Western and Central Pacific Fisheries Commission

**1st Meeting of the Scientific Committee of the
Western and Central Pacific Fisheries Commission
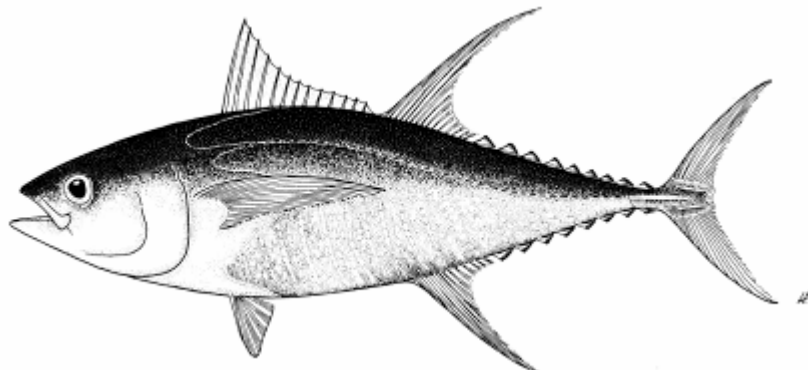WCPFC–SC1**
Noumea, New Caledonia
8–19 August 2005

Application of SEAPODYM to the Pacific Pelagic Ecosystem.
Recent results and perspectives

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August 2005

Introduction

The Spatial Ecosystem And Populations Dynamics Model (SEAPODYM) has been continuously developed at the Oceanic Fisheries Programme since 1995 and its evolution regularly presented in last SCTB meetings and several scientific articles.

Using predicted environment from ocean-biogeochemical models (primary production and physical environment), SEAPODYM simulates the pelagic ecosystem in two trophic levels: tuna or associated species (one or several species, top level) and its forage (several components, mid-trophic level). SEAPODYM integrates spatio-temporal and multi-population dynamics and considers interactions among populations of different species and between populations and their physical and biological environment. The model also includes a description of multiple fisheries and then predicts spatio-temporal distribution of catch, catch rates, and length-frequencies of catch based either on observed or simulated fishing effort, allowing respectively to evaluate the model or to test management options (e.g., changing the fishing effort in the different fleets, implementing no-fishing areas, etc…).

A reference version will be released on a web site and details of the model with the necessary information to run simulations are provided in a reference manual and presented at the methodology working group (Lehodey 2005a). Since last year (Lehodey 2004a, 2004b), the main changes in the model concerned the achievement of the modeling of the mid-tropic forage components into 6 components distributed in three vertical layers, the change to a new numerical scheme allowing to use non-uniform (stretched) spatial grids (Senina et al., 2005), and a better description of tuna movements and habitats.

This paper presents the progress towards the application of this model to the main tuna species exploited in the tropical Pacific Ocean. Since details of the model are described in the reference manual, this document provides only parameterization and results.

Environmental input data files

Predicted fields of environmental variables (temperature, currents, primary production) are from a coupled physical biogeochemical model developed at the ESSIC (Univ Maryland, USA). This carbon-based biogeochemical model (Hackert et al. 2001, Christian et al. 2002) is coupled to the sigma-coordinate general circulation model of Gent and Cane (1989) as further developed by Chen et al (1994) and Murtugudde et al. (1996), and the ecosystem model of Leonard et al. (1999). The most recent simulation covered the period 1948-2004 at a 10-day half-degree square resolution. However, simulations of tuna populations used monthly one-degree square resolution.

Primary production (mmol C d^{-1} m^{-2}) was integrated over the vertical layer while temperature, currents and dissolved oxygen concentration (for this latter only a climatology is available) were averaged over the three vertical layers defined for the forage, i.e., 0-100m, 100-400m and 400-1000m. The ESSIC physical-NPZD model predicts reasonably well the main basin-scale features (cold-tongue associated to the equatorial upwelling, low productive central gyres, and seasonal enrichment in temperate latitudes) as well as the interannual ENSO (Fig.

1) and decadal variability. However, the temperature fields still present some bias in subtropical regions though the seasonal cycle is well reproduced.
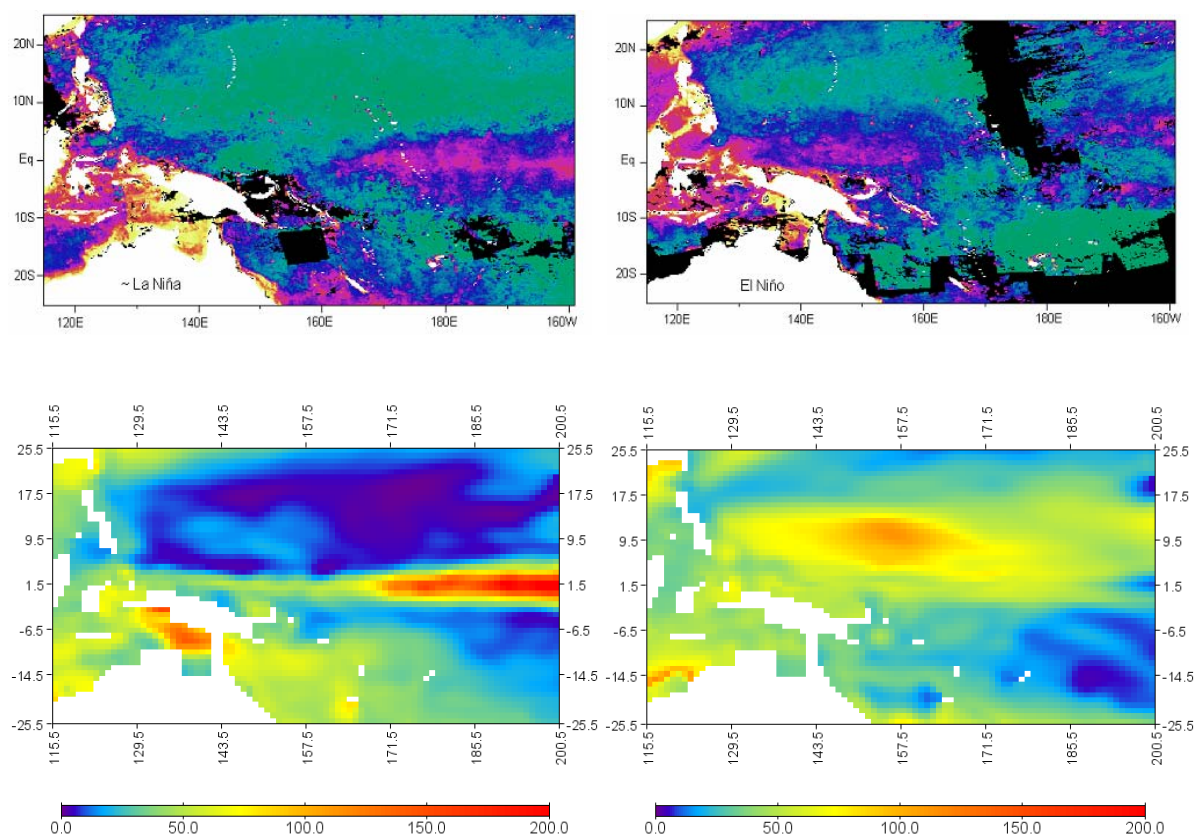

Figure 1. Comparison between observed (top) chlorophyll concentration (CZCS satellite) and predicted primary production (ESSIC NPZD model) during La Niña and El Niño phases in the western equatorial Pacific (Sept. 1981 and Dec. 1982 respectively).

Mid-trophic Forage components

The model describes the mid-trophic levels with six components distributed over 3 vertical layers: epi-pelagic (0-100m), meso-pelagic (100-400m), and bathy pelagic (400-1000m). The meso- and bathy-pelagic layers have migrant and non-migrant components (Fig. 2), so that in the night the biomass in the epipelagic is the sum of epi-pelagic, migrant meso-pelagic and highly migrant bathy-pelagic components (Fig. 2). Estimation of energy transfer coefficients (table 1) is based on limited available information (Lehodey 2004) and still requires further evaluation using acoustic biomass estimates of micronekton in different regions of the ocean.

The changes in biomass in the three layers between day and night are illustrated in figure 3. The biomass in the upper layer increases by a factor 3 to 5 due to migration of meso- and bathy-pelagic components. As in previous simulations the distribution in the epi-pelagic layer is the most contrasted due to a strong dynamical circulation in this layer, particularly in the equatorial region, and a faster turnover due to higher temperature than in the deeper layers.

Logically, the ENSO variability (Fig. 4) characterized by large changes in surface circulation, primary production and temperature distribution strongly affects the forage biomass distribution in the tropical regions.

Figure 5 gives the time series of production and biomass averaged for each forage component over two large regions corresponding to the regions 3 and 4 used for MULTIFAN-CL assessment analyses of bigeye and yellowfin tuna. Total production is slightly lower in the western area (region 3) with a larger proportion in the epipelagic component, partly due to the topographic configuration since in shallow waters of the archipelagic Philippines-Indonesia region, only epipelagic component exists to which all energy transfer has been directed (Table 1), leading to a relatively high proportion of epipelagic forage biomass in this region with a higher productivity regime predicted after the mid-70's. In the central region, the biomass is two times higher than in the west with a higher proportion of bathypelagic forage, the epipelagic forage representing about 10% of the total biomass in agreement with observations by Legand et al. (1972) and Grandperrin (1975). All series in the equatorial regions present clear ENSO-related interannual variability, but while there are high peaks of forage biomass after El Nino in the west (region 3), e.g. 1983 and 1998, the situation is opposite in the central region with low peaks in El Nino and high peaks after La Nina events, e.g. 1989 and 1999.
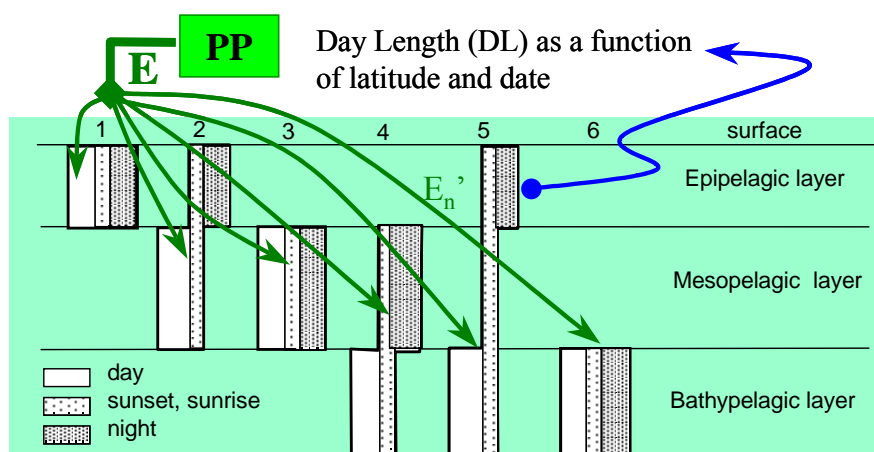

