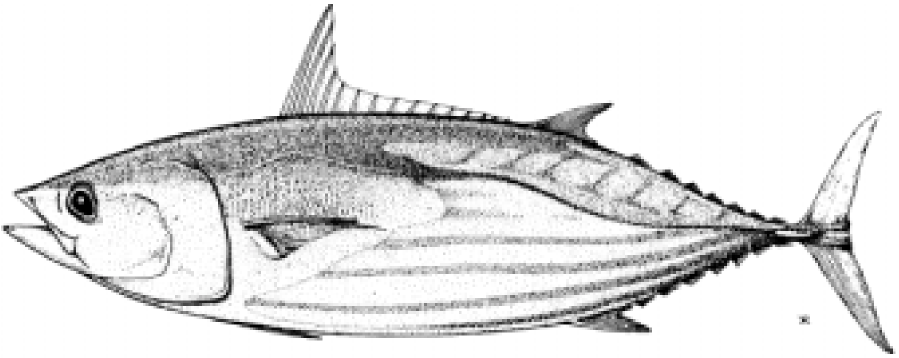
SCTB17 Working Paper

SA-6

17th Meeting of the Standing Committee on Tuna and Billfish

SCTB 17
Majuro, Marshall Islands
9-18 August 2004

A spatially based analysis of purse-seine skipjack CPUE from unassociated sets in the equatorial area of the WCPO, including the development of an oceanographic model for the fishery.



Adam Langley

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

July 2004

1.0 INTRODUCTION

The current WCPO skipjack stock assessment is conducted using a spatially disaggregated age structured model implemented in MULTIFAN-CL (Langley et al. 2003). The WCPO region is divided into six sub-regions in the stock assessment. Most of the annual skipjack catch is taken within the two equatorial regions, regions 5 and 6, and the stock assessment indicates these two regions account for about 90% of the total stock biomass in recent years (Langley et al. 2003).

The current stock assessment indicates skipjack biomass in regions 5 and 6 increased considerably in the late 1990s and current biomass levels are at historically high levels. The assessment model attributes the recent high biomass levels to exceptionally high recruitment in recent years. However, since the early 1990s, no direct estimates of exploitation rate are available from the equatorial area of the fishery, as previously provided from the results of large scale tagging programmes. For the recent period, the model is reliant on the available catch and effort data from the main area/method fisheries operating in these areas and from the associated length frequency data.

The stock assessment model attempts to estimate temporal changes in catchability for each area/method fishery, although in the absence of other data from the fishery, there may be insufficient information to resolve whether changes in catch rate are attributable to changes in catchability, changes in vulnerable biomass, or a combination of both. This paper examines a number of techniques for analyzing of catch and effort data from the unassociated (free-school) skipjack purse-seine fishery in the equatorial WCPO. These exploratory analyses may provide future directions for the interpretation of CPUE data to derive a more reliable index of stock abundance of skipjack tuna.

2.0 METHODS

The analysis applied a cluster analysis to logsheet data from the purse-seine fishery to identify the principal fishing areas (“patches”) for each month from 1998 to 2002. The clustering approach was then applied to a longer time-series of catch and effort data to calculate monthly spatially-based indices of CPUE for the WCPO skipjack fishery.

A generalized linear model was also developed, incorporating oceanographic data, to predict the magnitude of the total skipjack catch taken from each of the main patches identified in the initial cluster analysis. The resulting model was then used to predict the relative level of skipjack biomass vulnerable to the unassociated purse-seine fishery over the area of the equatorial WCPO. This predicted distribution was compared to the monthly distribution of fishing activity from each sector of the purse-seine fleet.

2.1 Cluster analysis

The cluster analysis included all logsheet records of fishing activity (fishing and searching) data from purse-seine fishery from United States, Korean, and Taiwanese vessels operating within the equatorial area (10°S to 10°N) of the WCPO between 1998 and 2002. These three data sets represent the most comprehensive coverage of the WCPO fishery. The data set was further limited to exclude records from individual purse-seine trips that included a significant component of fishing associated with drifting FADs (greater than 20% of all sets from the trip). The data set included 76,342 logsheet records, 72% related to purse-seine sets and 28% to searching activity. An average of about 1,300 records were included within each month (Figure 1). The main area encompassed by the fishery is presented in Figure 2. For these three fleets, the core area of the fishery is between longitude 150°E and 180° and latitude 5°S and 5°N.

A cluster analysis was applied to each month of fishing activity. The analysis was implemented in R using a partitioning around mediods approach (pam function). The approach requires a fixed number of clusters to be defined for each monthly time-step. The number of clusters was fixed at 30. An examination of alternative numbers of monthly clusters (within a reasonable range i.e. 20–40) indicated that this variable had no impact on the results of the subsequent analysis.

For each monthly cluster (5 years * 12 months * 30 clusters), the total catch of skipjack taken by the three fleets, the total number of days fished (searching and sets), the total number of sets, the minimum and maximum calendar days of fishing, and the number of vessels fishing was determined. The central location of each cluster, latitudinal and longitudinal range, and the approximate area of each cluster (in km^2) were also calculated.

The clustering approach assigns every record to a cluster. Consequently, numerous clusters are generated that do not represent patches of fishing effort, but rather are large spatial clusters including dispersed logsheet records, usually with a relatively small number of records (less than 10) (Figure 3). Initial examination of all clusters resulted in the definition of some range checks to limit the clusters to those that contained aggregated fishing effort. The criteria for selecting an individiual cluster were as follows;

Variable	**Range**	**Comment**
Area of cluster	< 77,000 km^2	Approximately less than the area of 2.5 deg lat/long square.
Number of records	> 10	Avoid clusters with small sample or disaggregated (dispersed) fishing activity.
Longitudinal range of cluster	< 4 deg	Minimise longitudinal extent of cluster.
Longitudinal range of cluster	< 4 deg	Minimise longitudinal extent of cluster.

2.2 Spatially based CPUE indices

The equivalent clustering approach described in Section 2.1 was applied to catch and effort data from the United States, Taiwanese, and Korean fleets from the period 1990 to 2004. For the latter two fleets, data prior to 1994 were excluded due to unreliability of logsheet catch estimates.

For each month, an area weighted index of skipjack CPUE was determined based on the following formulae.

$$CPUEm = \sum_{i}^{nclust} \left(\frac{catch_i}{effort_i} * area_i * days_i \right)$$

Where:
$CPUEm$ is the monthly CPUE index;
$nclust$ is the number of qualifying clusters in the month (m);
$catch_i$ is the total skipjack catch (in mt) from cluster$_{i,m}$;
$effort_i$ is the total number of days fished (including searching) by vessels within cluster$_{i,m}$;

$area_i$ is the area (km^2) of cluster$_{i,m}$;
$days_i$ is the duration over which fishing occurred (calendar days) in cluster$_{i,m}$;

The resulting monthly indices were compared with nominal CPUE indices (catch per day fished) for the equivalent fleet operating in the equatorial area of the WCPO.

2.3 Oceanographic model

A model was developed to relate the magnitude of skipjack catch taken from individual clusters (as defined in the Section 2.1) with the prevailing oceanographic conditions.

A series of oceanographic variables were derived for the equatorial WCPO fishery, stratified by month 2° lat/long for 1998–2002. These variables were determined from various oceanographic data sets listed in Table 1. The relatively broad spatial and temporal scale of the oceanographic data (generally 1–2° of latitude/longitude by month) limited the resolution of the analysis. On this basis, variables describing the prevailing oceanographic conditions were derived for each month for individual 2° squares of latitude and longitude within the core fishing area. The variables included sea surface temperature, thermocline depth, temperature at 155 m depth, chlorophyll-a concentration (sea colour), sea surface height anomaly (SSHA, altimetry data), and current flow. For most variables, the average and range of values from each month * 2° lat/long strata was calculated. A full list of the oceanographic variables is given in Table 2.

Individual records of qualifying clusters were linked to the respective month * 2° lat/long strata based on month and location.

