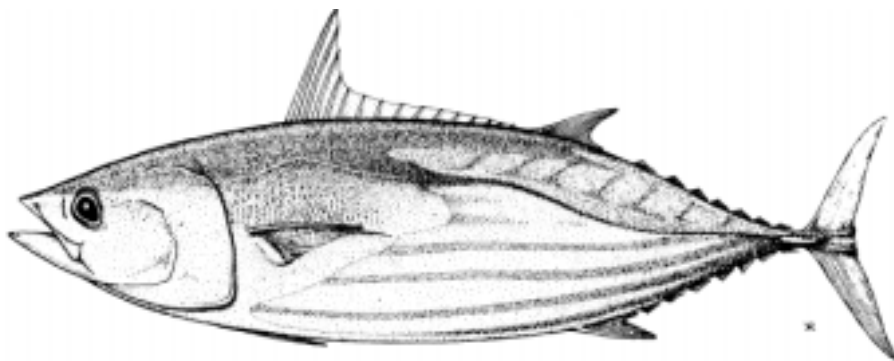


ALB-9



**SEPODYM application to albacore (*Thunnus alalunga*)
in the Pacific Ocean**



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Introduction

Tagging and fisheries data suggest that albacore's distribution in the Pacific Ocean shows separate concentrations north and south of the 5°N-5°S equatorial band, with a large extension to temperate latitude (45°N, 40°S) roughly delineated by the 15°C sea surface temperature (SST) isotherm. Comparatively to other tropical and sub-tropical tuna species (skipjack, yellowfin and bigeye), albacore is characterised by slower growth, lower natural mortality and longer life spans (15-20 years). The first maturity occurs around 4-5 years of age (~ 90 cm), and there is an apparent seasonal spawning (with a peak in summer).

Similarly to the other tuna species, albacore have high fecundity, spawn in warm waters over wide areas and feed upon a similar large spectrum of prey species. Concentrations of albacore larvae were observed in the sub-equatorial regions, between 5 and 25° of latitude with highest densities west of 160°W and west of 130°W respectively in the northern and southern hemisphere. That is roughly associated with water temperature above 24°C in surface. Though there is no direct observation of spawning in the equatorial waters, presence of juveniles (under 200 mm) between 0° and 10°S has been noted by Yoshida (1968, in Foreman 1980).

The recruitment of juveniles occurs in the surface fisheries (troll and pole-and-line) in both north and south Pacific stocks at 2 years of age (~ 40 cm). These surface fisheries occur in sub-tropical waters (e.g., the Sub-Tropical Convergence Zone in the south) and are highly seasonal (during summer), while longline fisheries operate throughout the year in tropical and subtropical waters.

Results of the SEPODYM simulation are evaluated by comparing predicted and observed catch by fishery (at the spatial level), predicted and observed length frequencies distribution of the catch, and predicted biomass and recruitment with independent estimates provided by the statistical population dynamics model MULTIFAN-CL (Fournier et al., 1998; Hampton and Fournier, 2001) for the south Pacific albacore stock.

Environmental variables

Environmental fields used in this application are predicted from a coupled ocean-biogeochemical model as described in the SEPODYM application to skipjack (Lehodey 2003).

SEPODYM

Documentation of the model features is provided in Bertignac et al. (1998), Lehodey et al. (1998), and Lehodey (2001). Additional information on recent developments was provided at the last Standing Committee on Tuna and Billfish (Lehodey, 2002a, 2002b) and is detailed in Lehodey et al. (in press). Below are described the main components and structure of the model.

Population structure

The tuna population is age-structured to account for growth and gear selectivity. Albacore tuna population is described with 60 age classes of 1 quarter (15 years), though the time step of computation has a higher time resolution (one month). The last age class is a “+ group” in which are accumulated the oldest individuals. Four components of the population are recorded: juveniles (1st cohort of age 1 quarter), young tuna (from age 2 quarter to age of 1st maturity), adults (all cohorts after age of maturity) and recruits (cohort at age of recruitment). For albacore, age of first maturity is considered to be 4.5 years (18 quarters) and age of recruitment is two years.

Age and Growth

Growth parameters are based on those estimated from MULTIFAN-CL analyses (Labelle and Hampton, 2003). Length-at-age and weight-at-age relationships for albacore tuna are presented on Figure 1.

Tuna Forage

Given the large spectrum of prey organisms of tuna and the lack of information on their spatio-temporal dynamics, the tuna forage is modeled as a single population (Lehodey et al., 1998; Lehodey, 2001). With the extension of the model to the whole Pacific basin, the parameterization of the forage population has been revised (Lehodey, 2002a, Lehodey et al., in press).

Adult habitat index H_a

The adult habitat index H_a combines the spatial distribution of tuna forage biomass F with an oxygen function (Lehodey 2002b) and a temperature function (eq. 1) defined for each species (Lehodey, 2001). Oxygen and temperature functions are presented on figure 2. H_a is used to constraint the tuna movement and to modulate the natural mortality (see below).

$$\theta_a = 1 / (1 + e^{-0.8 (SST - 15)}) \quad (1)$$

Tuna movement

Tuna movement is described with an advection-diffusion equation. Tuna larvae are passively transported by surface currents during their first quarter of life (as the forage organisms). Then, young and adult tuna movements are constrained by the adult habitat index H_a . The parameterization is the same than for skipjack (Lehodey 2003a) and yellowfin (Lehodey 2003b).

Spawning habitat index H_s and Recruitment

A spawning habitat index (H_s) is used to constrain the recruitment to environmental conditions. At each point of the grid, the number of recruits is given by the product of a recruitment scaling value (R_s) and the spawning habitat index. R_s is used to scale the total biomass to independent estimates from the MULTIFAN-CL model. The spawning habitat for albacore is similar to the one defined for skipjack (Lehodey 2003a) but with a different parameterization of the temperature function. This function is described by a Normal distribution with an average of 26°C and a standard error of 2°C.

