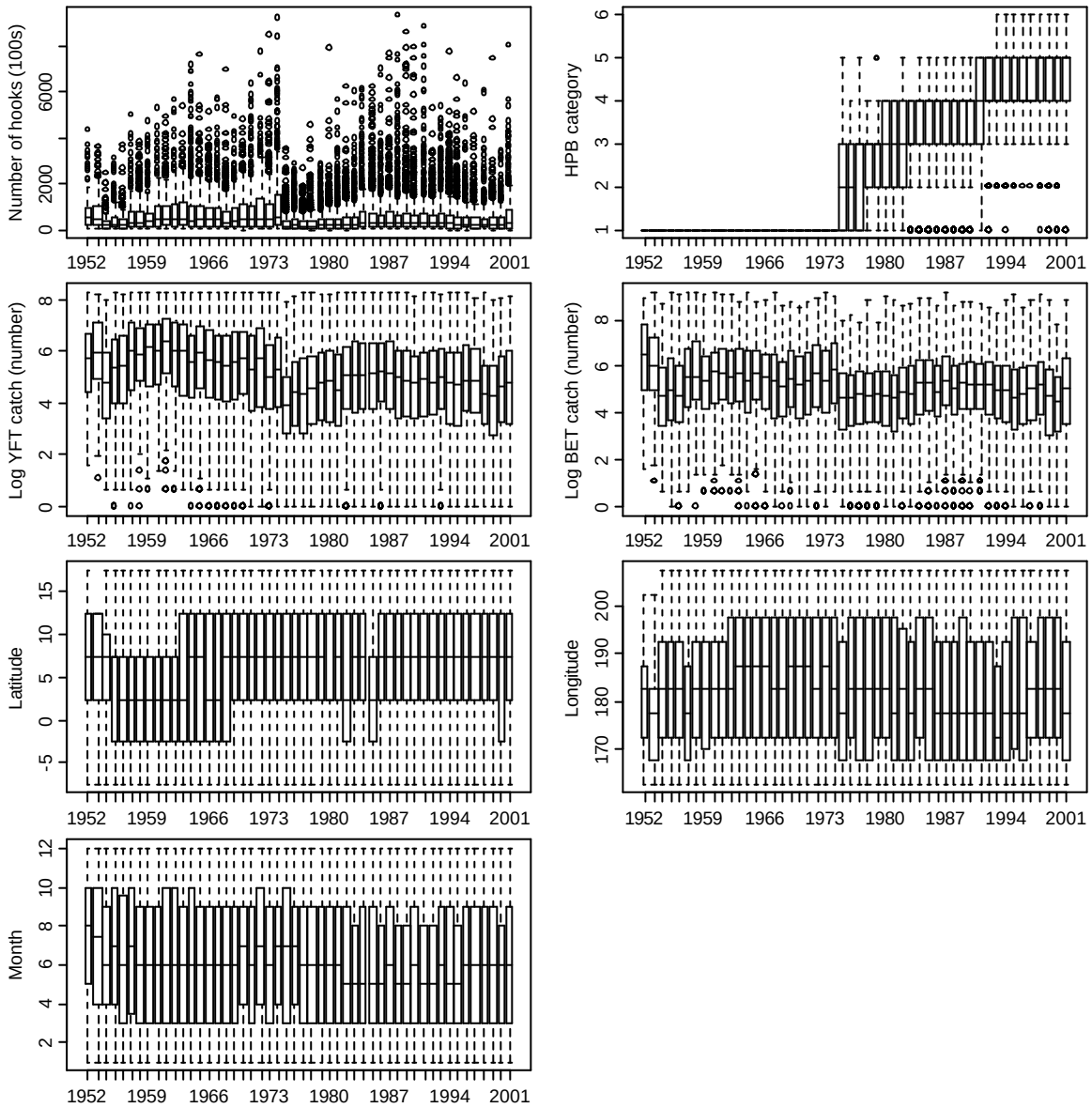


Figure B3: Boxplots of the main variables included in the MFCL area 3 data set by year.