A generalized linear modeling approach was implemented using the stepAIC function in R. The model was developed to predict the total catch of skipjack from individual clusters (could look at weighting by number of vessels). The dependent variable was the natural logarithm of the skipjack catch (in mt). A small nominal catch (0.1 mt) was added to each catch observation to avoid the inclusion of null catch values (two records only).

Potential explanatory variables (see Table 2) were included in the model using a stepwise procedure (forward/backward) and the improvement of each model was assessed using Akaike's Information Criterion (AIC) at each iteration. Most of the continuous variables were included in the model as second order polynomial functions, although an initial examination of some of the data revealed the relationship between the dependent variable and latitude and longitude was adequately described by a simple linear function.

2.4 Model predictions

The oceanographic model developed described in the previous section was assumed to provide an indication of the relative catchability of skipjack in relation to the main variables included in the model. This model was applied to predict the relative catchability of skipjack tuna for each monthly 2° lat/long strata within the equatorial region of the WCPO based on the variables included in the oceanographic data set described in the previous section.

Initially, the area for the model predictions included the longitudinal range 148°E to 170°W and the latitudinal range 10°S to 8°N. However, this area extended beyond the geographical range of most of the observations and the range was subsequently limited to the core area of the fishery (longitudes 150°E to 180° and latitude 5°S to 5°N). This area included a total of 90 2° lat/long strata.

For each month, the individual 2° lat/long strata were ranked according to the relative catchability of skipjack tuna predicted from the oceanographic model. Individual logsheet records (all records from non FAD trips) from each fleet were assigned to their respective 2° lat/long strata and the proportion of the effort records in the strata with the higher predictions of skipjack catchability was determined. This was expressed as the proportion of total monthly effort in the top 20, 40, and 60 strata. For each fleet, the trend in the proportion of the total fishing effort included within the higher ranked strata was examined.

3.0 RESULTS

3.1 Cluster analysis

Overall, about 45% of the 30 clusters per month met the criteria for definition as an area of principal fishing activity (Figure 4). The data set included 36,003 fishing days (47% of total) and 853,000 mt of skipjack catch. Total area of all clusters approximated 20 million km^2 for all months combined.

There was a general increase in the number of clusters and the proportion of monthly records within clusters from early 1998 to 2000 (Figure 4 and Figure 5). The spatial stratification of the fishery, imposed by the cluster analysis, remained relatively constant from 2000 to early 2002, but there was a sharp decline in both the number of clusters and the proportion of the effort within core clusters in late 2002 (Figure 4 and Figure 5).

The principal fishing areas yielded considerably higher catch rates of skipjack than the outer areas and a revealed different temporal trend in nominal catch rates (Figure 6). Trends in the overall catch rate from the fishery were driven by the trends in catch rate from the core areas (Figure 6). Despite these areas accounting for only 47% of the effort they accounted for 62% of the total skipjack catch included in the data set.

Overall, the total area included within the principal fishing areas remained relatively constant from 1998 to early 2002, at about 400,000 km^2 per month (Figure 7). This equates to approximately 10% of the core area of the equatorial WCPO fishery (about 3.7 million km^2 within an area delineated by longitudes 150°E to 180° and latitude 5°S to 5°N). There was a general decline in the average area of individual clusters between 1998 and 2000 (Figure 7), while the number of clusters increased during the same period (Figure 4).

In 2002, there was a sharp decline in the total area included within the principal fishing areas consistent with the decline in the number of qualifying strata, although this was partly compensated by an increase in the median area of the selected strata (Figure 7).

There was considerable variation in the density of both fishing effort and skipjack catch in the principal fishing areas over the study period (Figure 8).

3.2 Spatially based CPUE indices

The spatially-based indices derived for 1990 to 2003 reveal high variation in the skipjack CPUE over the time period, with periods of low catch rates associated with El Nino events in 1992, 1994, 1997-98, and 2002 and higher catch rates in La Nina conditions (1996, 1991-2001) (Figure 9). There is no overall trend in the CPUE indices over the entire time period, although CPUE indices were generally higher between 1999 and 2003 compared to the earlier period (Figure 9). This appears to be the mainly attributable to the frequency of El Nino events during the two periods.

The indices are broadly similar to the nominal indices derived from the catch and effort data from the same sector of the fleet, although the magnitude of the variation in the nominal CPUE indices is considerably less than for the spatially-based index (Figure 9).

3.3 Oceanographic model

The oceanographic model explained 29.2% of the observed variation in the skipjack catch from the clusters defining the principal fishing areas (determined from the cluster analysis). The main explanatory variables were year and month followed by 10 different oceanographic variables and the latitude of the cluster (Table 3). The oceanographic variables included a number of variables related to water temperature at the surface, the depth of the thermocline, current flow, and chlorophyll-A concentration. Overall, these variables accounted for about 50% of the explained variation (Table 3).

The model predicts that skipjack catches increased with decreasing sea temperature at 155 m, probably relating to a more restricted vertical distribution of skipjack and, consequently, greater catchability of the species to purse seine gear (Figure 10). Catches increased with an increase in the range of the depth of the thermocline (Figure 10). This variable may indicate the presence of a “front” between two water masses resulting in the aggregation of species and increasing the vulnerability to purse-seine gear.

Skipjack catches were generally highest associated with areas of moderate primary productivity (as indexed by chlorophyll-A concentration) and lower at the extremes in the observed range of average chlorophyll-A values (Figure 10).

Catches were predicted to be highest when current flows were general in an easterly direction in the area west of the cluster, while catches were higher when north/south flows were neutral or converging (Figure 10).

3.4 Model predictions

The oceanographic model consistently predicted the areas of highest skipjack catchable biomass to be in the northeast of the study area (east of 180° and north of the equator) (Figure 11). However, there are very few observations of high catch clusters from this area and confidence in these predictions is low (high standard errors). Similarly, predictions of high catchability for skipjack were derived from the southwest of the study area, despite few actual observations of high catches in this area (Figure 11). Therefore, for the purpose of comparing the actual distribution of fishing effort, the model predictions were limited to the core area of the fishery (longitudes 150°E to 180° and latitude 5°S to 5°N). There were few extreme predictions (low or high catchable biomass) from within this area (Figure 11) and model predictions had a higher associated level of confidence.

The model predicts that in 1998 a high proportion of the fishing effort by the Korean, Taiwanese, and Japanese fleet occurred in the cells predicted to have the highest catchability for skipjack (Figure 12 and Figure 13). For these fleets, there was considerable seasonal variation in the proportion of effort in the most preferred cells over the subsequent two years, with effort in the preferred cells peaking in the third quarter of the year. During 2001 and 2002, a higher proportion of the overall effort from these fleets was allocated to the preferred cells throughout the year (Figure 12 and Figure 13).

Limited data were available to undertake a similar analysis for the United States fleet, although in recent years the proportion of effort occurring in the more preferable cells was generally lower than for the other fleets (Figure 13).

The recent increase in fishing in the preferred cells may represent an increase in the efficiency of the fleet in locating the areas of higher skipjack catchability. However, some of the observed trends may simply be due to the limitations of the predictive power of the model. The higher model predictions in the northwestern area appear to correspond to periods of strong westward current flow, while few actual observations of high catch corresponded to these events (for example see Figure 14). This may account for the low proportion of effort allocated to the cells with high predicted catchability in early 1999 and early 2000; two periods that exhibited conditions of strong westward flow in the equatorial area.

4.0 DISCUSSION

The cluster analysis reveals that a high proportion of the monthly skipjack tuna catch from the unassociated purse-seine fishery is taken from a relatively small area and that fishing effort is concentrated in these areas. Catch rates from these areas are high and dominate overall trends in catch rate from the fishery. The potential for effort to be increasingly concentrated in these more preferable areas is likely to result in “hyperstability” of the nominal CPUE from the fishery (Hilborn and Walters 1992). This undermines the assumption of proportionality between nominal CPUE and stock abundance and, thereby, reduces the utility of CPUE data in providing a reliable index of stock abundance.