Mortality

The total mortality rate (Z) is the sum of natural (M) and fishing mortality (f). The model is age-structured and natural mortality-at-age estimates are those estimated from MULTIFAN-CL (Figure 3). However, these values are expressed in terms of the habitat assuming that the mortality rates are increasing in unfavourable habitat. The parameterization is similar to the one used for skipjack and yellowfin (Lehodey 2003b). The fishing mortality is proportional to the fishing effort, the catchability coefficient of the fishery and the selectivity coefficient for the gear and age (size) considered.

Fisheries

In this first analysis, six fisheries were defined for all the Pacific Ocean. Four longline fisheries following the same definition than for the yellowfin fisheries (Lehodey 2003b): shallow, deep, mixed and unknown longline fisheries. The last two fisheries are the surface troll fishery and the gillnet fishery that operated during the 1980s. Each fishery has one constant catchability coefficient and an age-based selectivity function. The selectivity functions (Fig. 4) are adjusted to obtain predicted length frequency distributions of catch in agreement with the observed distribution. As such observations were not available for the deep longline and the troll fisheries, the selectivity of mixed longline and gillnet were used respectively for these two fisheries. Fishing effort of each fishery vary by month and in space, with a one degree square resolution for the surface fisheries and five degree square resolution for the longline fisheries. However the longline fishing effort has been proportionally redistributed on a one-degree square resolution to match the grid of the model. The catchability coefficients are scaled to obtain estimated catches at the same average level as observed catches.

Results

Recruitment and biomass

Total recruitment and biomass for regions 1 to 3 defined in MULTIFAN-CL application (Fig. 5) are presented in Figure 6 and detailed by region in Figure 7 and 8. The total biomass estimated by SEPODYM is lower than the MULTIFAN-CL estimate and refinement of the scaling value R_s is needed to obtain similar absolute biomasses. However, both SEPODYM recruitment and biomass time series converge with MULTIFAN-CL estimates, showing the same interannual variability in the recruitment that leads to a long-term declining trend of the population biomass during the 80's (Fig. 6). Comparison by region shows the same converging series (Fig. 7 and 8). Most of the biomass comes from the central and equatorial regions (2 and 1 respectively), with the same proportions predicted by both statistical (MULTIFAN-CL) and environmental (SEPODYM) models. The biomass is much lower in the southern region (region 3), with a higher recruitment and biomass predicted to occur in this area from SEPODYM comparatively to MULTIFAN-CL.

When taking into account a shift of two years corresponding to the age of recruitment, it appears that recruitment fluctuates in opposition to the recruitment of skipjack (Lehodey 2003a) and yellowfin (Lehodey 2003b). There are higher recruitments after La Niña years (1971, 1974-1976, 1989) and lower recruitment after El Niño years (1972-73, 1982-83, 1987, 1992, 1997-98). The succession of El Niño events during the 80's and 90s only interrupted by one La Niña event of 1989 is sufficient to explain the long-term declining trend in the

population. Though the same mechanisms are used to constrain the recruitment of skipjack yellowfin and albacore in SEPODYM, the parameterization of the temperature function of the spawning index has been changed to reproduce the different spawning grounds of these species. While the main skipjack and yellowfin spawning grounds in the WCPO are associated with the warm pool, those of albacore are roughly extending through the central Pacific on each side of the equatorial 5°N - 5°S band, and consequently under the influence of the productivity of the equatorial upwelling (the cold tongue). Therefore, the out of phase primary productivity between western (warm pool) and central (equatorial upwelling) Pacific creates similar out of phase recruitment fluctuations between species associated to one or the other areas. In addition, the extension of the warm waters in the central Pacific during El Niño events that extends the skipjack and yellowfin spawning grounds conversely reduce those of the albacore. The predicted distributions of albacore larvae during opposite ENSO phases are shown on Figure 9. A natural separation appears between north and south stocks.

Catch by fishery

Overall, the estimated length frequency distributions are in good agreement with the available observations for the fisheries, indicating that selectivity coefficients are reasonably defined (Figure 4 and 10). Most of the catch is taken by ‘mixed’ and ‘unknown’ longline fisheries for which there is a good agreement with the predicted catch (Figure 11). During its period of exploitation, gillnet fishery in the southern subtropical convergence zone produced high levels of catch that are also well predicted by the model. The fit between predicted and observed catch for other fisheries is fairly good excepted in the first years of the shallow longline fishery time series and the last years of both this series and the troll fishery. This is reflected by a decrease in the monthly spatial correlation in the last years of the series for these two fisheries (Figure 12). Otherwise the spatial monthly correlations range between medium to good values. As for the other applications to skipjack and yellowfin, these predictions could be likely improved with a more detailed description of the fisheries.

Spatial distribution

Compared to skipjack and yellowfin tuna, the longer life span and lower natural mortality coefficients of albacore, together with a different spawning habitat produce very different spatial distributions of populations in agreement with present knowledge on the distribution of this species essentially based on catch distribution. This is illustrated on Figure 13 where average spatial distribution of albacore and contour of high catch rates are superimposed. The distribution does not show a real symmetry between the two hemispheres. In the southern hemisphere there is a permanent band of high biomass corresponding to high catches between 5°S and 20°S along an axis WNW-ESE that corresponds to the maximum of predicted forage biomass in the tropical region. In the northern hemisphere, though there is also high level of biomass in a latitudinal 5 - 20°N band, there is also a maximum of biomass occurring north of 25°N , in the extension of the Kuroshio and the transition zone between tropical and temperate regions and where the catch is concentrated.

Conclusion

This simulation reproduced reasonable distribution of albacore stocks in the Pacific Ocean and provides a plausible explanation of the effects of ENSO on the recruitment of albacore. It is remarkable to obtain realistic distributions and converging recruitment and biomass estimates with independent statistical estimates for this species as well as for skipjack and

yellowfin, by using the same mechanisms to describe the spatio-temporal dynamics of the tuna populations.

Additional simulations are needed to refine the parameterization, the fisheries definition and to test the sensitivity of this parameterization. It is particularly necessary for this species because the long life span of albacore makes the results of the simulation quite sensitive to the initial conditions. Longer time series will help also to evaluate and confirm the good fit with independent estimates from the statistical model. Independent biomass estimates for the north Pacific albacore stock would be also helpful.