Figure 2. The different daily vertical distribution patterns of the micronekton in the pelagic ecosystem. 1, epipelagic; 2, migrant mesopelagic; 3, non-migrant mesopelagic; 4, migrant bathy-pelagic; 5, highly-migrant bathypelagic; 6, non-migrant bathypelagic. The part of energy (E) transferred from primary production (PP) to intermediate trophic levels is redistributed (En') through the different components

Table 1. Matrix of Energy transfer coefficients used for the 6 forage components

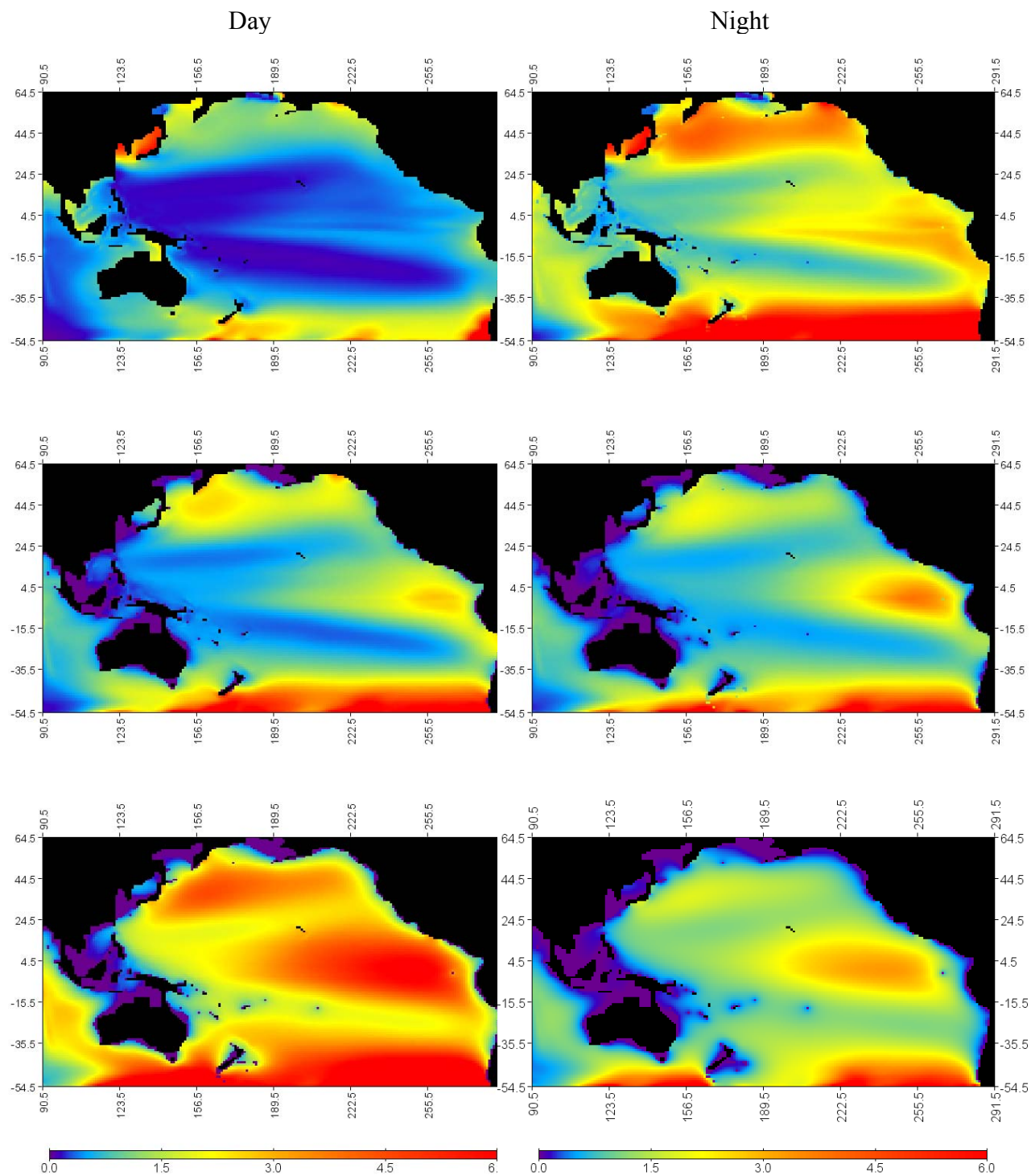| Layer	Forage component					
	epi	meso	m-meso	bathy	m-bathy	hm-bathy
Epi (0-100m)	1	0	0	0	0	0
Meso (100-400m)	0.30	0.23	0.45	0	0	0
Bathy (400-1000m)	0.17	0.10	0.22	0.18	0.13	0.20

Day   Night

Figure 3. Average distribution of forage biomass in January during day (left) and night (right) in the epi-pelagic (top), meso-pelagic (middle) and bathy-pelagic (bottom) layers.
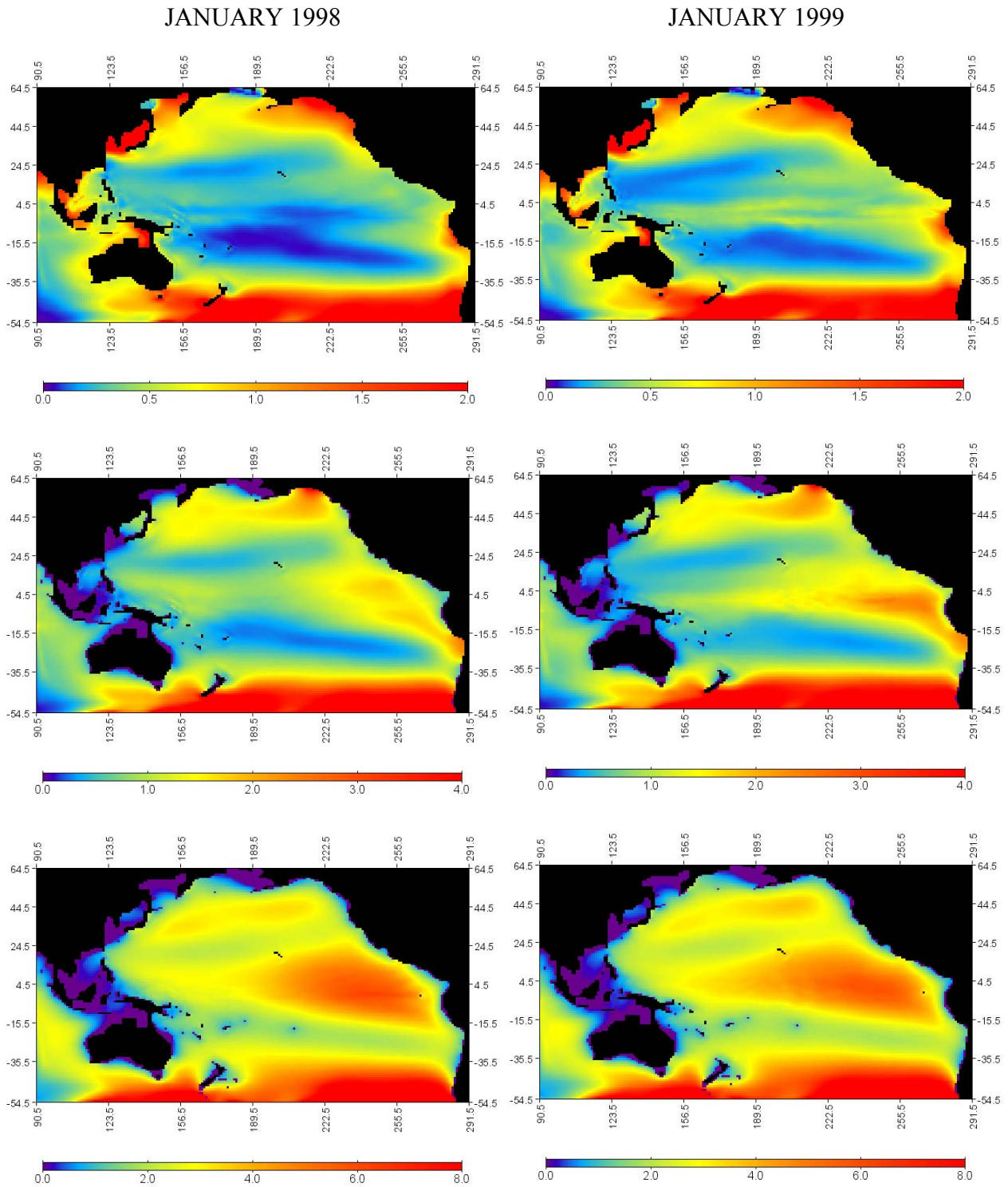
Figure 4: Average distribution of forage biomass in January (day time) in the epi-pelagic (top), meso-pelagic (middle) and bathy-pelagic (bottom) layers in January 1998 and 1999 during El Niño and La Niña periods respectively. (Note that there is a factor x2 in the color scale between epi- and meso-, and meso- and bathy-pelagic layers)
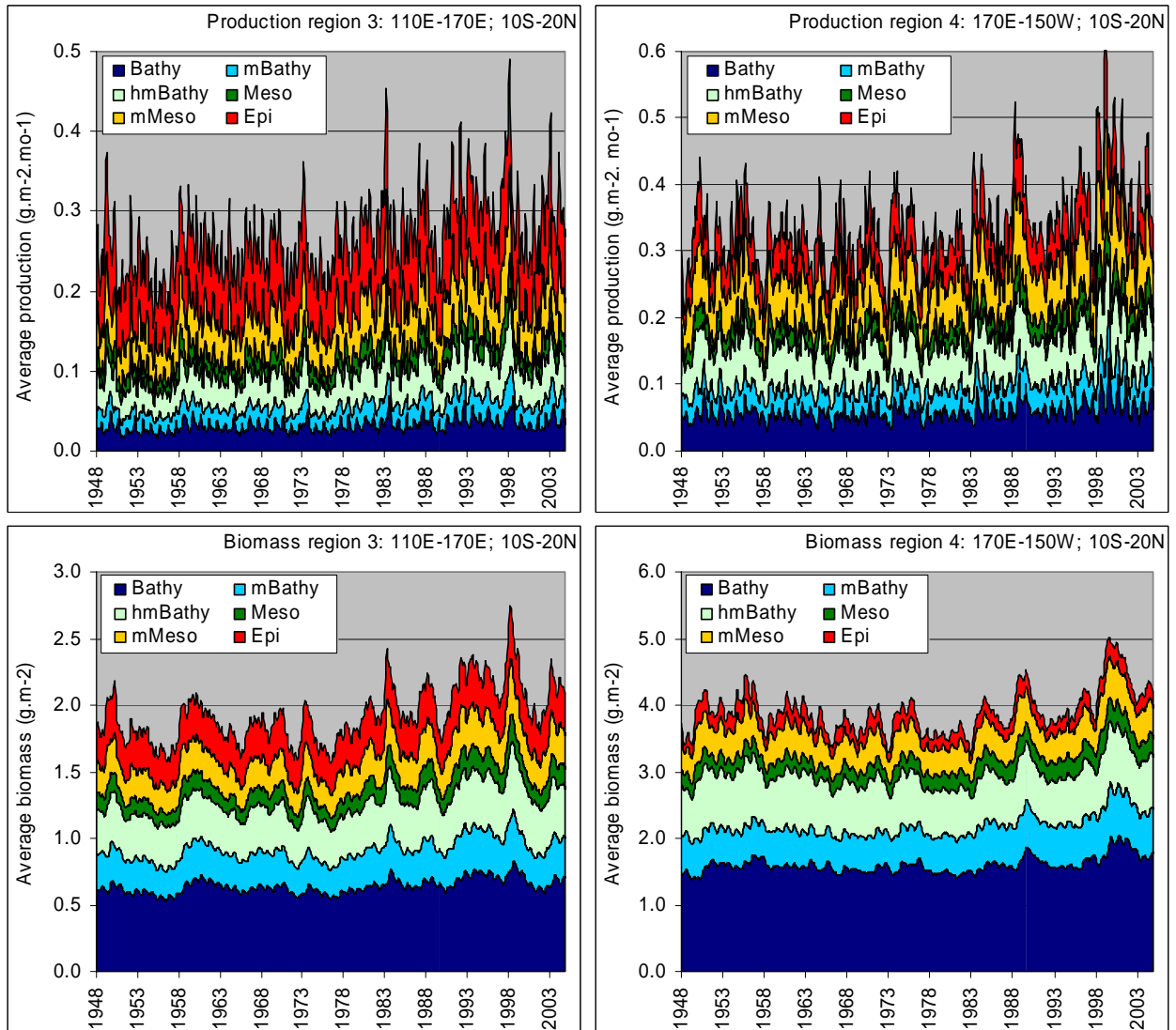
Figure 5. Time series of production and biomass averaged for each forage component over two large regions corresponding to the regions 3 and 4 used for MULTIFAN-CL assessment analyses of bigeye and yellowfin tuna.