This paper considers alterative methods for interpreting catch and effort data to develop some basic performance indicators for the WCPO purse-seine fishery. These include determining the spatial extent of the main area of the fishery and extent of the aggregated fishing operations. Further development of this spatially-based approach may enable catch and effort data from the purse-seine fishery to derive a more reliable index of stock abundance for skipjack tuna. Such an approach would integrate the spatial and temporal distribution of fishing effort and the relative density of skipjack within the core areas fished to determine an area weighted estimate of the relative density of skipjack tuna. The calculation of spatially-based indices of relative abundance from the unassociated purse-seine fishing data would require consideration of the following points.

a. Determination of the number of clusters representing areas of high skipjack catchability (inferred from cluster analysis).
b. Determination of the density of skipjack within each cluster (inferred from catch rates).

c. Determination of the spatial extent of each cluster (mapped by the distribution of fishing effort).
d. Determination of the temporal extent (duration) of each cluster (duration of fishing activity in the cluster).
e. Proportion of biomass inside/outside clusters (assume constant or potentially develop oceanographic model to predict temporal changes in catchability).
f. The sensitivity of the indices to the total amount of effort in the fishery and in individual clusters (short-term depletion due to high levels of catch).

A number of additional factors requiring consideration in such an analysis are described in Hilborn and Walters (1992). These principally relate to aspects of fleet behaviour that will influence CPUE even on a small scale, including efficiency of search, handling time, and interaction between vessels.

The successful application of the above approach would require an underlying assumption that the fleet's ability to locate significant aggregations of skipjack has not increased significantly over time and that there has been no significant increase in fishing power of the vessels operating within a cluster. It also assumes that there has been no shift in the minimum density and areal/temporal scale of the fish aggregations the fleet is capable of fishing. These assumptions are likely to be violated to some extent. However, the biases may be considerably less than the effect of using nominal catch and effort data without attempting to account for the high level of hyperstability attributable to the concentrated targeting behaviour. More detailed analyses of the operation of the fishery at a fine scale may enable refinement of some of the variables that are likely to have influenced catchability (fishing efficiency) over the history of the fishery.

The results of a preliminary spatially-based analysis are presented in the current paper. The analysis attempted to account for the first four points in the above list, but did not consider trends in the fine scale CPUE at the level of the individual cluster. It is proposed to undertake further analysis of the factors influencing catchability at the operational level of the fishery, although this will be limited by the available data from vessel logsheets augmented, where possible, by observer data.

The development of an oceanographic model has provided some insight into the factors that influence the location of areas of higher skipjack catches. The current model has relatively low explanatory power and may be improved with alternative parameterisation of some of the oceanographic variables and incorporation of data from other sources, for example estimates of skipjack biomass derived from a spatial environmental population dynamic model (SEPODYM) (Lehodey 2003). The application of an oceanographic model to compare the distribution of fishing effort relative to the areas of highest vulnerable skipjack abundance may provide insights into changes in fleet efficiency, principally in regard to the ability to locate areas of highest abundance.

References

Hilborn, R.; Walters, C.J. (1992) Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall. 570 pp.

Langley, A.; Ogura, M.; Hampton, J. (2003). Stock assessment of skipjack tuna in the western and central Pacific Ocean. Working Paper SKJ-1. Sixteenth meeting of the Standing Committee on Tuna and Billfish, 9–16 July 2003, Mooloolaba, Australia. Secretariat of the Pacific Community, Noumea, New Caledonia. 46 pp.

Lehodey, P. (2003). SEPODYM application to skipjack tuna (*Katsuwonus pelamis*) in the Pacific Ocean: impact of ENSO on recruitment and population. Working Paper SKJ-5. Sixteenth meeting of the Standing Committee on Tuna and Billfish, 9–16 July 2003, Mooloolaba, Australia. Secretariat of the Pacific Community, Noumea, New Caledonia. 16 pp.

Table 1: Sources of oceanographic data used to derive oceanographic variables.

Variable	Resolution		Period	Source
	Temporal	Spatial		
Sea surface temperature	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Temperature at 155 m	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Thermocline depth	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Chlorophyll-a concentration	Monthly	Approx. 1°long, 1°lat	1998 onwards	SeaWiFs http://seawifs.gsfc.nasa.gov/SEAWIFS.html
Current flow	Monthly	1.5°long, 1°lat	All years	NOAA NCEP EMC CMB Pacific
Sea surface height anomaly	10 days approx.	Satellite track	1992 onwards	TOPEX, SSALTO/DUACS http://ibis.grdl.noaa.gov/SAT/hist/tp_products/topex.html

Table 2: Potential explanatory variables included in the skipjack oceanographic CPUE model.

Variable	Description
Year	Year
Month	Month of the year
Latitude	Latitude (nearest degree) of the location of the cluster
Longitude	Longitude (nearest degree) of the location of the cluster
Lat5 * quarter	Interaction between latitude (in 5 degree bins) and quarter
Long10 * quarter	Interaction between longitude (in 5 degree bins) and quarter
SST_average	Average monthly sea surface temperature in 2° lat/longitude.
SST_range	Range of average monthly sea surface temperature in 2° lat/longitude.
Colour_average	Average monthly chlorophyll-a concentration in 2° lat/longitude.
Colour_range	Range of monthly chlorophyll-a concentration in 2° lat/longitude.
Thermocline_depth_avg	Average monthly depth of 27°C isotherm in 2° lat/longitude.
Thermocline_depth_range	Range of monthly depth of 27°C isotherm in 2° lat/longitude.
Temp155	Average sea temperature at 155 m in 2° lat/longitude.
Current	Total monthly current flow (meridional + zonal) in 2° lat/longitude.
Current_north (south)	Total monthly meridional current flow in 5° latitude to the north (south) of 2° lat/longitude cell. Positive values northward flow; negative values southward.
Current_east (west)	Total monthly zonal current flow in 5° longitude to the east (west) of 2° lat/longitude cell. Positive values eastward flow; negative values westward.
Current_NS	Variable describing convergence (positive) divergence (negative) of meridional component of current flow.
Current_EW	Variable describing convergence (positive) divergence (negative) zonal component of current flow.
SSHA_average	Average monthly SSHA in 2° lat/longitude.
SSHA_range	Range in monthly SSHA in 2° lat/longitude.

Table 3: Percentage of variation in logarithm of skipjack catch (t) from each of the clusters comprising the principal fishing area explained at each iteration of the oceanographic model.

Iteration	**Variable**	**R^2 (%)**
1	Year	13.6
2	Month	20.1
3	Thermocline_depth_avg	22.7
4	Current_west	24.3
5	Temp155	25.2
6	Current_NS	26.0
7	Thermocline_depth_range	26.8
8	Colour_average	27.4
9	Current_south	28.0
10	Latitude	28.4
11	SST_range	28.6
12	Current	28.8
13	SST_average	29.2