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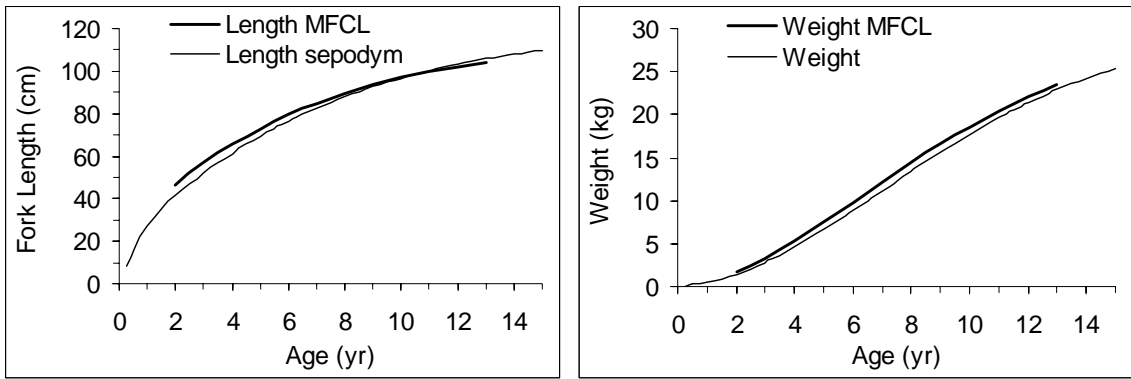


Figure 1. Length-at-age and weight-at-age relationships for albacore tuna used in SEPODYM application (thin curve) compared to MULTIFAN-CL estimates (thick curves)

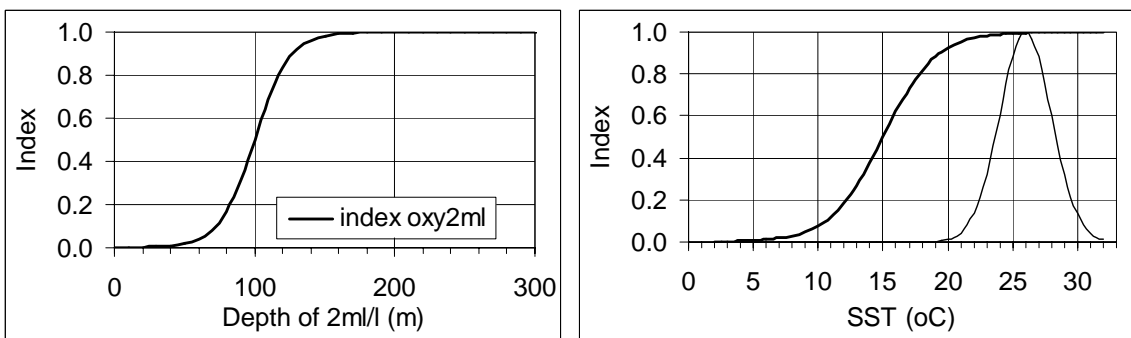


Figure 2. Oxygen (left) and temperature (right) functions used for defining the adult habitat (thick curve) and the spawning habitat indices of albacore tuna

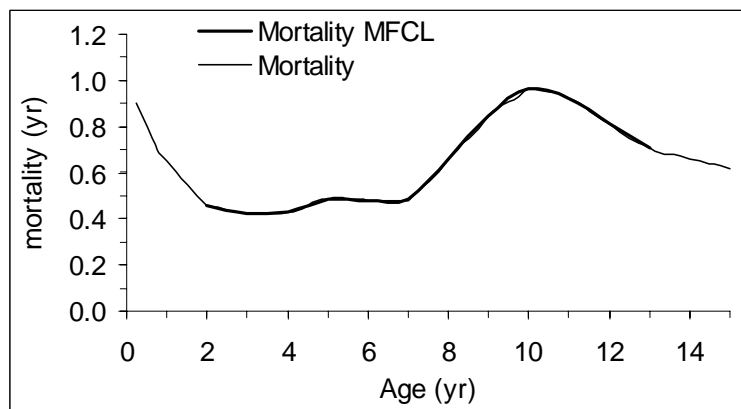


Figure 3. Natural mortality-at-age coefficients used in SEPODYM for albacore (thin curve) and compared to MULTIFAN-CL estimates (thick curve; Labelle and Hampton 2003).