Tuna

The parameterization for each tuna species was estimated using single species, multiple-fisheries simulations. Results from these single species simulations are presented here and will be compared to a multi-species simulation in a further study.

Population structure, age and growth

Number of age classes, length-at-age and weight-at-age coefficients are identical to those defined or estimated for/by Multifan-CL, excepted for albacore since MFCL assessment used annual age classes for this species (Fig. 6). Three additional monthly age classes for larvae and juvenile phases are added (cf. reference manual). Though the model uses quarterly age-classes, computations are based on the time steps of the simulation, i.e. here on a monthly basis. Ages at first maturity and at recruitment are provided in table 2.

Table 2. Parameterisation of the populations structure in SEAPODYM

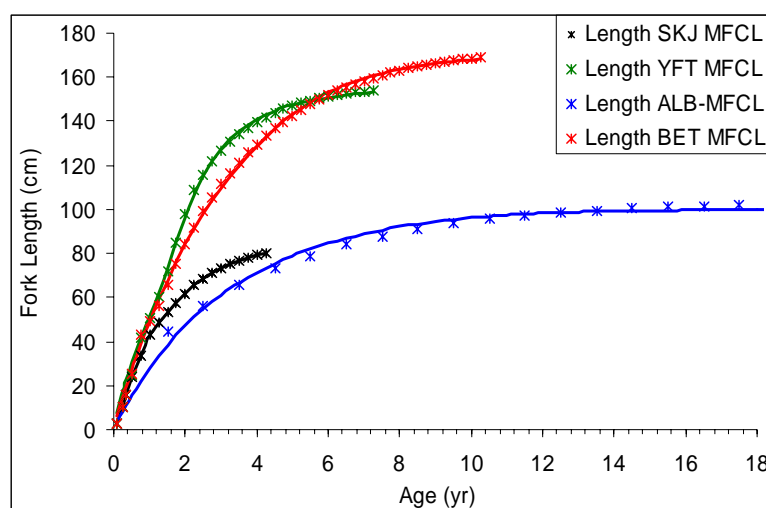|	skipjack	yellowfin	Bigeye	Albacore
Number of age classes (quarter) after juvenile phase	16	28	40	74
Age at first maturity (quarter)	4	7	11	17
Age (quarter) at recruitment	3	3	3	7

Figure 6a. Length-at-age coefficients estimated from MFCL analyses (crosses) and growth curves used to define the coefficient used in SEAPODYM simulations
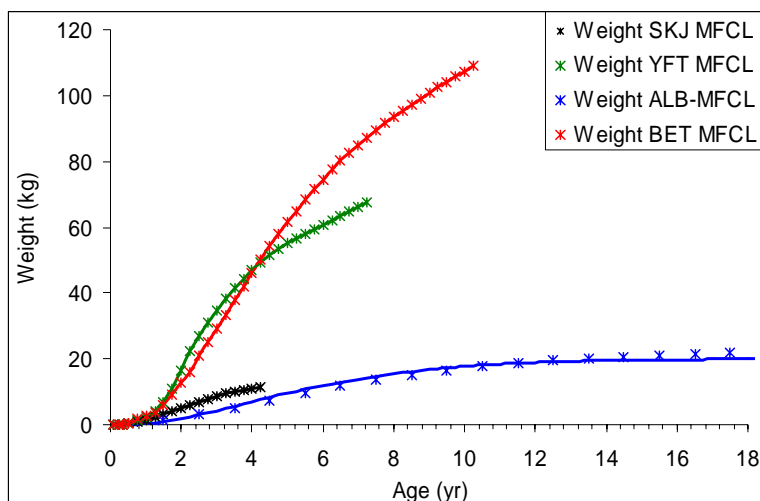
Figure 6b. Weight-at-age coefficients estimated from MFCL analyses (crosses) and weight-age (length) functions (curves) used to define the coefficient used in SEAPODYM simulations

Natural mortality

Natural mortality is described as the sum of two functions representing the mortality occurring during the juvenile and young phases (M_p) that is mainly due to starvation and predation, and the natural mortality associated to senescence and diseases in the adult phase (M_s). The average natural mortality-at-age coefficients for the four species are presented on Figure 7 with corresponding parameters in Table 3. The parameterization is defined to obtain coefficients of natural mortality-at-age in agreement with those estimated statistically with MULTIFAN-CL and to have coherent parameters between species.
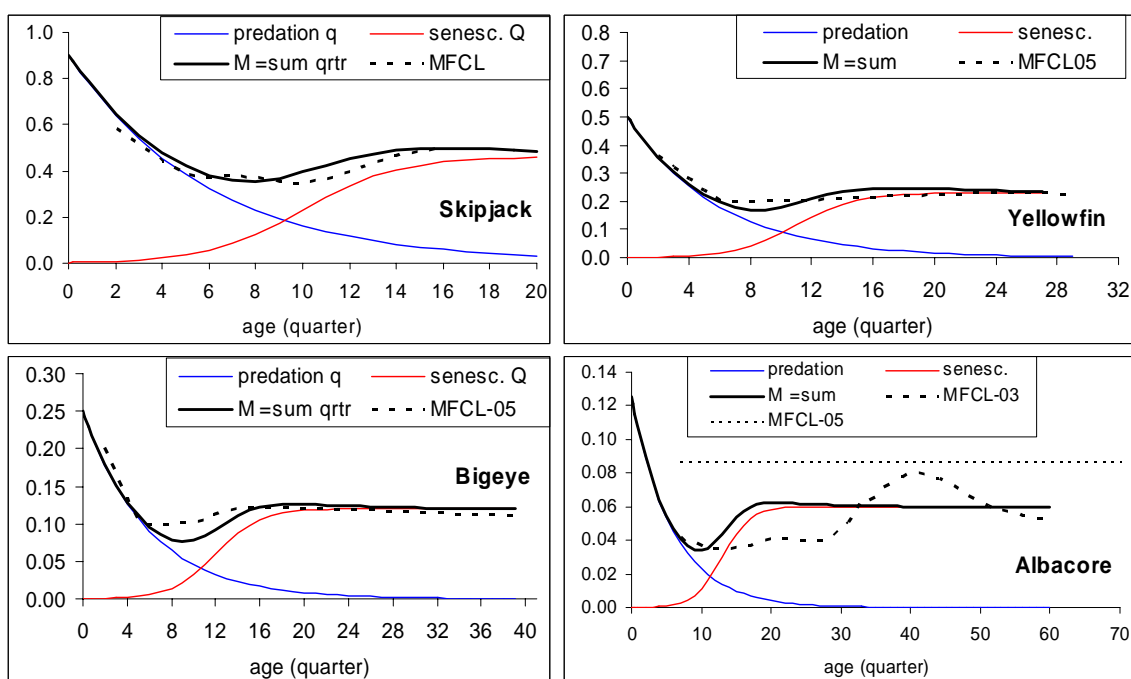

Figure 7. Natural mortality of tuna species defined in the model (thick curves) and compared to estimates from MULTIFAN-CL (dotted curves).

Table 3. Parameterization of the natural mortality functions for skipjack, yellowfin and bigeye tuna species

	Skipjack	Yellowfin	Bigeye	Albacore
Mpmax (qtr^{-1})	0.9	0.5	0.25	0.125
Mp_exp	0.17	0.17	0.17	0.17
Msmax (qtr^{-1})	0.46	0.23	0.12	0.06
Ms_slope	-0.5	-0.5	-0.5	-0.5
Ms_half (qtr)	10	11	12	13

In addition, the natural mortality coefficient-at-age can be linked to habitat values (cf reference manual). Effect of such spatio-temporal variability in natural mortality has been tested and may have significant effect (see below).

Fishing mortality

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.

Spawning and feeding Habitats

The spawning habitat is defined by a temperature function and the value of the coefficient α. When α is set to 0, only temperature has an effect. Increasing value of α increases the effect of the P/F ratio used to introduce a match/mismatch mechanism between spawning and presence/absence of food and predators of larvae. The feeding habitat is based on a temperature and oxygen function to define the accessibility of the species (by age) to the different forage components. Both habitats are standardized between 0 and 1.

There is a range of potential combinations of temperature and oxygen parameters to test. However, since the interest here was to test new changes introduced in the model, i.e. seasonality, time-space variability of natural mortality and the multi-species simulation, only one parameterization (Table 4) of temperature and oxygen function was tested. It is worth to note that here we refer to the average temperature of the layer, which is lower than the Sea Surface Temperature frequently used in the literature when trying to link spawning behavior, maturation, or habitat to environmental condition.