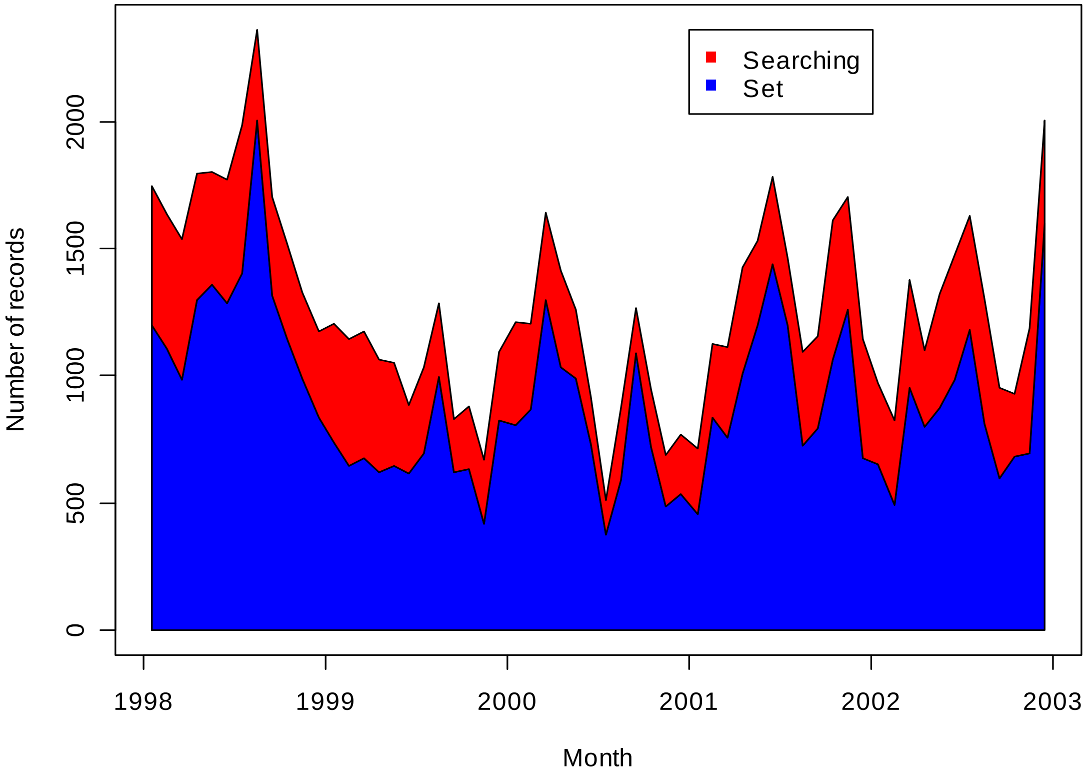


Figure 1: Number of logsheet records (searching and purse-seine set) by month included in the analysis.

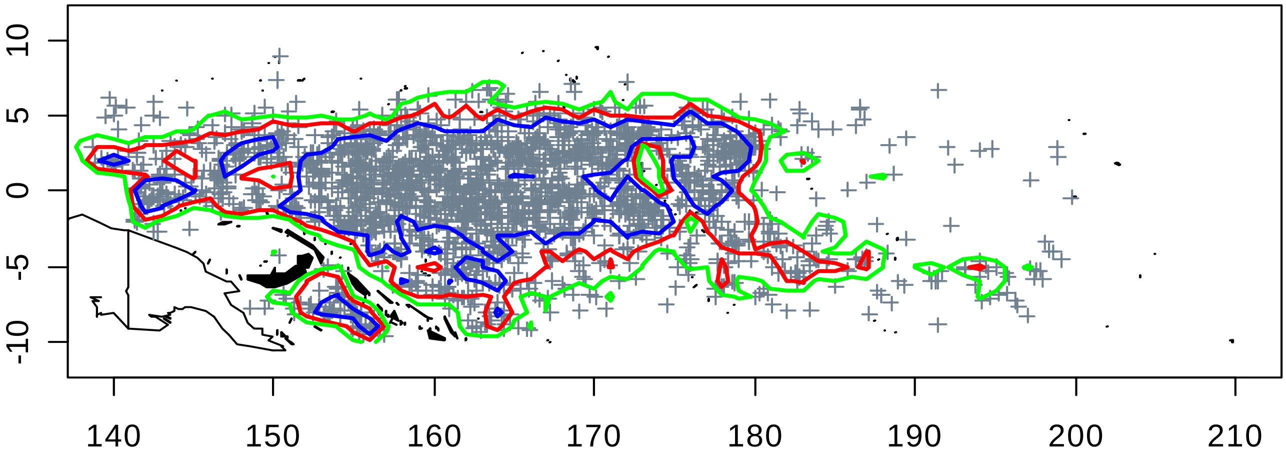


Figure 2: A sample of the purse-seine activity records included in the analysis (gray crosses). The contour lines denote the boundaries of the main fishing area (blue) and the peripheral areas fished during 1998-2002.

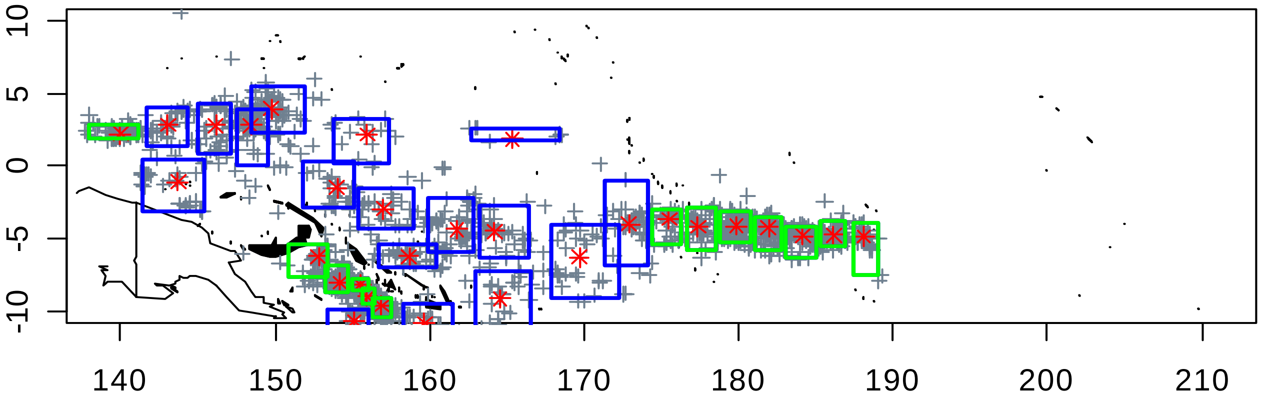


Figure 3: An example of the monthly clustering of individual logsheet records into clusters that meet the criteria (green boxes) and clusters that are excluded (blue boxes). The red stars represent the meroidial centre of each cluster. The boxes represent the approximate boundaries of the clusters only.

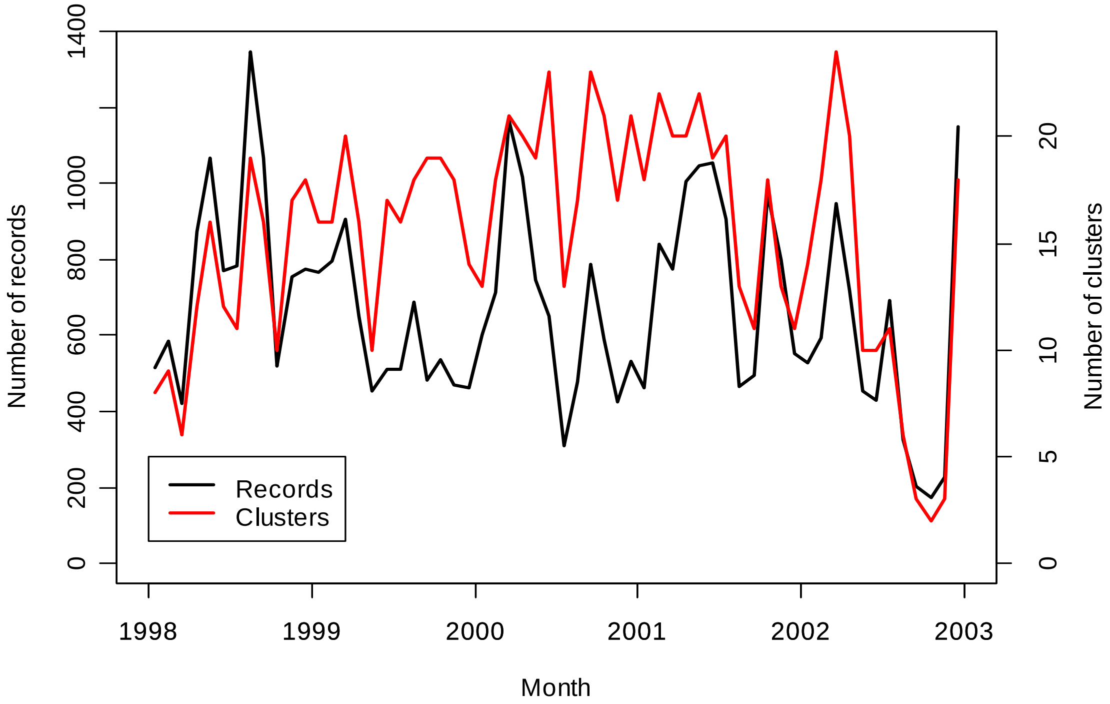


Figure 4: Number of accepted purse-seine logsheet records and number of clusters from the cluster analysis that met the qualifying criteria for definition as a "patch" by month from 1998 to 2002.