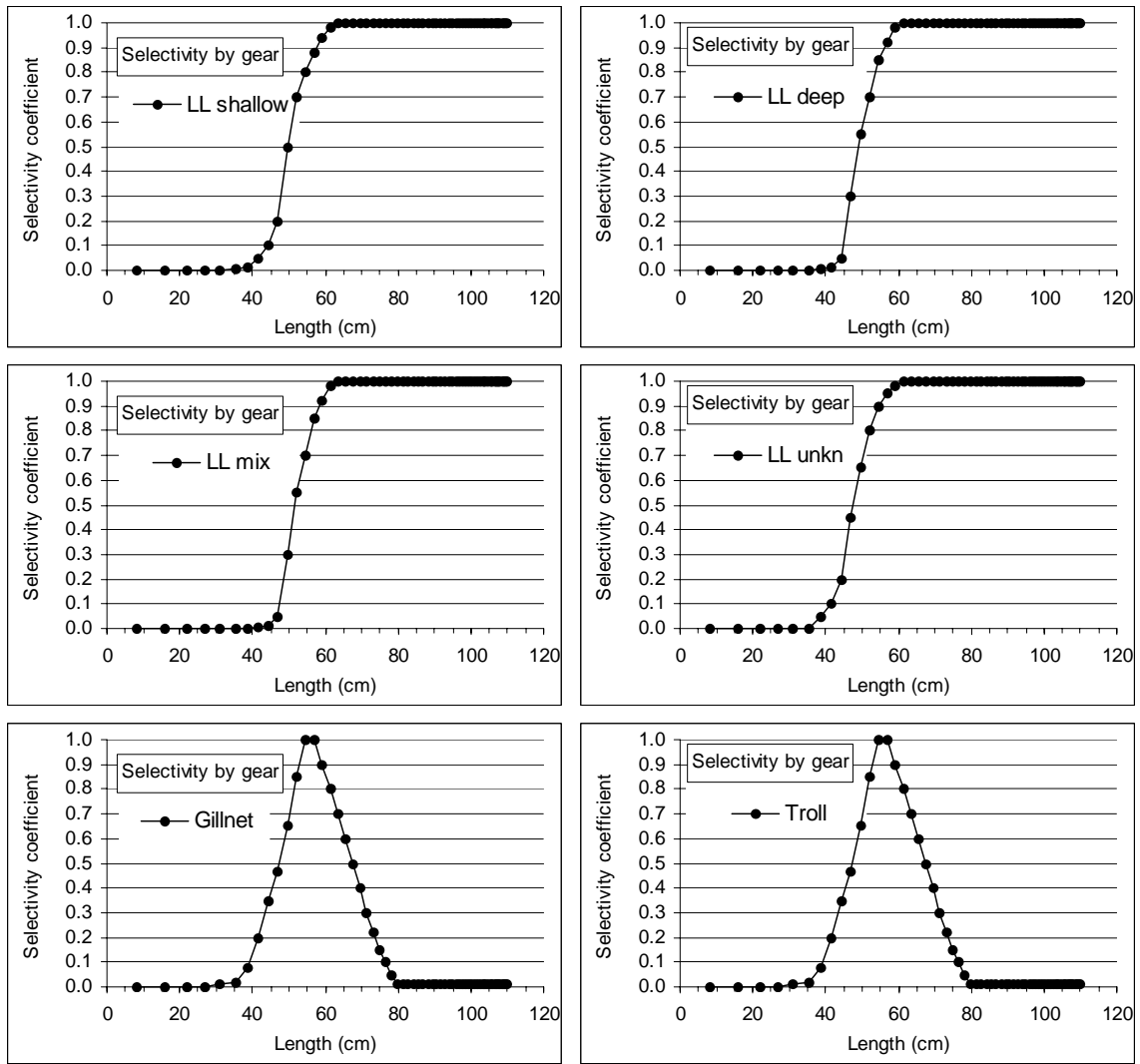


Figure 4. Selectivity functions defined for the fisheries described in the albacore SEPODYM application

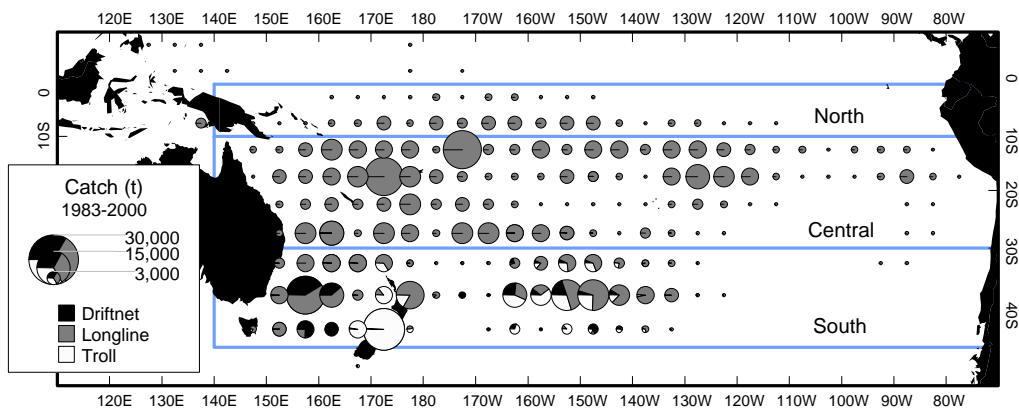


Figure 5. Distribution of south Pacific albacore tuna catch, 1990–1998. The heavy lines indicate the spatial stratification used in the MULTIFAN-CL model (from Labelle and Hampton 2003).

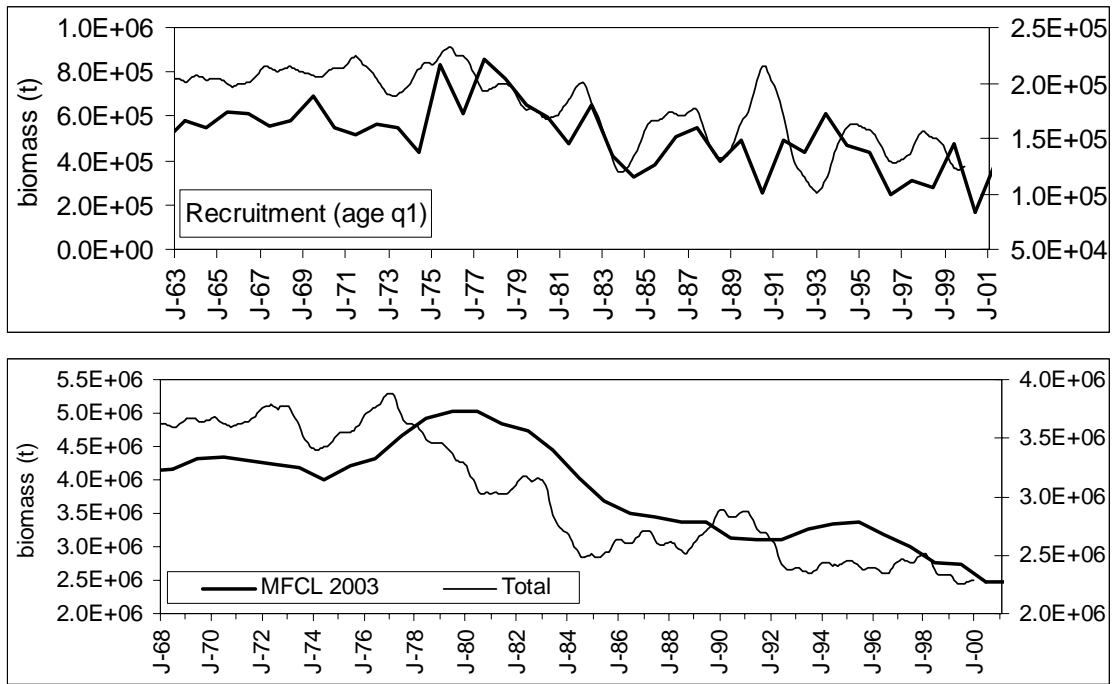


Figure 6. South Pacific albacore recruitment (top) and total biomass (bottom) in the WCPO (sum of 5 regions shown on Fig. 5) predicted from SEPODYM (thin curve) and comparison with MULTIFAN-CL biomass estimates (Labelle and Hampton 2003). Recruitment is assumed to occur at age 2 years.