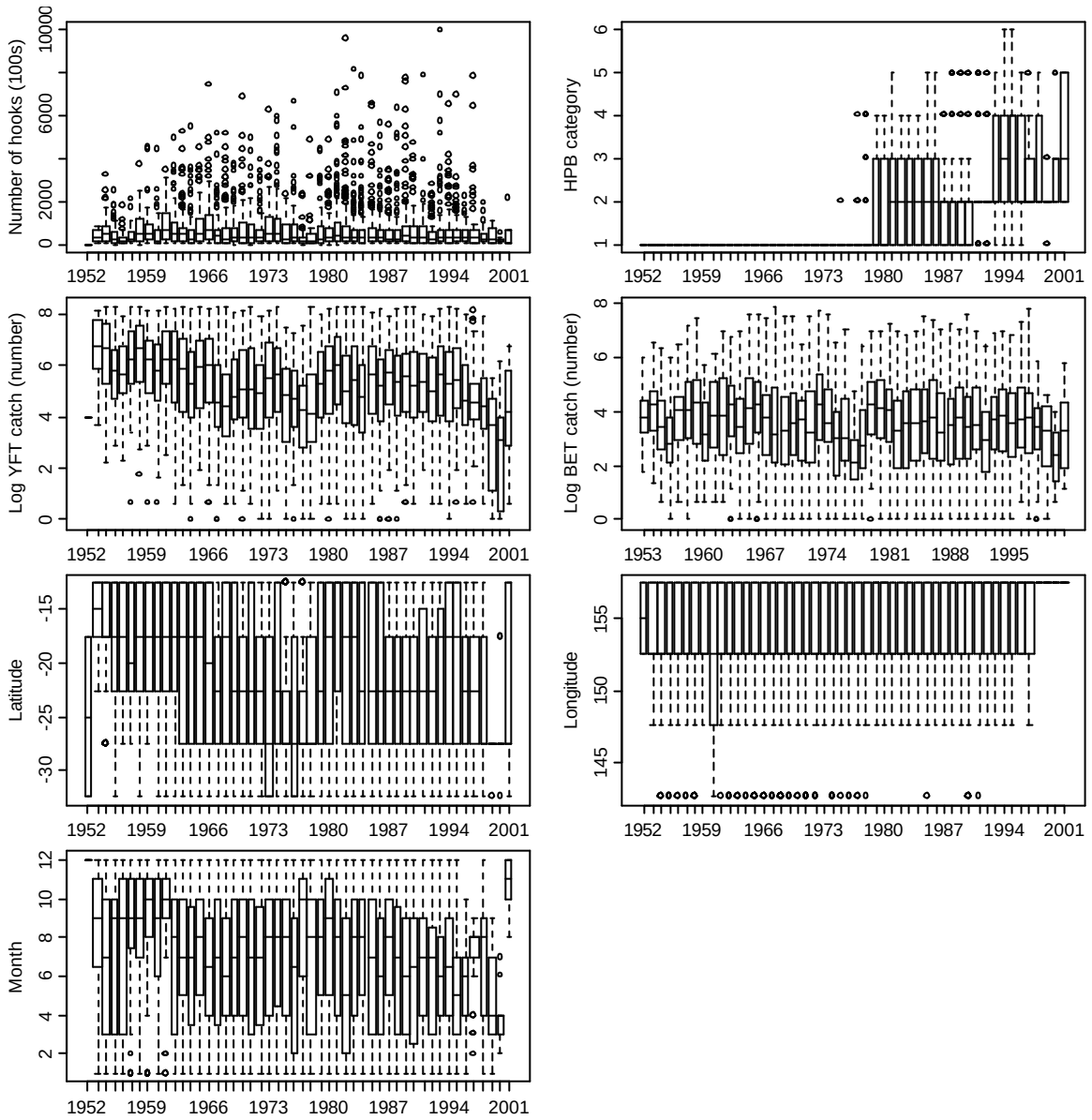


Figure B4: Boxplots of the main variables included in the MFCL area 4 data set by year.