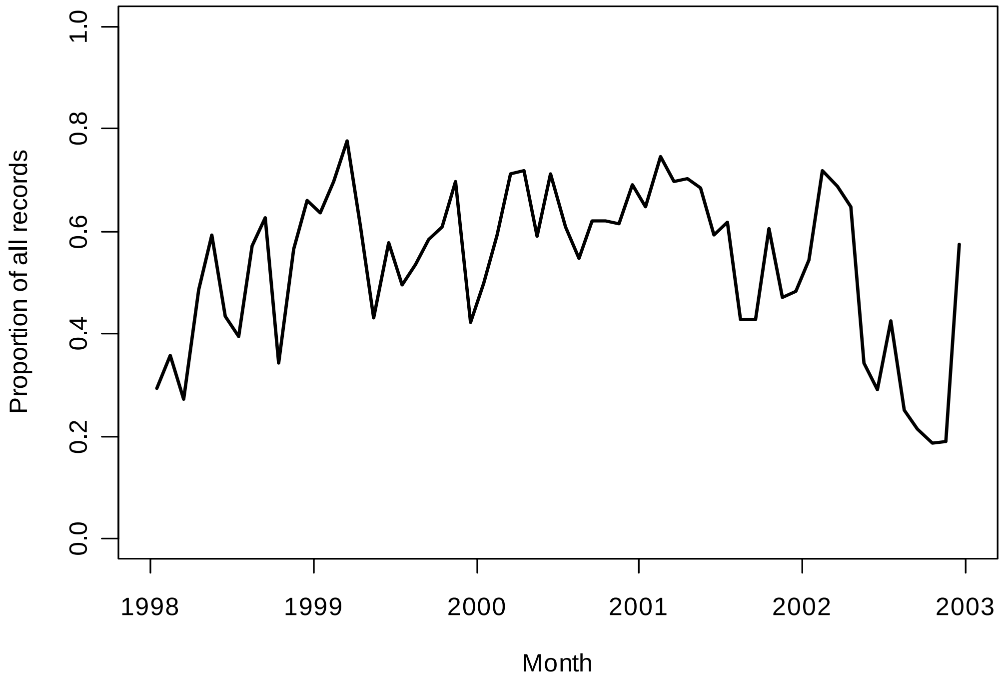


Figure 5: Proportion of all initial logsheet records included in clusters meeting the qualifying criteria by month from 1998 to 2002.

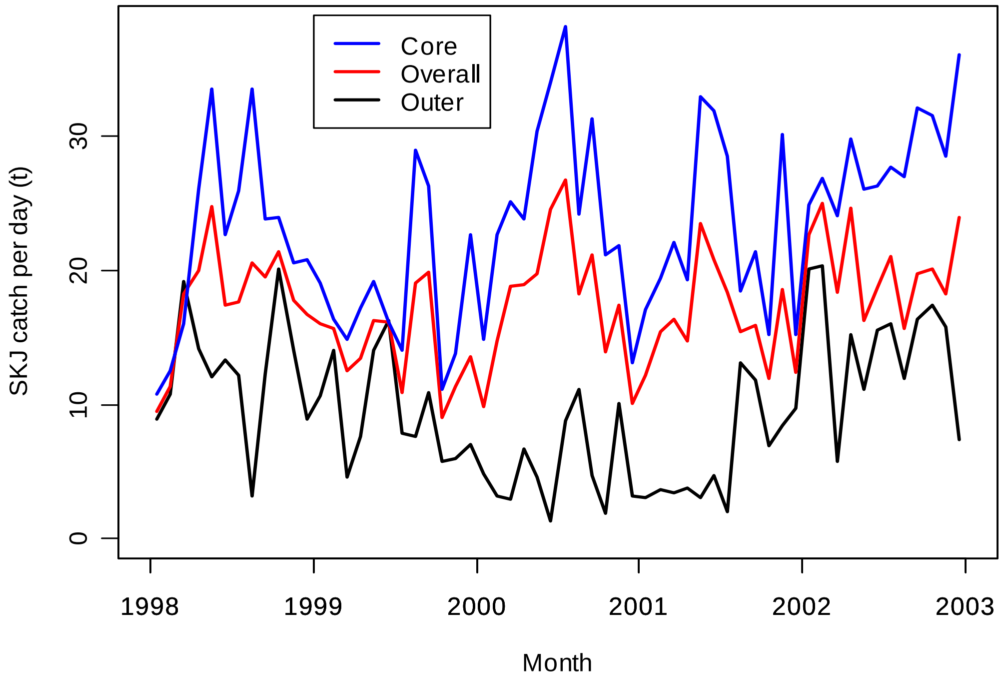


Figure 6: A comparison of skipjack monthly nominal CPUE (mt per day) for the main clusters, outer clusters (not meeting the qualifying criteria), and overall for all areas combined.

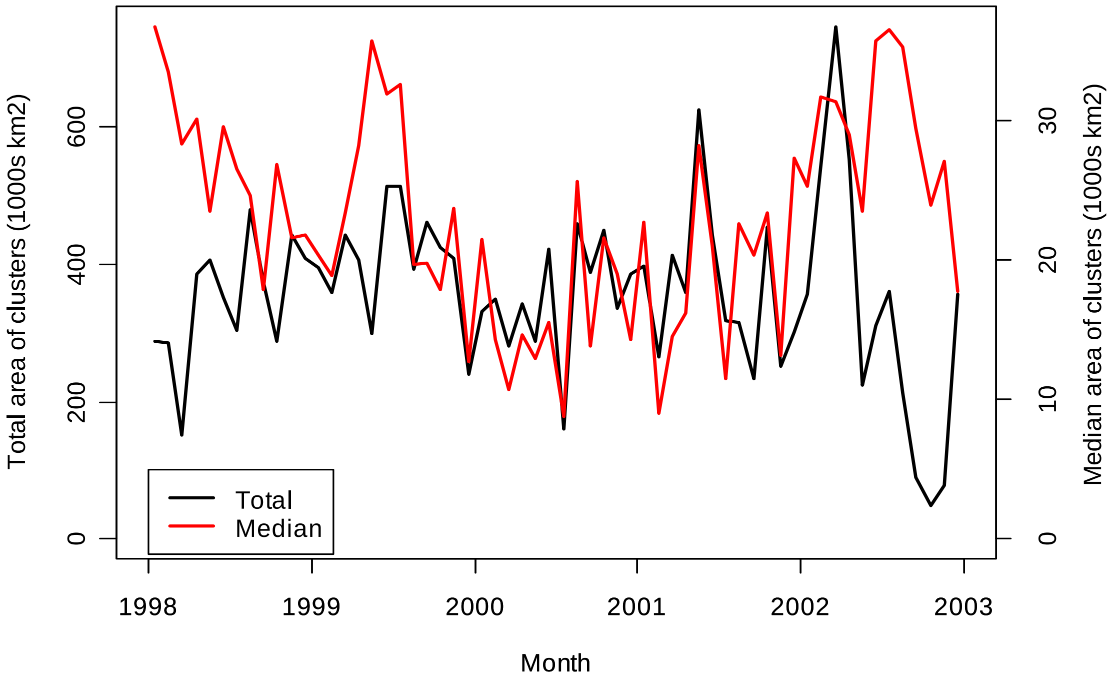


Figure 7: Total and median area (thousands of km^2) of qualifying clusters by month from 1998 to 2002.