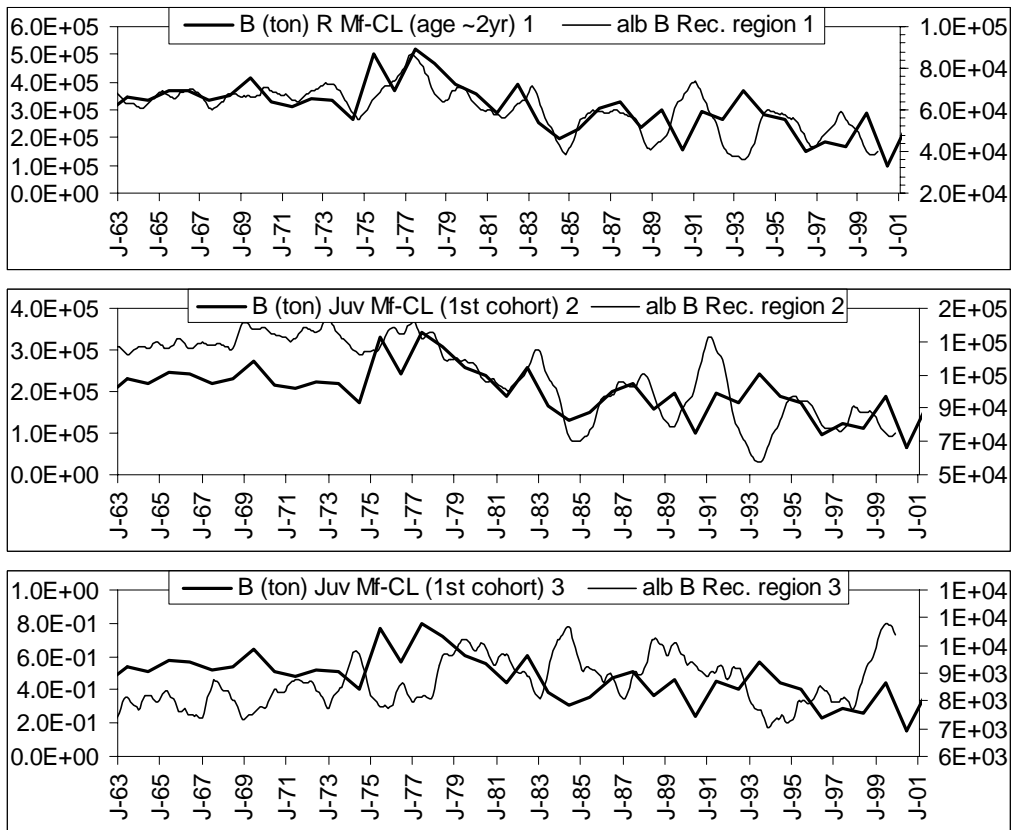


Figure 7. Albacore recruitment by region 1 to 3 (cf. Fig. 5) estimated by MULTIFAN CL (thick line) (Labelle and Hampton, 2003) and by SEPODYM (thin line).

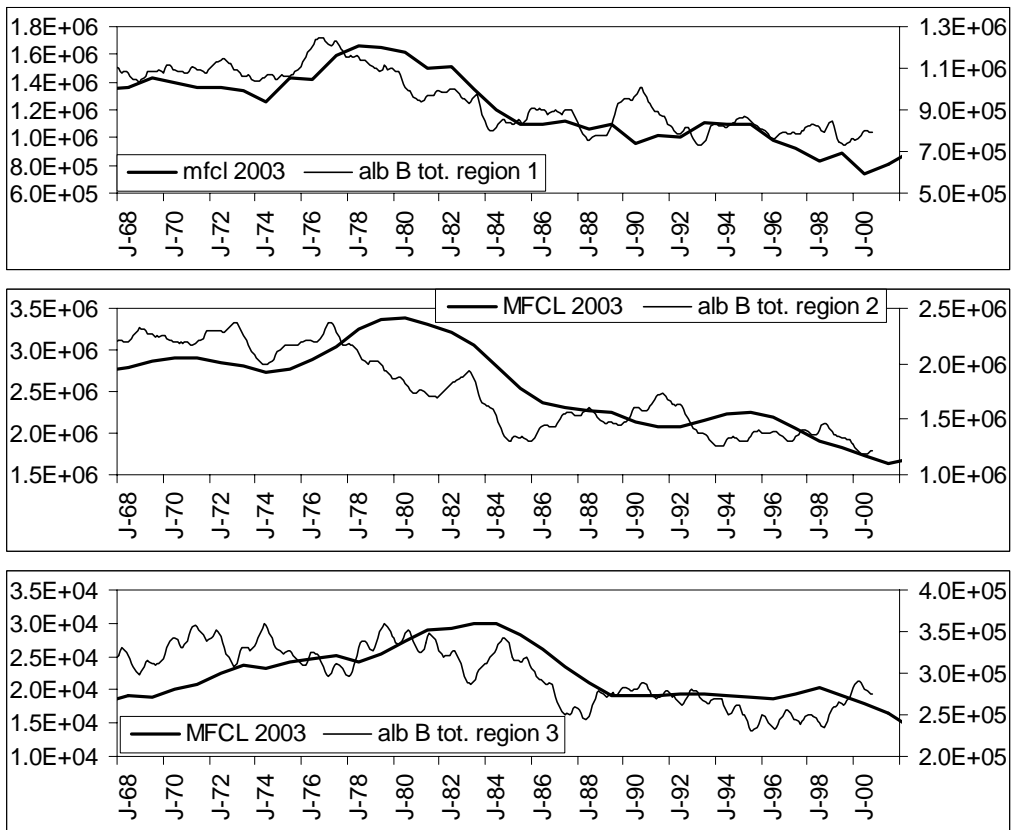


Figure 8. Albacore total biomass by region (cf. Fig. 2) estimated by MULTIFAN CL (thick line, left axis) (Hampton 2002) and by SEPODYM (thin line, right axis).