Table 4. Parameterization of temperature and oxygen functions for habitat indices

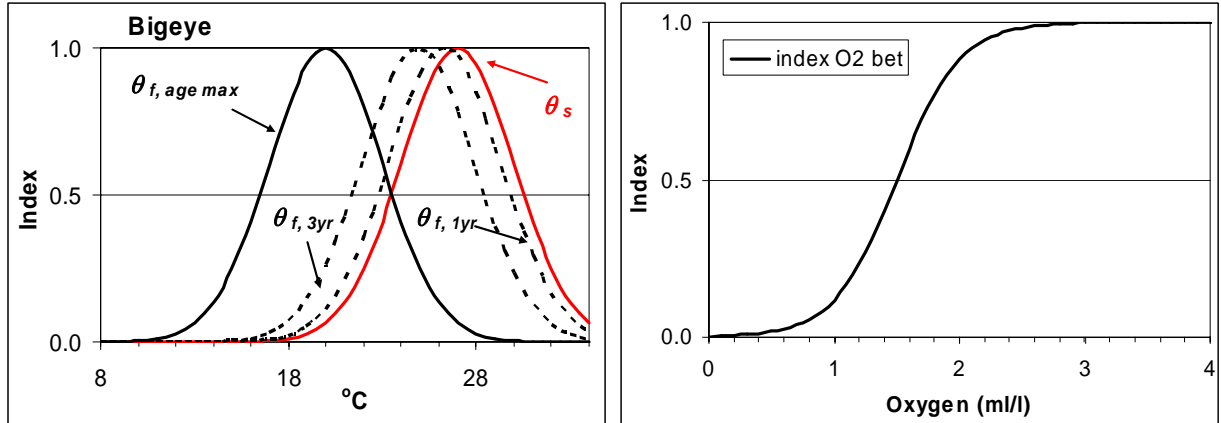| Parameter	Skipjack	Yellowfin	Bigeye	Albacore*
θ_s	29	28	27	
σ_s	3	3	3	
θ_a	25	23	20	
σ_a	3	3	3	
$O_{1/2}$	2.5	2	1.5	
O_{slope}	-4	-4	-4	

*Not yet defined

Figure 8. Change in temperature function with age from age 0 (spawning) to maximum age (left) and habitat function for the oxygen (right).

Adult Habitat

The adult habitat on which the movement of tuna is based remains the feeding habitat if seasonality is not required. On the other case, the adult habitat switches from feeding to spawning habitat based on a threshold in the gradient of day length (set to ≥0.02h per day).

Movement

Maximum sustainable speed (MSS) is set to 1 body length per second for all species. The diffusion is decreasing with adult habitat value according the following equation:

$$f(H_a) = 1 - \left[\frac{H_a}{\beta + H_a} \right]$$

with H_a the standardized habitat value between 0 and 1 and $\beta = 0.3$.

Definition of Fisheries

A simple definition of tuna fisheries was sought to keep a reasonable number of fisheries in a multi-species simulation. The first criteria was the fishing gear, but it is also necessary to consider some large spatial-scale stratification, different fishing strategies, and also changes in the longline gear associated to a shift in the fishing strategy for fishing deeper and targeting bigeye tuna (Table 5). Each fishery has one constant catchability coefficient and an age-based selectivity function. The selectivity functions are adjusted to obtain predicted length frequency distributions of catch in agreement with the observed distribution. Fishing effort of each fleet varies by month and in space at a monthly one-degree square resolution. When the fishing data were at a lower resolution (e.g., longline fishing data are at a 5-degree square resolution), the fishing effort was subdivided accordingly. The catchability coefficients are scaled to obtain estimated catches at the same average level as observed catches.

Table 5: Definition of fisheries used in the single and multi-species simulations

Category code	Description / source / resolution
PURSE SEINE	
WPSASS	Aggregated data of purse seine fisheries in the WCPO Sets associated to animals, log or FAD SPC-OFP database Monthly one-degree square
WPSUNA	Aggregated data of purse seine fisheries in the WCPO Unassociated sets (i.e. free schools) SPC-OFP database Monthly one-degree square
EPSASS	Aggregated data of purse seine fisheries in the EPO Sets associated to animals, log or FAD IATTC database Monthly one-degree square
EPSUNA	Aggregated data of purse seine fisheries in the EPO Unassociated sets (i.e. free schools) IATTC database Monthly one-degree square
POLE-AND-LINE	
PLTRO	Aggregated data of tropical (25°N-25°S) pole-and-line fisheries data Monthly one-degree square SPC-OFP database
PLSUB	Aggregated data of sub-tropical pole-and-line fisheries (mostly Japanese domestic fleets) SPC-OFP database Monthly one-degree square
LONGLINE	
LLP80	Aggregated data of longline fisheries before 1980 (The pre-1980/post-1980 categories was to (very roughly) define the change from targetting yellowfin to targetting bigeye) SPC-OFP database Monthly 5-degree square
LLSHW	Aggregated data of longline shallow after 1980 (mainly TW and mainland Chinese LL offshore fleets) SPC-OFP database Monthly 5-degree square
LLDEEP	Aggregated data of deep longline fisheries after 1980 SPC-OFP database Monthly 5-degree square
LLMIX	Aggregated data of "mixed" longline fisheries after 1980 SPC-OFP database Monthly 5-degree square
DIVERSE	
RINGNET	Aggregated data of ringnet fisheries (mainly Philippines, Indonesia) SPC-OFP database

	(spatial/temporal components of these data have been estimated only since these data are based on landings only, i.e. no logsheet data available)
ARTSURF	Aggregated data of artisanal surface fisheries (including ringnet, mainly Philippines, Indonesia) SPC-OFP database (spatial/temporal components of these data have been estimated only since these data are based on landings only, i.e. no logsheet data available)
COMMHL	Aggregated data of commercial handline fisheries (Philippines, Indonesia, PNG, US) SPC-OFP database (spatial/temporal components of these data have been estimated only since these data are based on landings only, i.e. no logsheet data available) Doesn't include fisheries of PNG (very small) nor US
GILLNET	Aggregated data of gillnet fisheries SPC-OFP database Monthly five-degree square
TROLL	Aggregated data of troll fisheries SPC-OFP database Monthly five-degree square

Simulations

Single-species simulations using a basic scenario with no seasonality, constant natural mortality-at-age coefficients and spawning habitat driven by temperature only was used to fit the selectivity functions to have reasonable agreement between total observed and predicted length distributions of catch by species and fisheries, the value of R_s (cf reference manual) being scaled to obtain a biomass by species close in average to the biomass predicted by MULTIFAN-CL.

Testing the sensitivity of each parameter is obviously a lengthy task, and the objective of producing the best statistical parameterization would require an optimization function. This is a development that will be explored in the next versions. For the present study, the objective was to reach a first reasonable parameterization for each species after testing the effect of adding the seasonal effect and time-space variability of M.

Results of simulations were evaluated by checking the correlations between observed and predicted monthly time series of CPUE for the main fisheries of the species and the average correlation between monthly 1-degree square spatially disaggregated observed and predicted catch by fishery.

A first parameterization was obtained for the three tuna species, skipjack, yellowfin and bigeye and their fisheries.