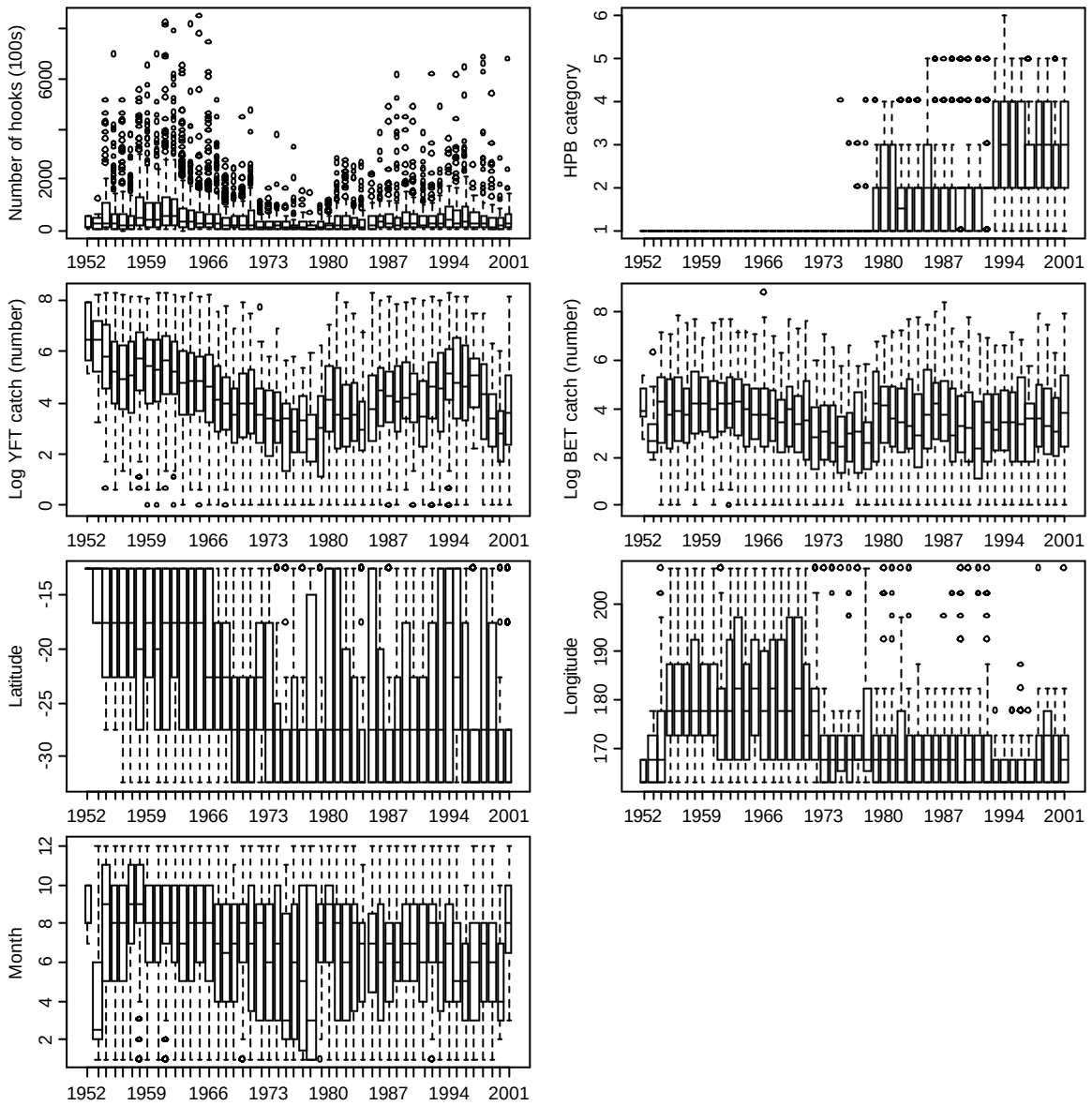


Figure B5: Boxplots of the main variables included in the MFCL area 5 data set by year.

Appendix 3. Major ocean currents in the Pacific Ocean.

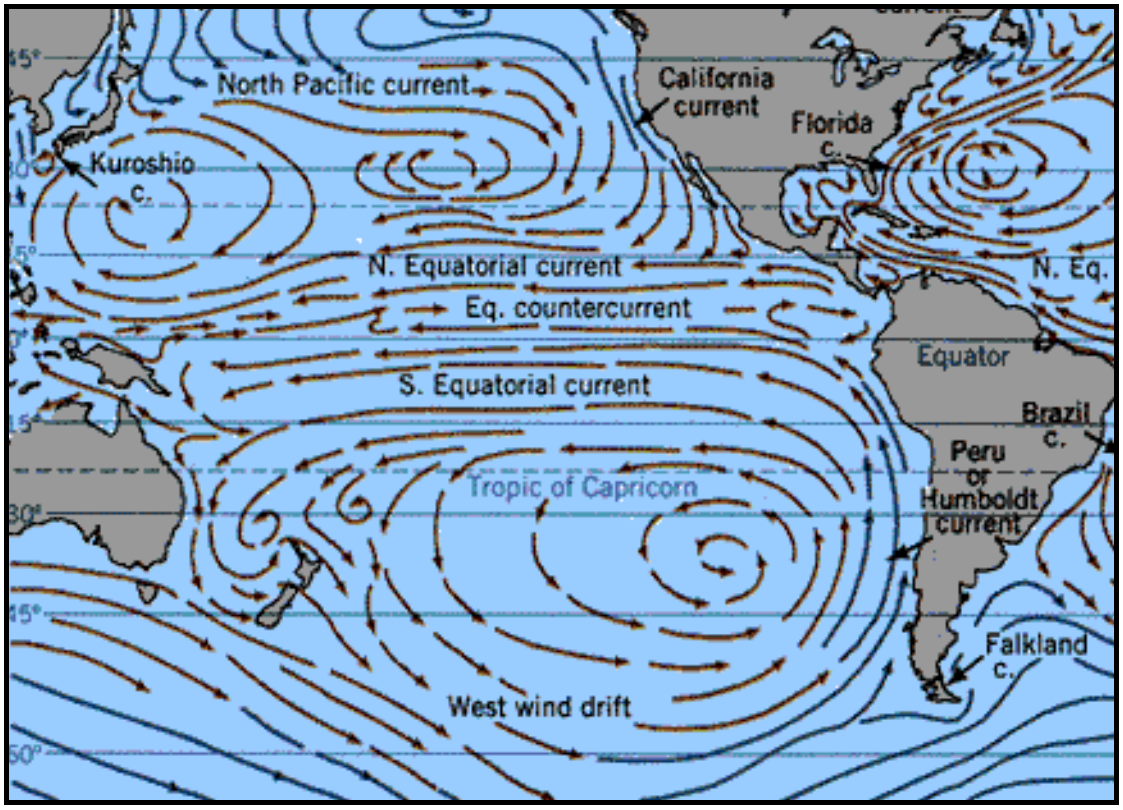


Figure C1: Major ocean currents (source: US Navy Oceanographic Office).