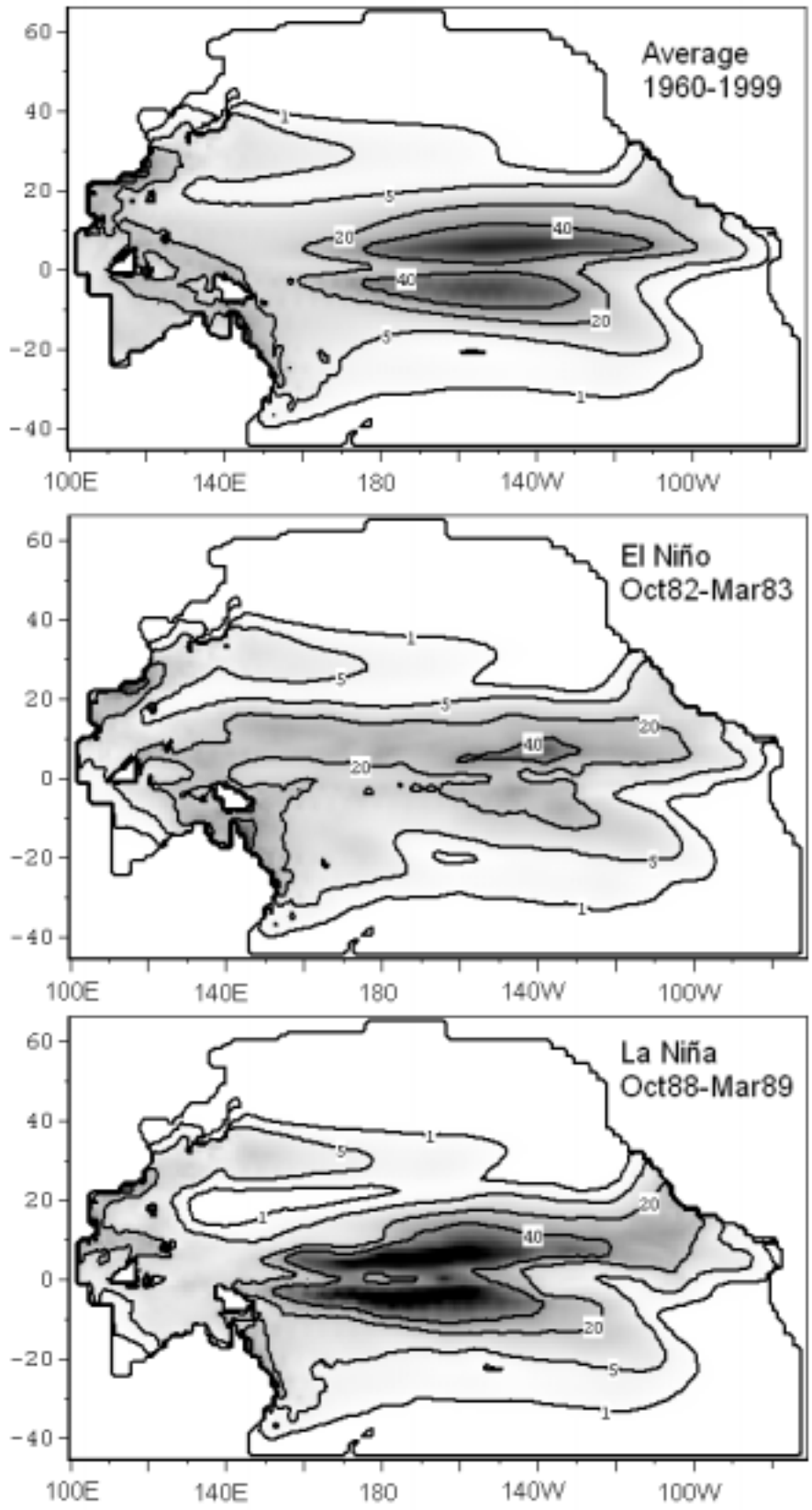


Figure 9. Biomass distribution of 1st albacore age class (0 to 3 months) in tonnes per degree square: average and distributions during El Niño (average distribution Oct 82-March 83) and La Niña (average distribution Oct 88-March 89) phases.