Results

Selectivity and predicted length frequencies of catch

The definition of fisheries did not allow to have observed length frequency data in all cases. When such data where missing the selectivity function of the most similar fishery for which length frequency data are available was used. Results are presented on figure 9. Predicted catch length frequencies are reasonably well reproduced excepted for the unassociated purse seine fishery in the WCPO that presents a bimodal distribution. This bimodal distribution may be due to higher catchability of adult deeper fish during El Niño events in relation with the rising of the thermocline (Lehodey 2000). It would be interesting to test if a relationship linking selectivity at age and thermocline depth can reproduce this type of distribution.
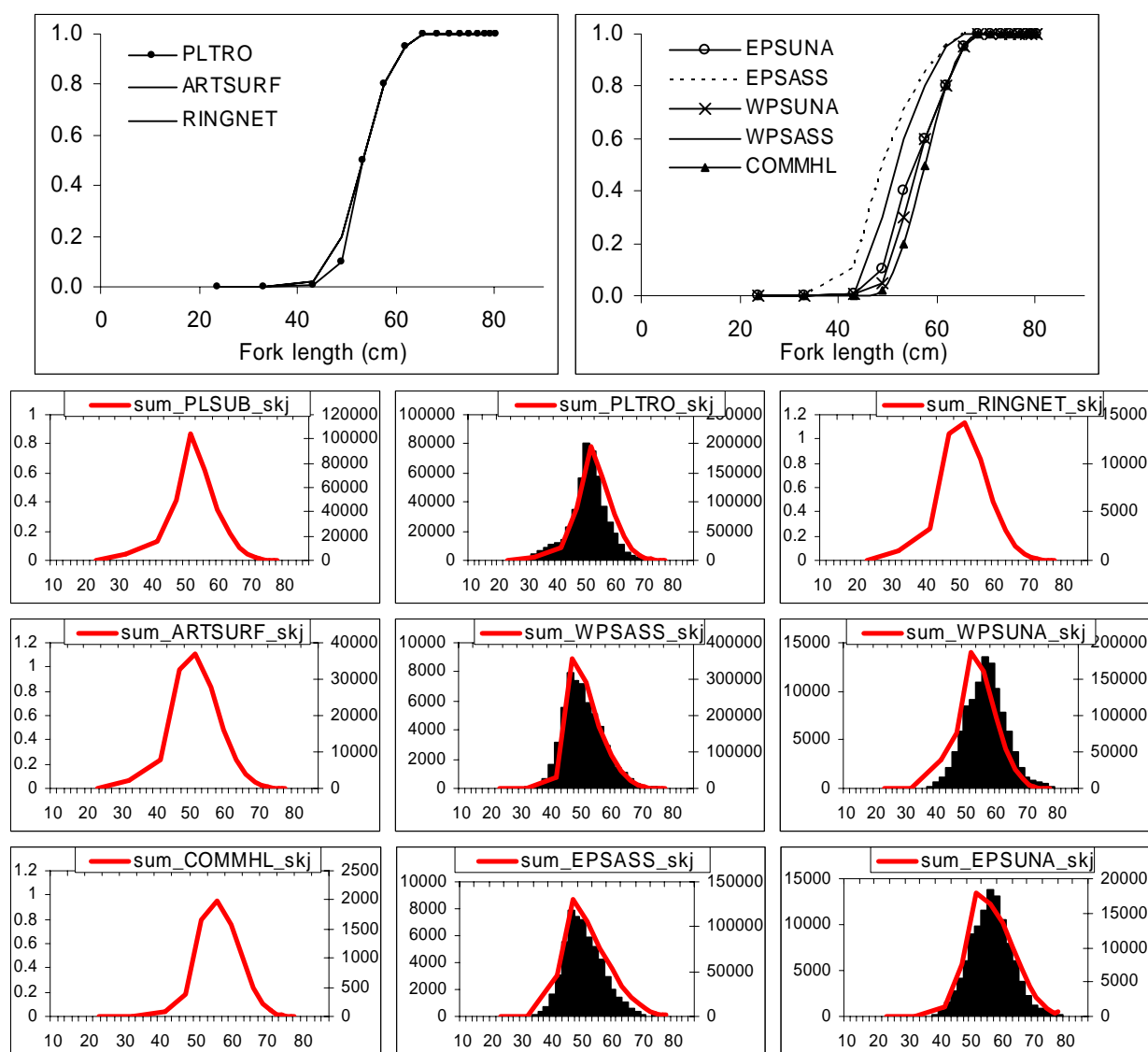
Figure 9. Selectivity functions for **skipjack** fisheries and comparison (when possible) between length frequency distribution of observed (histograms) and predicted (black curves) of catch
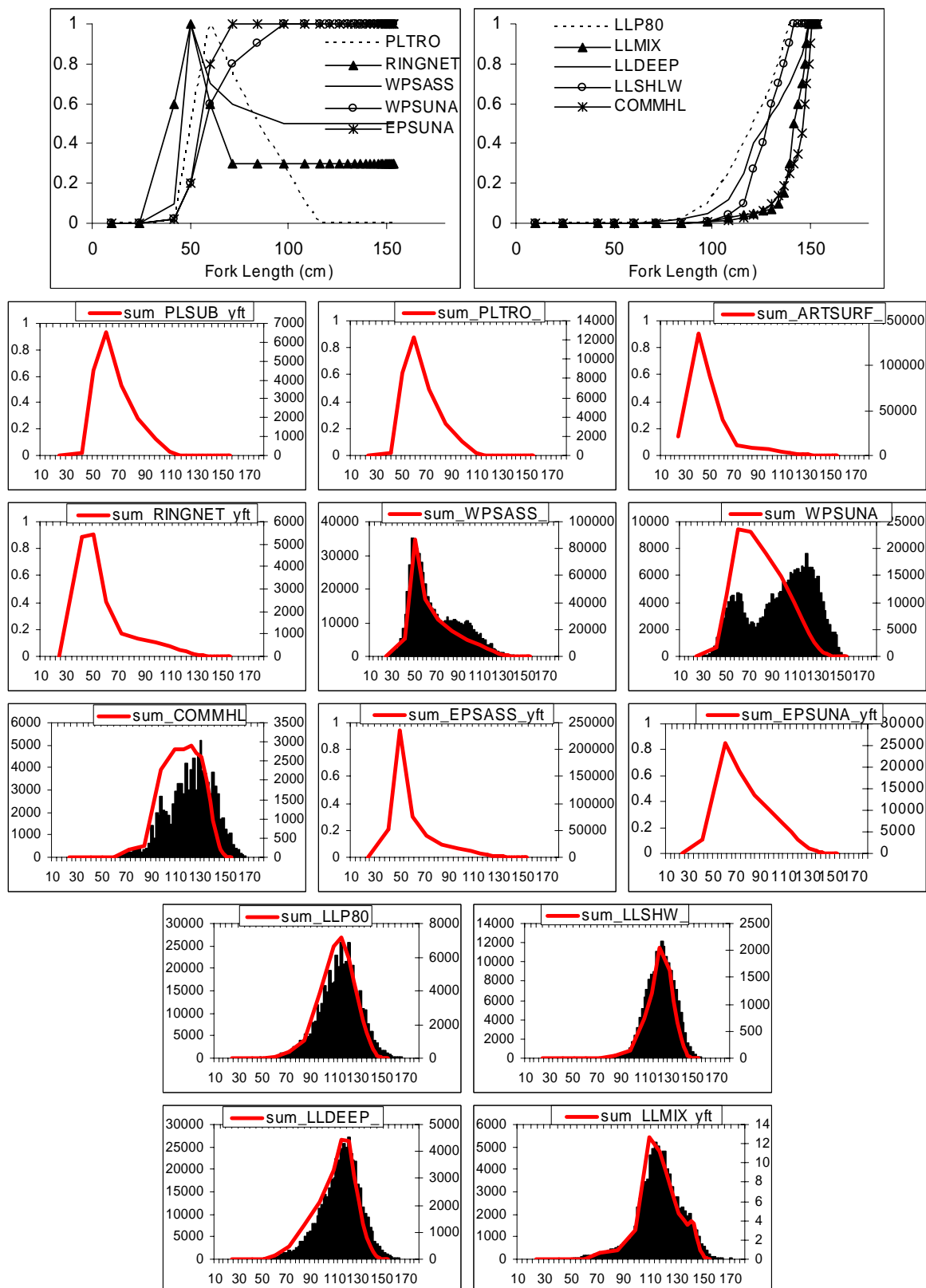
Figure 9 (cont.) Selectivity functions for **yellowfin** fisheries and comparison (when possible) between length frequency distribution of observed (histograms) and predicted (black curves) of catch
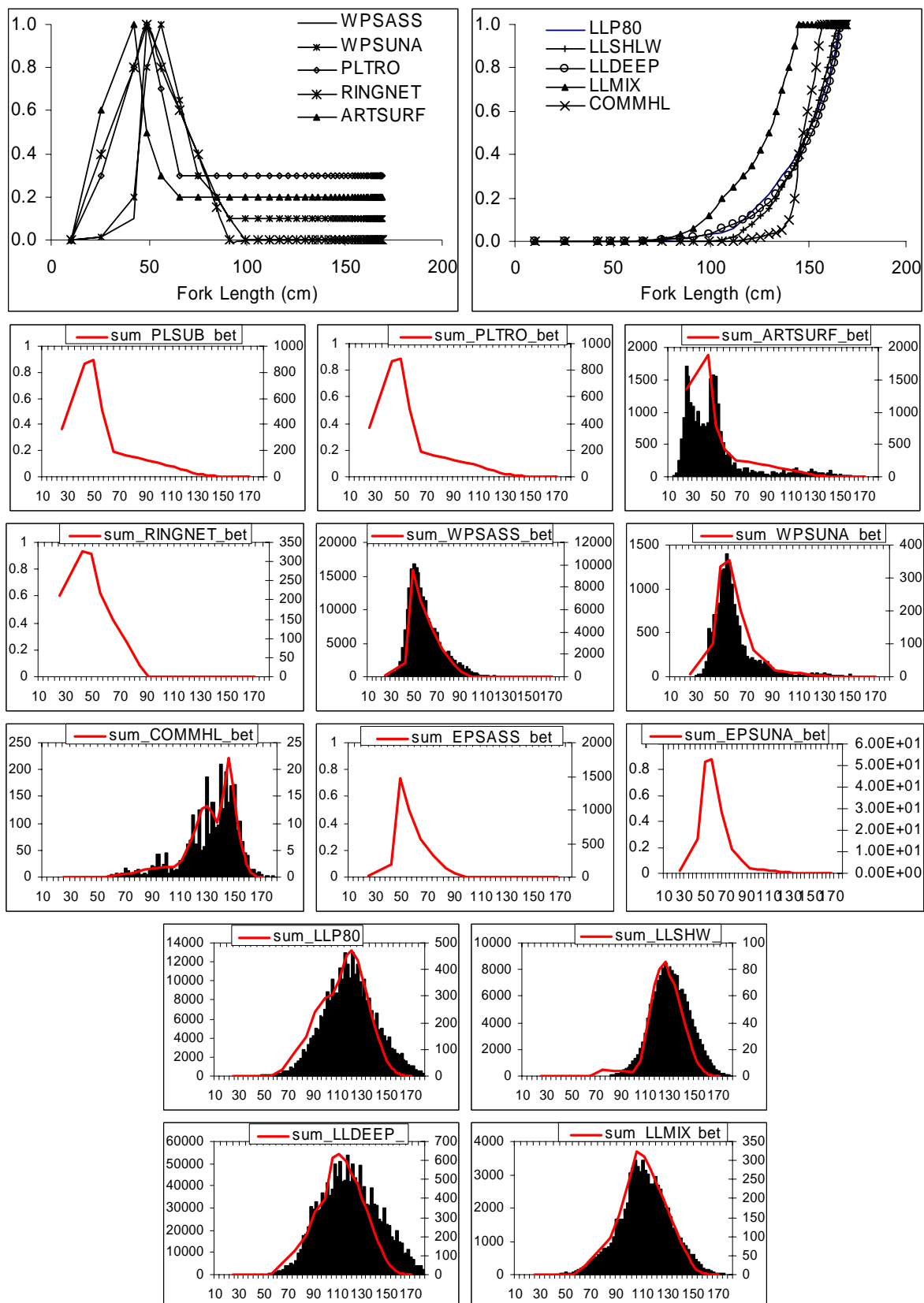
Figure 9 (cont.) Selectivity functions for **bigeye** fisheries and comparison (when possible) between length frequency distribution of observed (histograms) and predicted (black curves) of catch

Parameterization

Adding seasonality increases the correlation between observed and predicted CPUE, with only a slight effect for skipjack (with a decrease in spatial correlation) and the strongest positive effect on yellowfin. In all cases, adding variability of natural mortality related to habitat increases correlations both at spatial scale and for CPUE time series. From the series of simulations tested, the selected parameterization that was retained included seasonality for all species, a decreasing value of ε from 1.5 for skipjack to 1 for yellowfin and 0.5 for bigeye, and conversely an increasing value of α from 2 for skipjack to 3 for yellowfin and 4 for bigeye.

CPUE and spatial correlations

Comparison between observed and predicted CPUE for the main fisheries by species is presented on figure 10. In most cases, the large trends are reasonably reproduced. It is worth to note here that for several fisheries (ringnet, artisanal surface fisheries, and commercial handline), time space distributions of fishing effort and catch were extrapolated from aggregated data series (sometimes, only a total quarterly catch is available). In addition, identification of juvenile bigeye in the surface fisheries is a critical issue that likely led to biases in catch reports for this species, particularly in the early period of development of these fisheries in absence of well developed fishing observers networks. Taken into account such considerations and also the broad definition of fisheries and the constant catchability by fishery, this parameterization produced a set of CPUE trends that is fairly satisfactory for a first application. Obviously, increasing the fit between predicted and observed CPUE will remain an objective of future analyses and tests of parameterization.

Space-time correlation between predicted and observed catch is medium to high (Table 6). Depending of the fishery, and without considering the fisheries for which fishing effort was extrapolated, the model explains between 25 and 80% of the time-space variability.