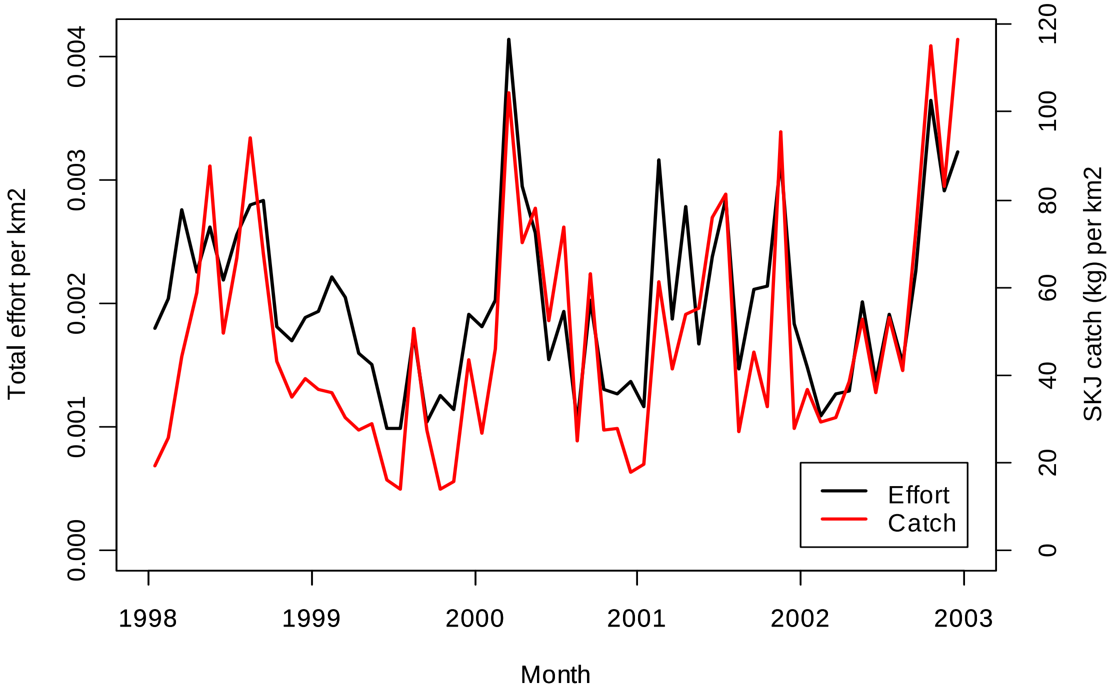


Figure 8: Average density of fishing effort (logsheet records) and skipjack catch (kg) per km^2 from qualifying area clusters by month from 1998 to 2002. Note catch and effort values are for the US, Korean, and Taiwanese fleets only.

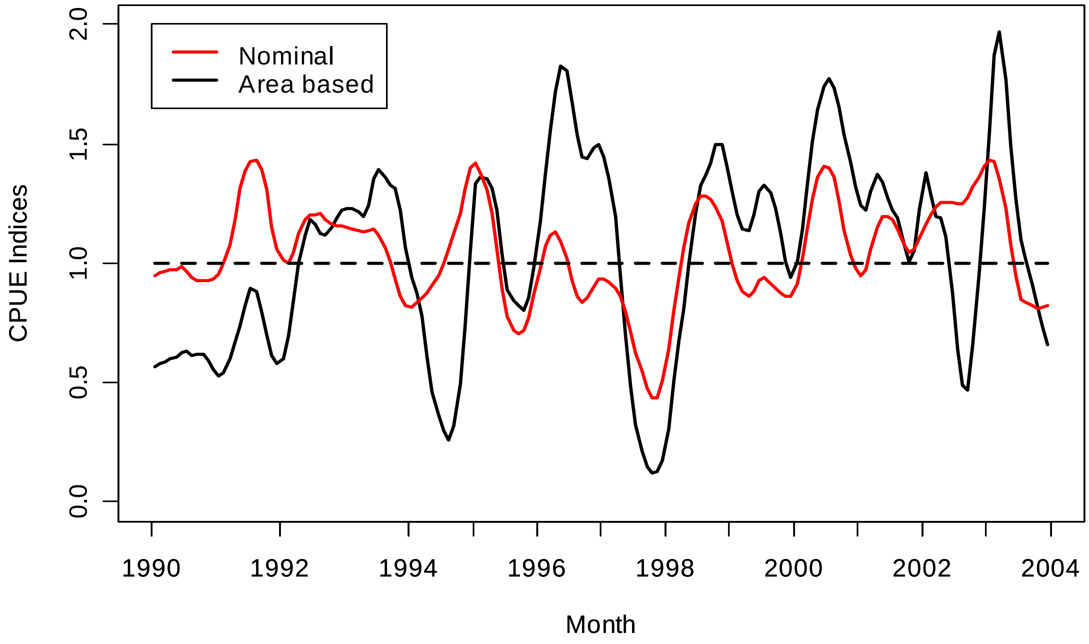


Figure 9: Nominal and area-based monthly skipjack CPUE indices derived from unassociated purse-seine fishing effort from the US, Korean, and Taiwanese fleets combined (logsheet data). Monthly indices were smoothed using a lowess function and scaled to the mean of the respective series. The dashed line represents the mean for both series.

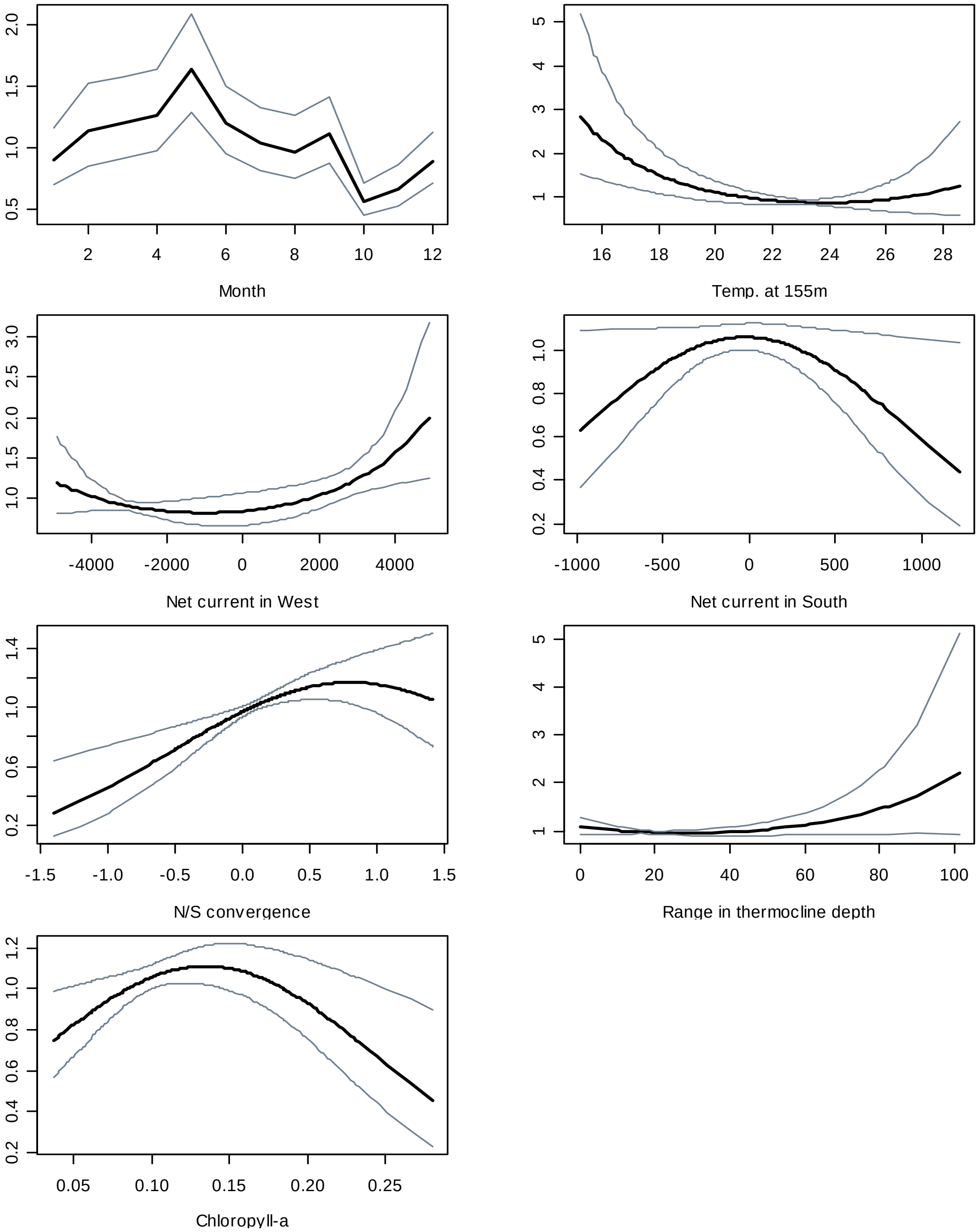


Figure 10: Examination of the parameterisation of the main effects included in the oceanographic model. The y-axis is expressed as relative catch of skipjack tuna per cluster. The confidence intervals (grey lines) represent +/- 2 standard deviations.