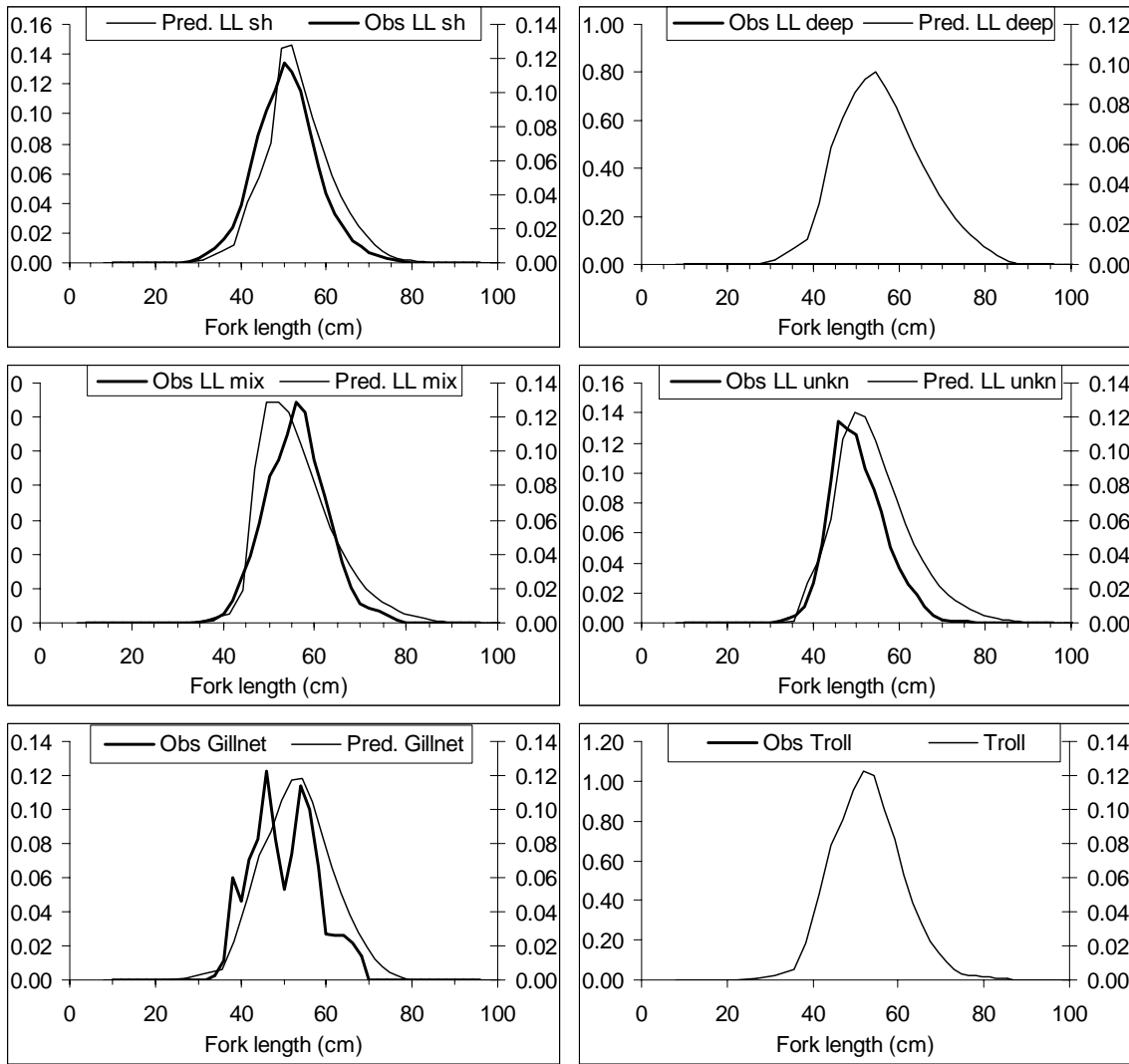


Figure 10. Predicted and observed (when available) length frequency distributions by fishery