Table 6. Average correlation between spatially-disaggregated monthly time series of observed and predicted catch by fishery and species

	Skipjack	Yellowfin	Bigeye
PLSUB	0.454	0.784	0.765
PLTRO	0.792	0.740	0.595
WPSUNA	0.604	0.632	0.624
WPSUNA	0.699	0.647	0.785
EPSASS	0.614	0.592	0.873
EPSUNA	0.583	0.671	0.929
RINGNET*	0.999	1.000	0.997
ARTSURF*	0.894	0.900	0.900
COMMHL*	0.950	0.985	0.979
LLP80		0.645	0.477
LLSHW		0.841	0.652
LLDEEP		0.681	0.569
LLMIX		0.821	0.575

* All or part of the fishing effort time-space distribution was missing and extrapolated proportionaly to the observed catch.
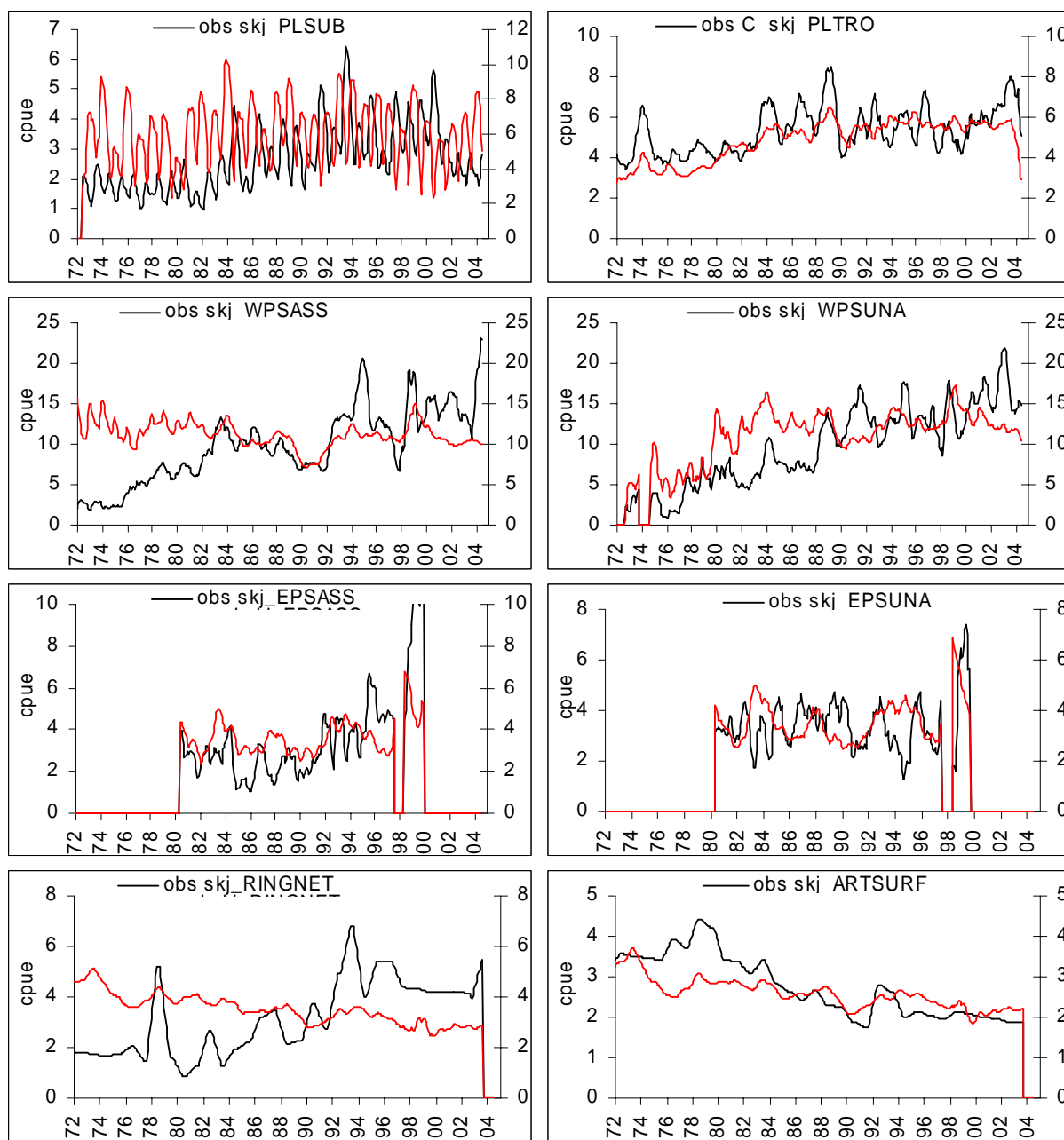
Figure 10. Comparison between observed (black curves) and predicted (red curves) monthly time series of CPUE for the main **skipjack** fisheries. CPUE are in tonnes per unit of fishing effort (days).
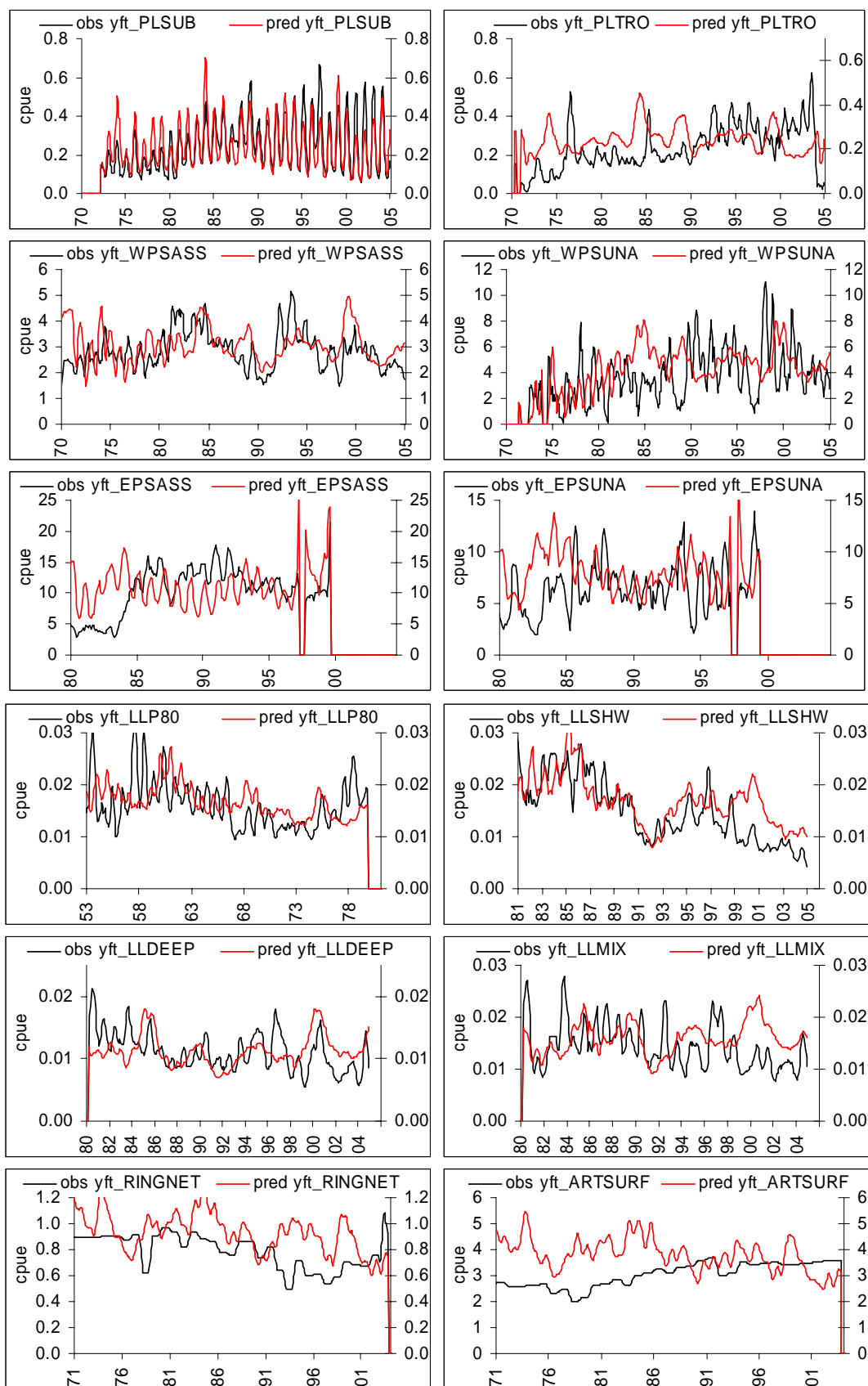
Figure 10 (cont.). Comparison between observed (black curves) and predicted (red curves) monthly time series of CPUE for the main **yellowfin** fisheries. CPUE are in tonnes per unit of fishing effort (either days or 100's hooks for longline).
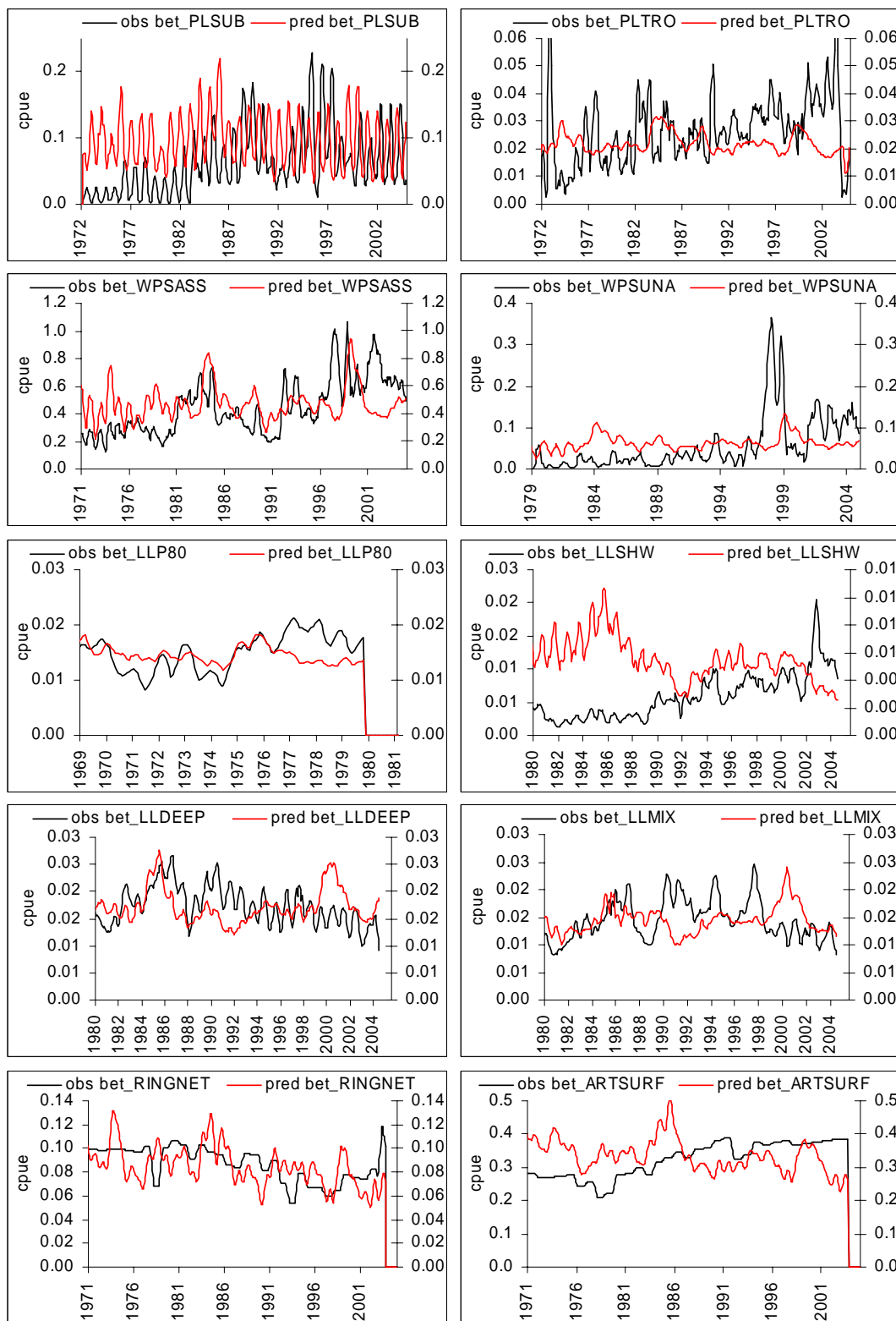
Figure 10 (cont.). Comparison between observed (black curves) and predicted (red curves) monthly time series of CPUE for the main **bigeye** fisheries. CPUE are in tonnes per unit of fishing effort (either days or 100's hooks for longline.