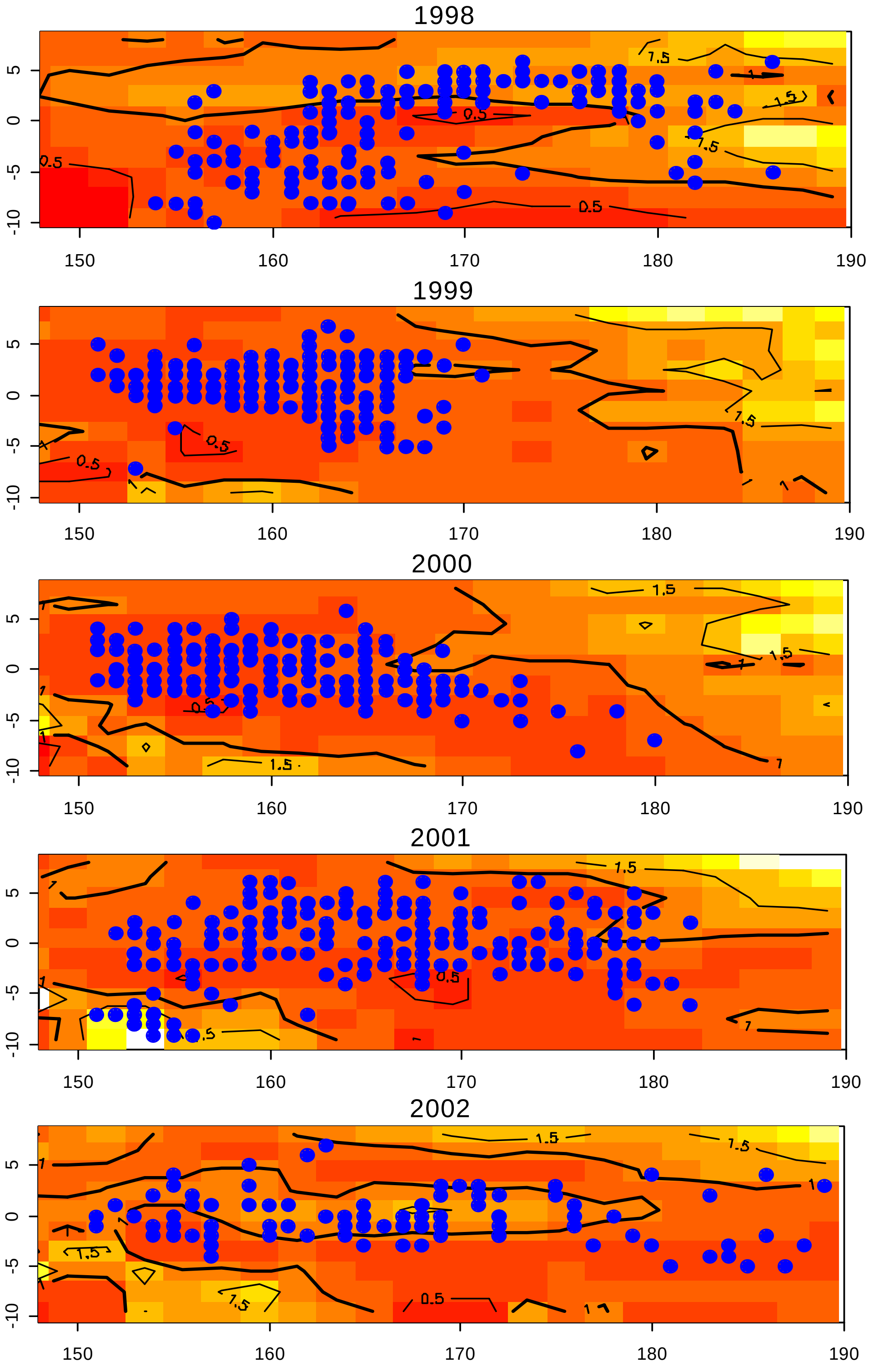


Figure 11: Model predictions (yellow, high; red low) of the relative catchability of skipjack tuna in the equatorial WCPO averaged over each year. The predictions were then scaled to the average for each year. The mean is represented by the heavy contour line. The blue circles represent the location of the individual clusters included in the model.

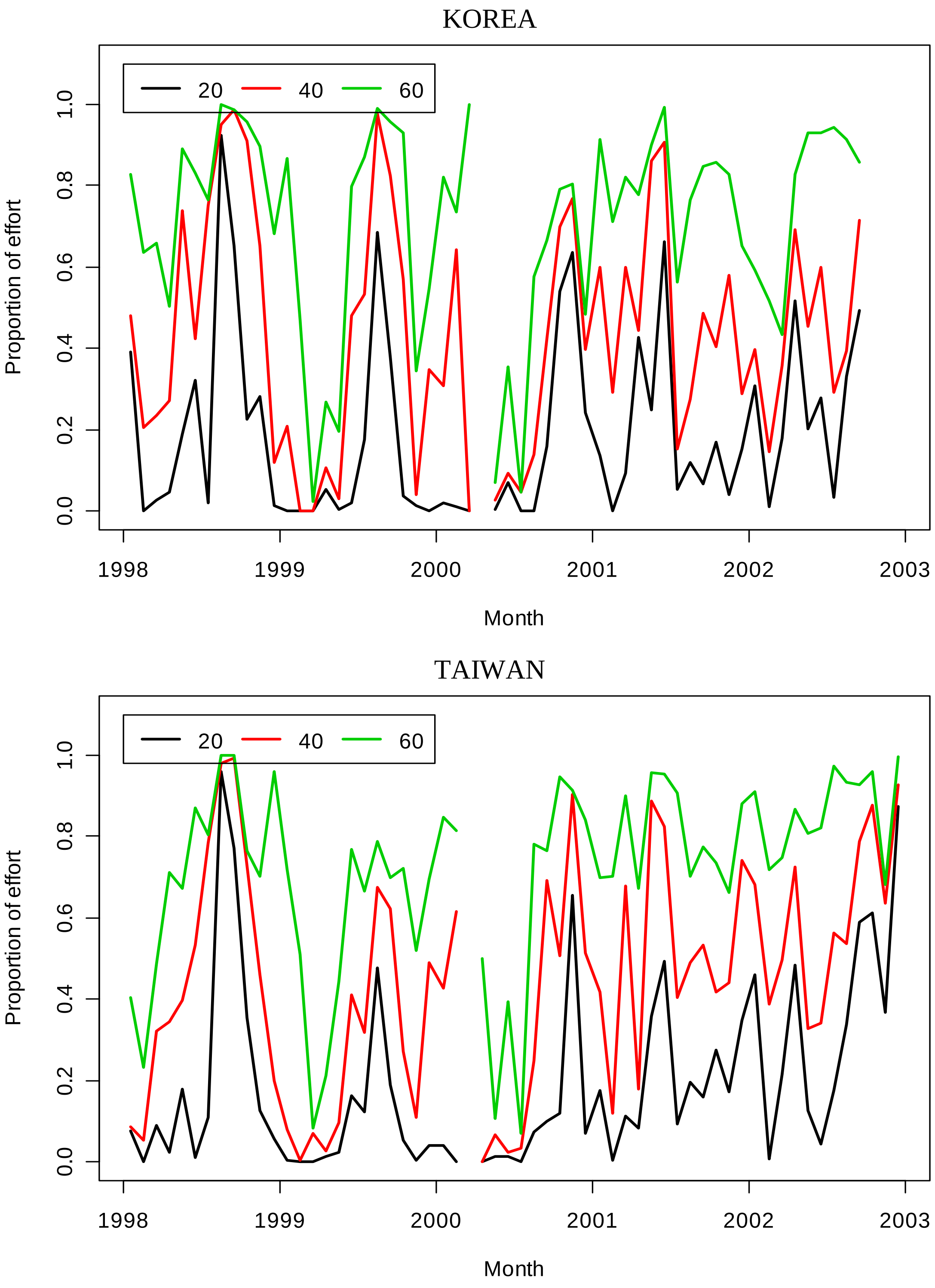


Figure 12: Proportion of total unassociated fishing effort of the Korean (top) and Taiwanese (bottom) purse-seine fleets allocated to the 20, 40, and 60 2 deg lat/long cells with the highest catchability of skipjack as predicted from the oceanographic model by month from 1998 to 2002.