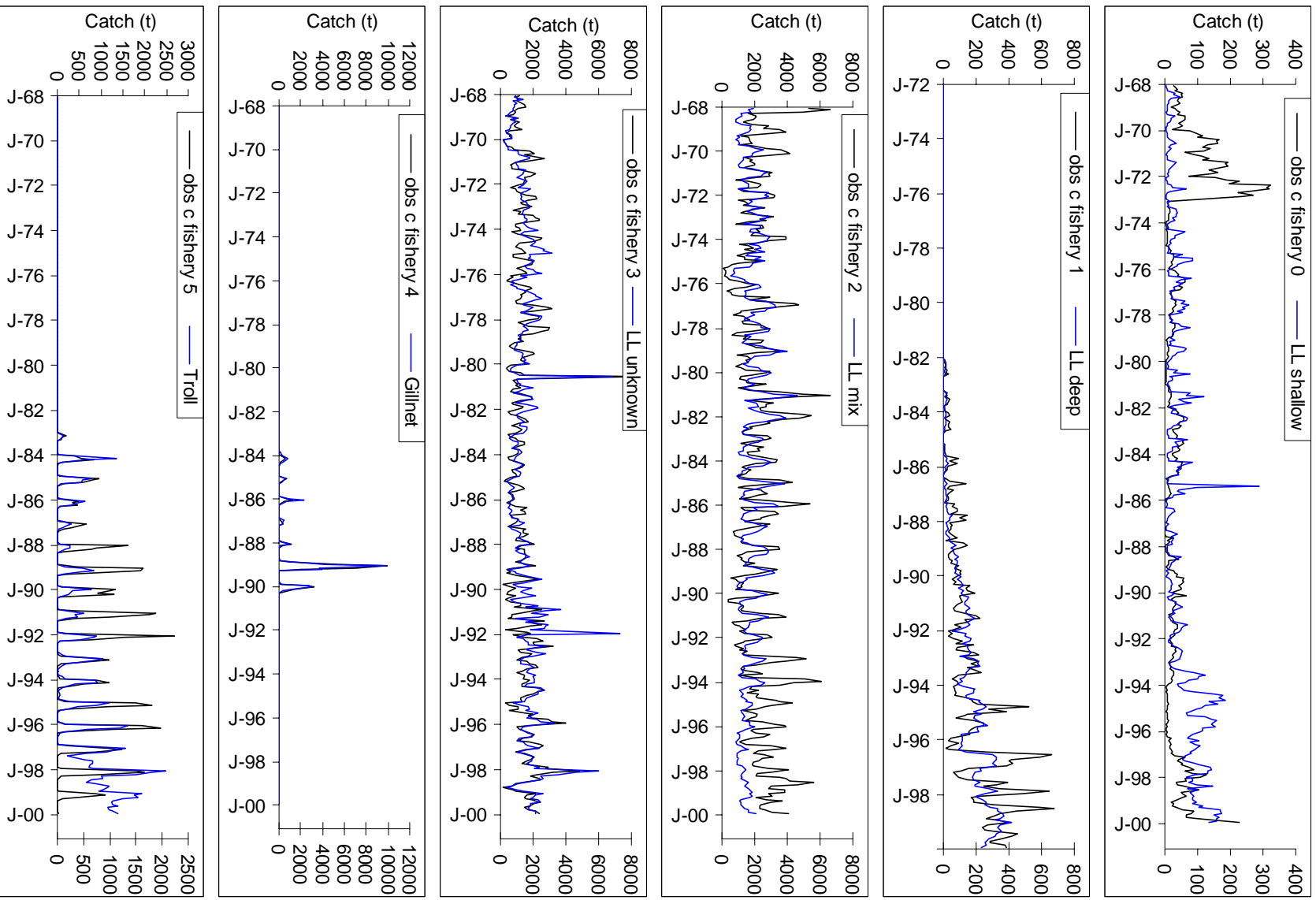


Figure 11. Predicted and observed monthly catch of albacore by fishery

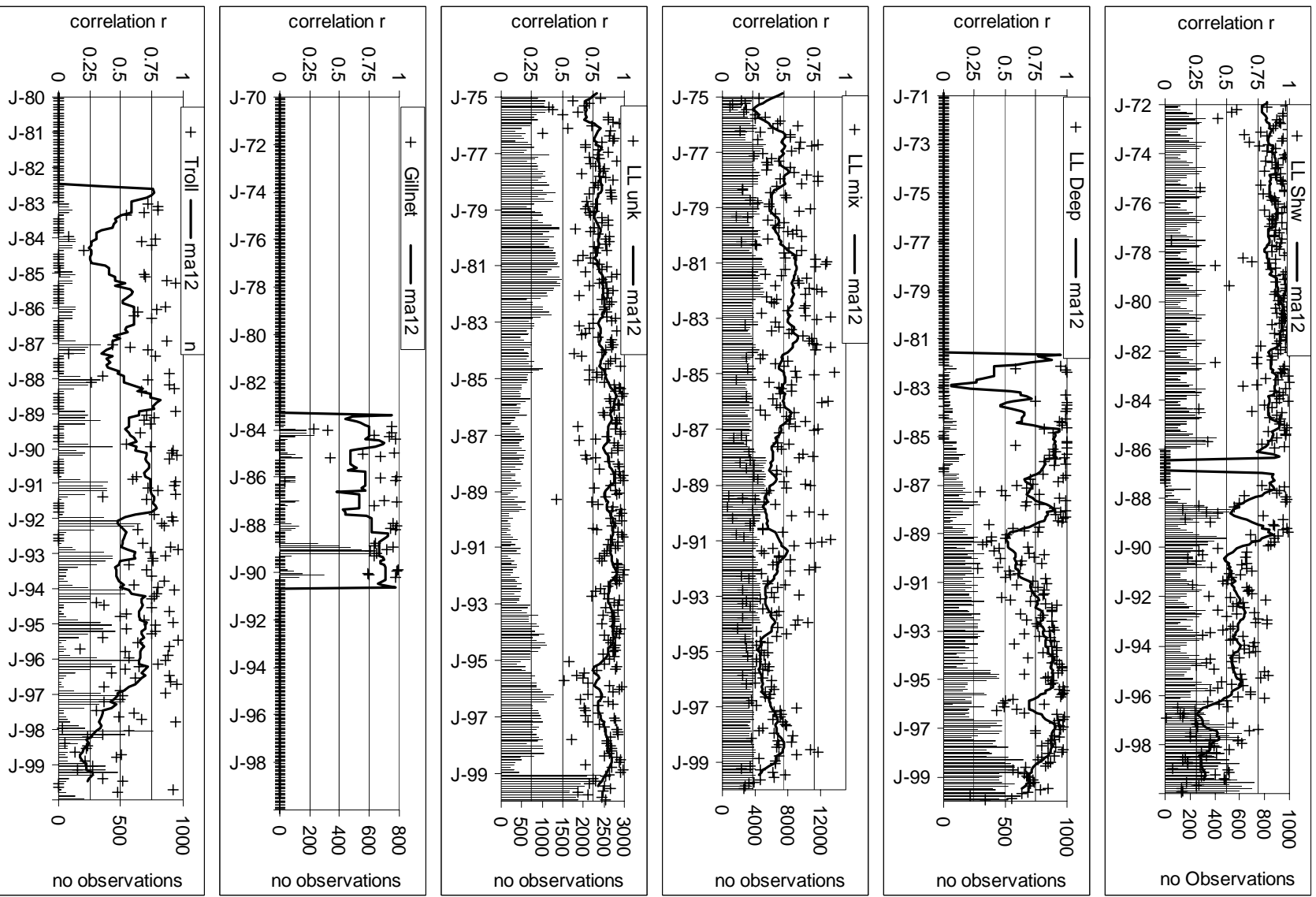


Figure 12. Spatial one-degree square monthly correlations (crosses = monthly values; thick line = 12-month moving average) between predicted and observed albacore catch (bars = number of observations) for the fisheries defined in the application

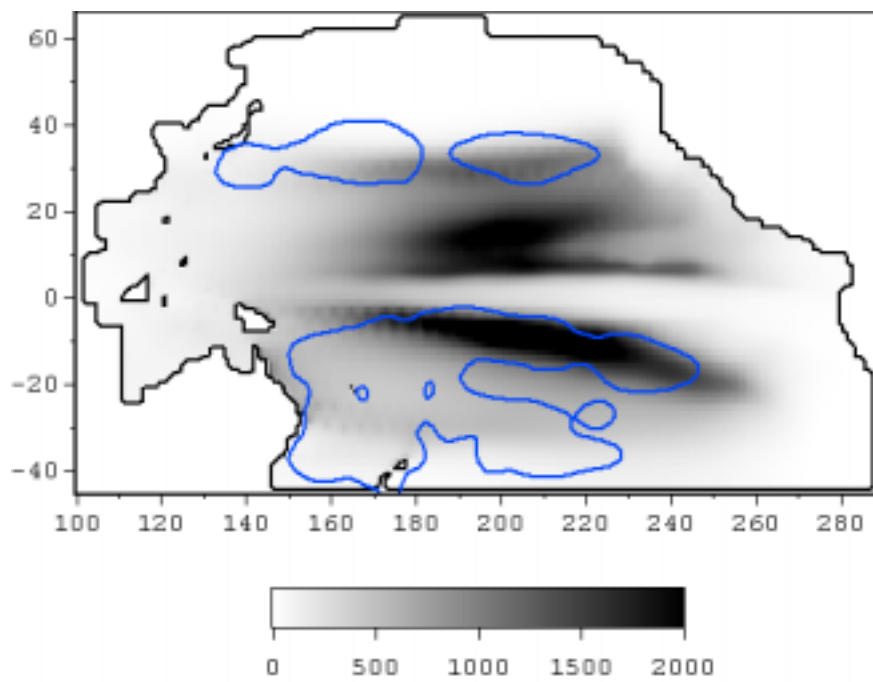


Figure 13. Average distribution of albacore tuna biomass in the Pacific Ocean (1968-1999) in ton per degree square and iso-contour delimiting average catch above 0.5 ton per degree square for the same period