Biomass time series

Figure 11 presents the biomass time series for the three species both in the western central (WCPO) and eastern (EPO) Pacific Ocean with a comparison to the statistical estimates of MULTIFAN-CL (Hampton et al. 2005a; 2005b) for the WCPO and A-SCALA (Maunder, 2003; Maunder et al., 2003) for the EPO. Details by region for bigeye tuna will be discussed during the Method Working Group (Lehodey 2005b).

SEAPODYM skipjack series has slightly lower amplitude in the fluctuation but presents a good match in the high and low peaks predicted by MULTIFAN-CL in the WCPO. However, the large increase predicted by MULTIFAN-CL in the recent years is not predicted. For yellowfin, both estimates predict a decrease from the early 60s to the mid-70s in the WCPO, then SEAPODYM predict two very high peaks in 1984 and 1999 but diverge from the MULTIFAN-CL estimates in the recent years. In the EPO, there is a large drop in the early 1980s clearly associated to the start of the purse seine fisheries (at least in the data series available) then both SEAPODYM and ASCALA series show an increase in 1984. Finally for bigeye, as for yellowfin there is a decrease in the WCPO during the 60s that is much marked than for yellowfin and stabilization with two high peaks also in 1995 and 2000, i.e. roughly shifted by one year when compared to yellowfin. In the EPO, a large peak also centered on 1985 is predicted by both SEAPODYM and statistical estimate from ASCALA.

Clearly, high peaks in biomass of these three species are following the strongest El Niño events, particularly those of 1982-83 and 1997-98.

It was interesting to test the same parameterization but without any fisheries effort to reproduce the natural trends in biomass of these stocks predicted without fishing impact. This is presented on figure 12 where both time series of biomass with and without fisheries are superimposed for the WCPO and EPO. The fishing impact is predicted to be very low for skipjack, but much higher for yellowfin and bigeye after the 1980's in both the WCPO and EPO. However, these results are strongly dependent of the scaling of the average biomass that is based on the average biomass predicted from MULTIFAN-CL.

It is worth noting that the increase of catch of the last three decades would have beneficiated of a natural trend to a higher productivity regime since the mid-70's. The question of a shift back to a lower productivity regime since 1999 is therefore critical for the management of these stocks in the next decades.

Impact of climate variability on spawning and recruitment

Most of the variability in the biomass of tuna stocks described above is predicted to be due to climate-related effects on the spawning and subsequent recruitment. The effect of interannual ENSO variability is easily visible on figure 13 with a large increase of juvenile biomass during El Niño events in the central Pacific region. Lower (higher) frequency of El Niño (La Niña) events during the period 1950-75 and conversely higher frequency during 1976-1998 have resulted in average decadal regimes of low and high productivity (Fig. 14). When comparing the recent period 1999-2004 to the previous one 1976-98 (Fig. 15), it appears that the three species have accumulated a deficit of biomass of their juvenile age classes in the

WCPO, with the likely consequence of a decline in the adult population of yellowfin and bigeye in the next few years, particularly if there is no El Niño events.
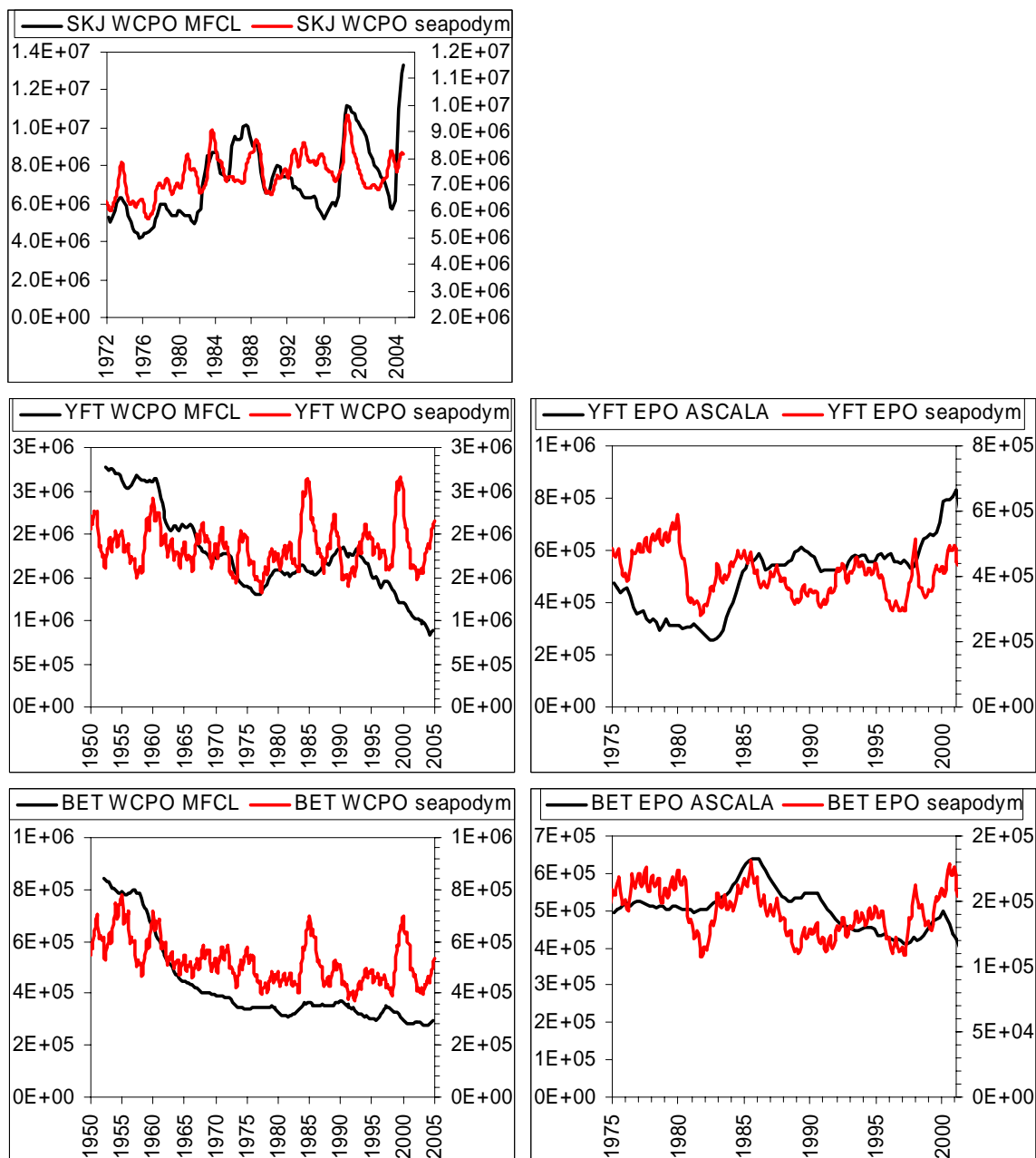