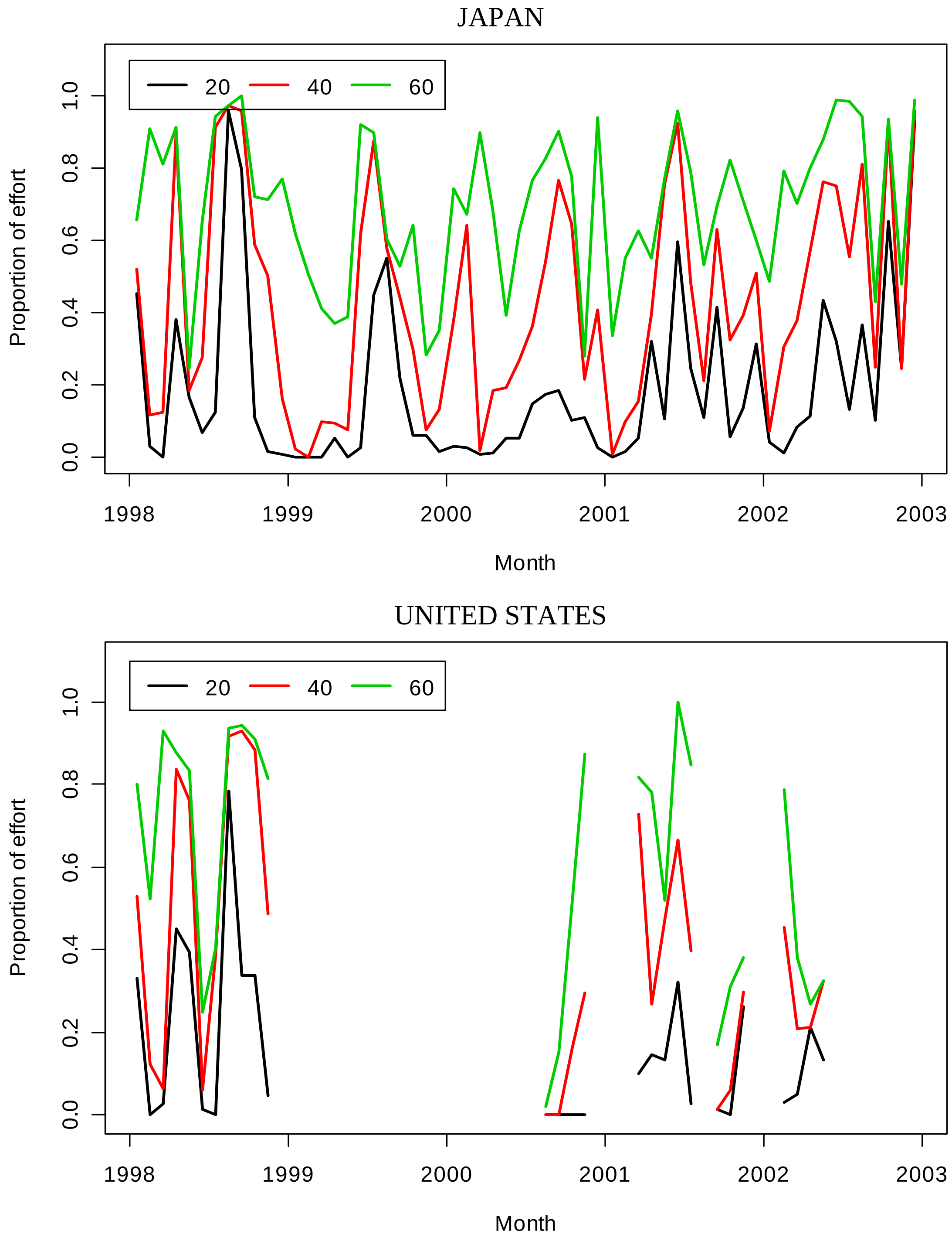


Figure 13: Proportion of total unassociated fishing effort of the Japanese (top) and United States (bottom) purse-seine fleets allocated to the 20, 40, and 60 2 deg lat/long cells with the highest catchability of skipjack as predicted from the oceanographic model by month from 1998 to 2002.

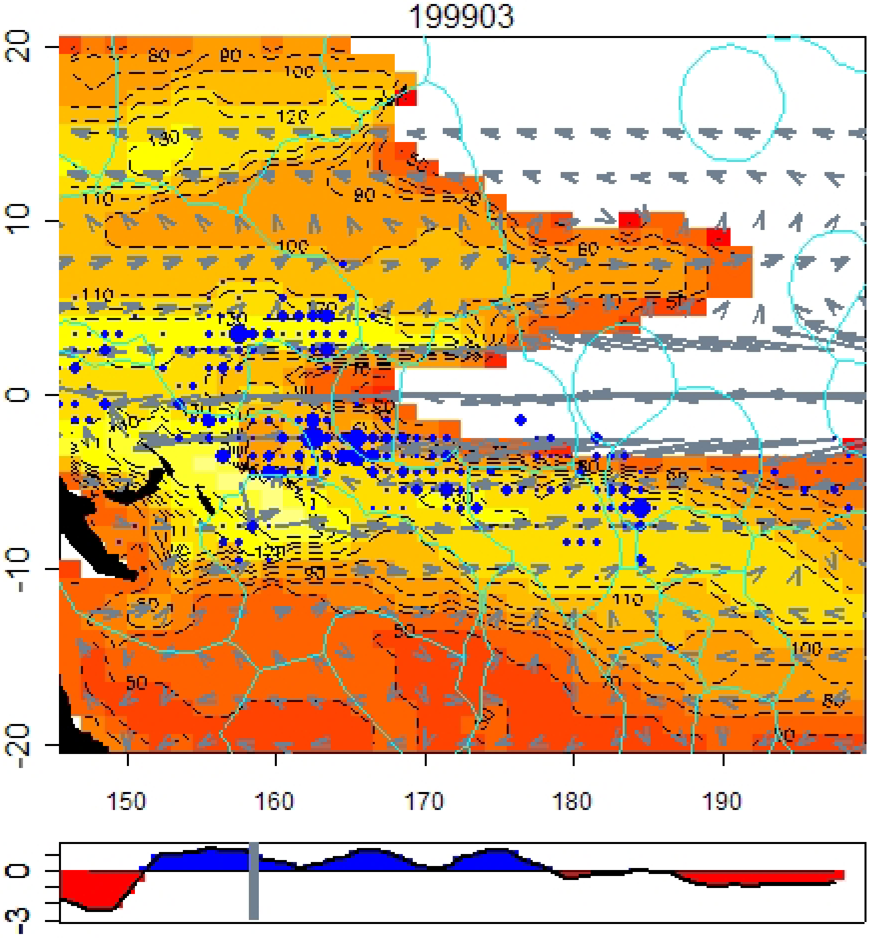


Figure 14: Average depth of the thermocline (red, shallow; yellow, deep) and skipjack catch for the WCPO for March 1999. Contour lines represent areas of equal thermocline depth. The area of the circles is proportional to the monthly skipjack catch from drifting FAD sets by degree of latitude and longitude. The EEZ boundaries are also shown. The bottom panel illustrates the SOI phase. The arrows represent average monthly current flow (at 45 m depth).