Figure 11. Time series of total biomass (tonnes) of skipjack yellowfin and bigeye tuna predicted from SEAPODYM (red curves) and compared to MULTIFAN CL and A-SCALA estimates (black curves) in the WCPO and EPO respectively
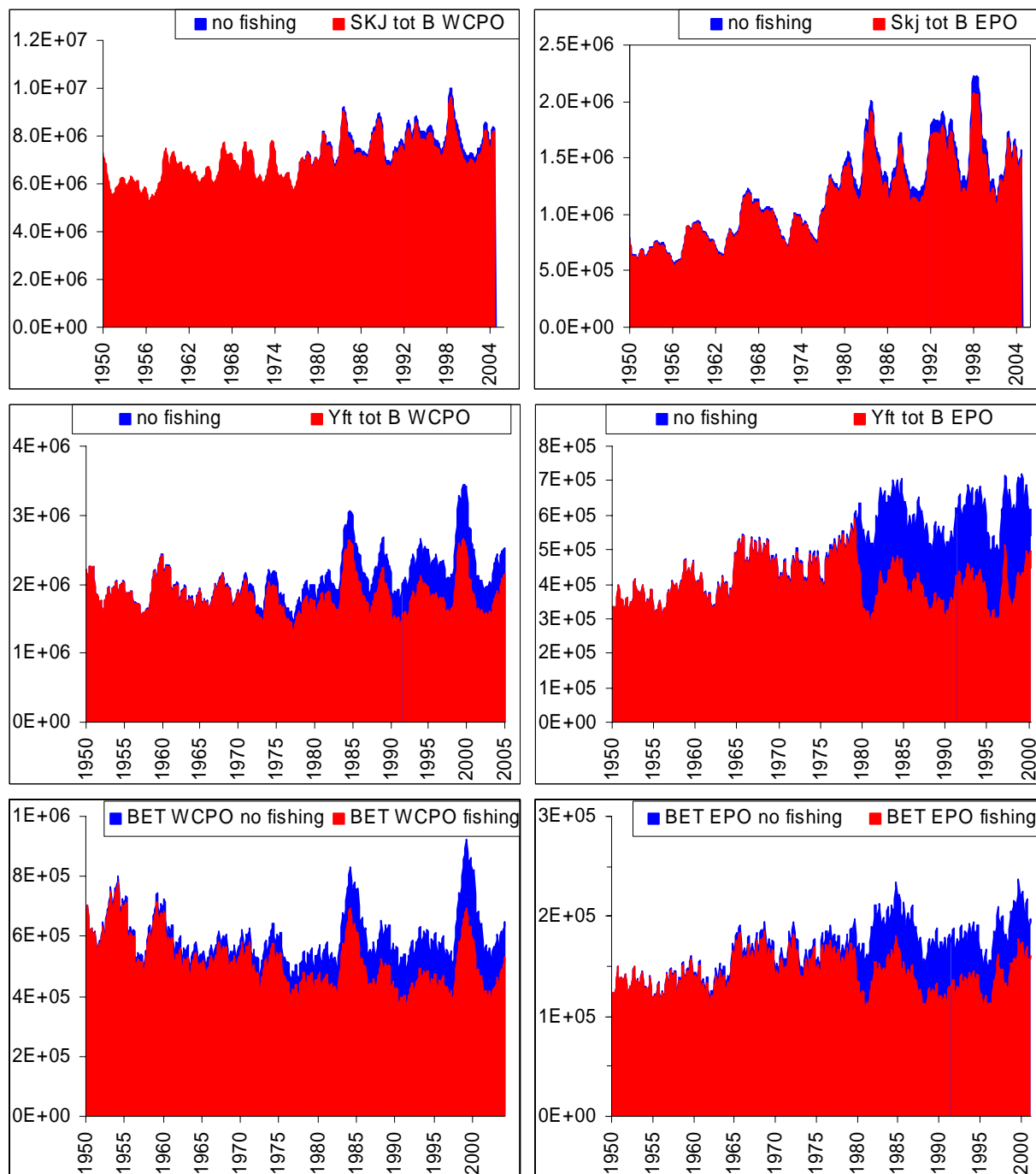
Figure 12. Time series of total biomass (tones) of skipjack, yellowfin and bigeye tuna with (red) and without (blue) fishing impact in the WCPO (left) and EPO (right).
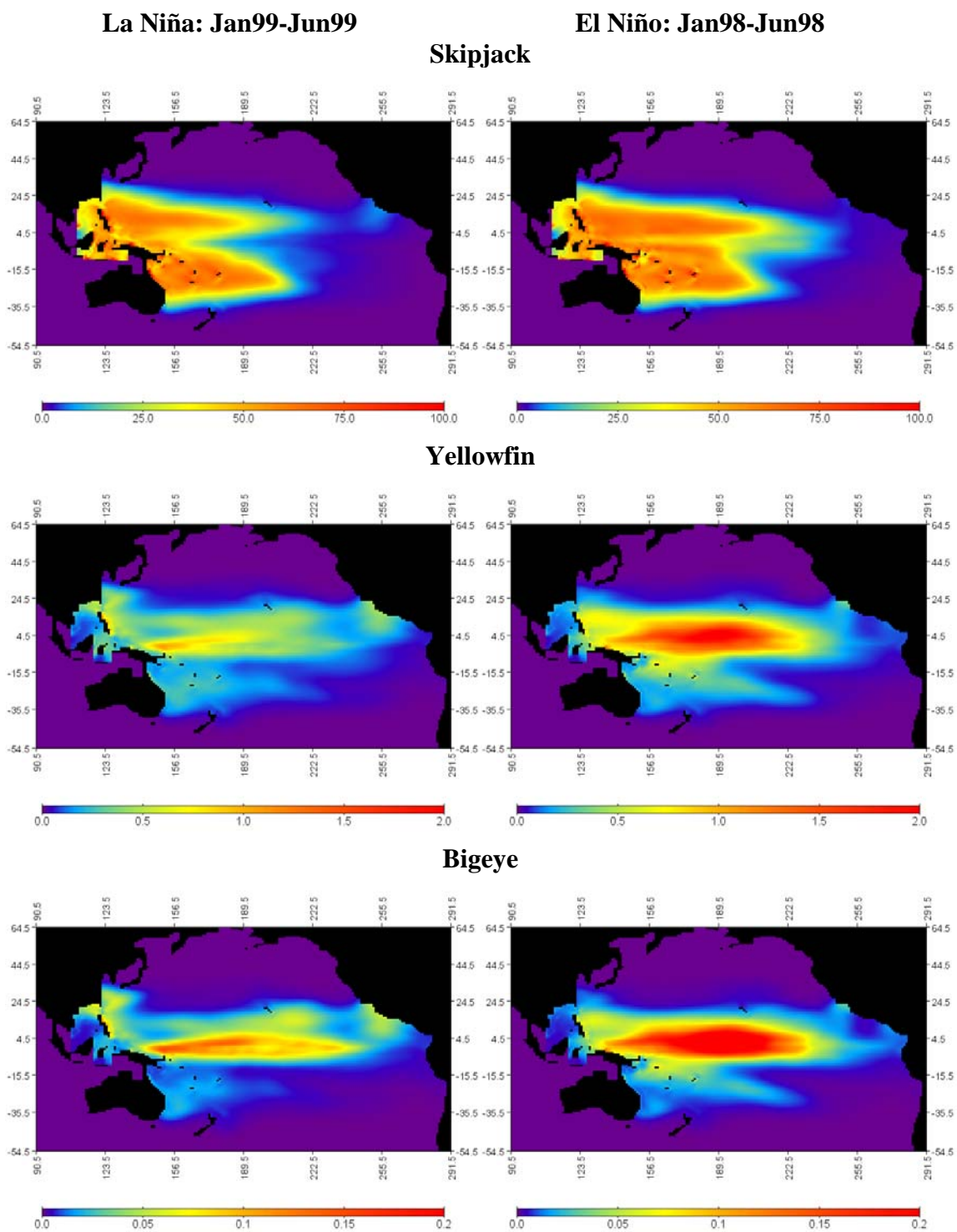
La Niña: Jan99-Jun99   **El Niño: Jan98-Jun98**

Skipjack

Yellowfin

Bigeye

Figure 13. Average predicted spatial distribution during La Niña (left) and El Niño (right) phase of juvenile (age 1 and 2 months) biomass (mg.m-2) of skipjack (top), yellowfin (middle) and bigeye (bottom).

1950-75　　　　　　　　　　　　　　　　**1976-98**

Skipjack
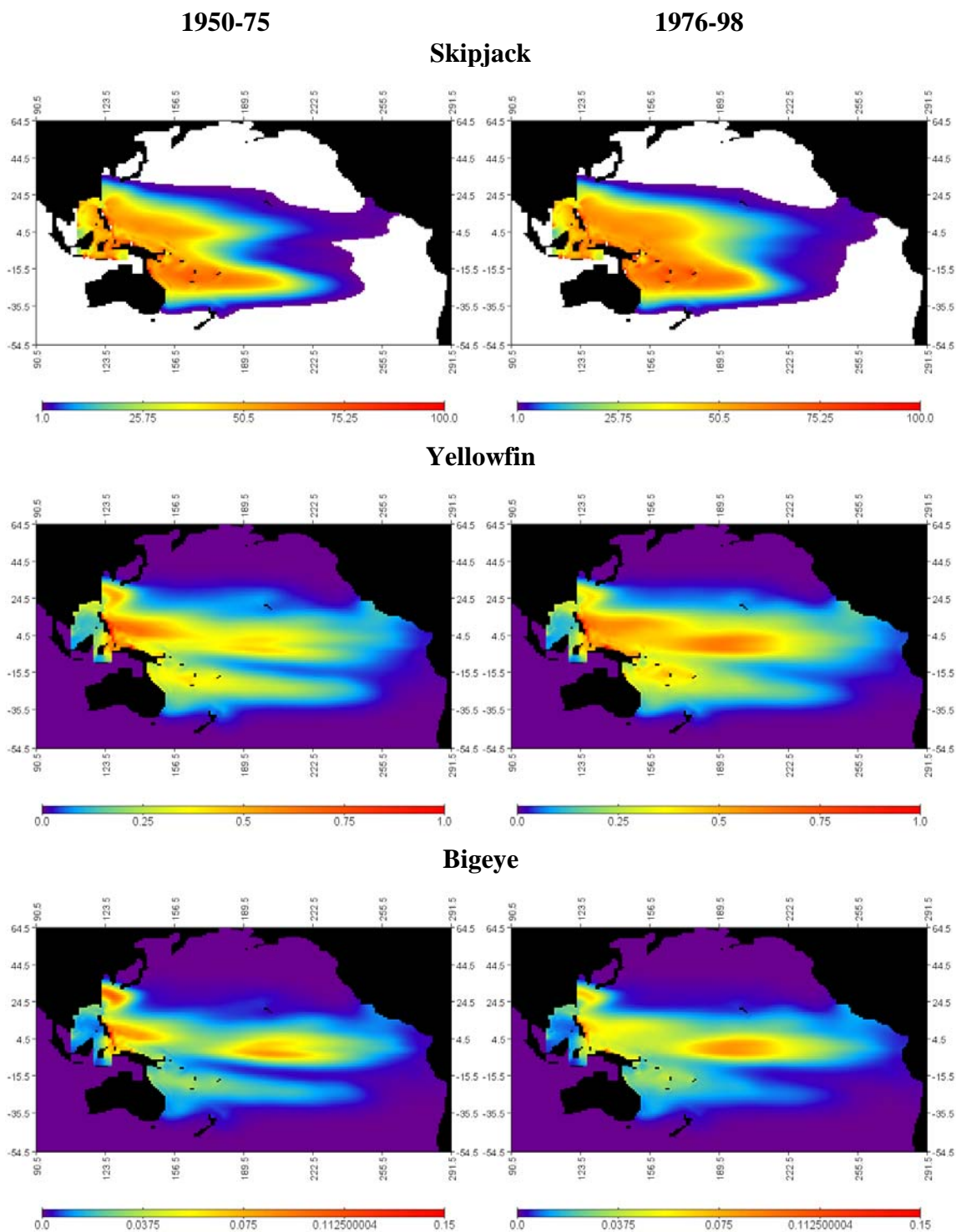
Yellowfin

Bigeye

Figure 14. Average predicted spatial distribution of juvenile (age 1 and 2 months) biomass (mg.m^{-2}) of skipjack, yellowfin and bigeye for the period 1950-75 (left) and 1976-99 (right).
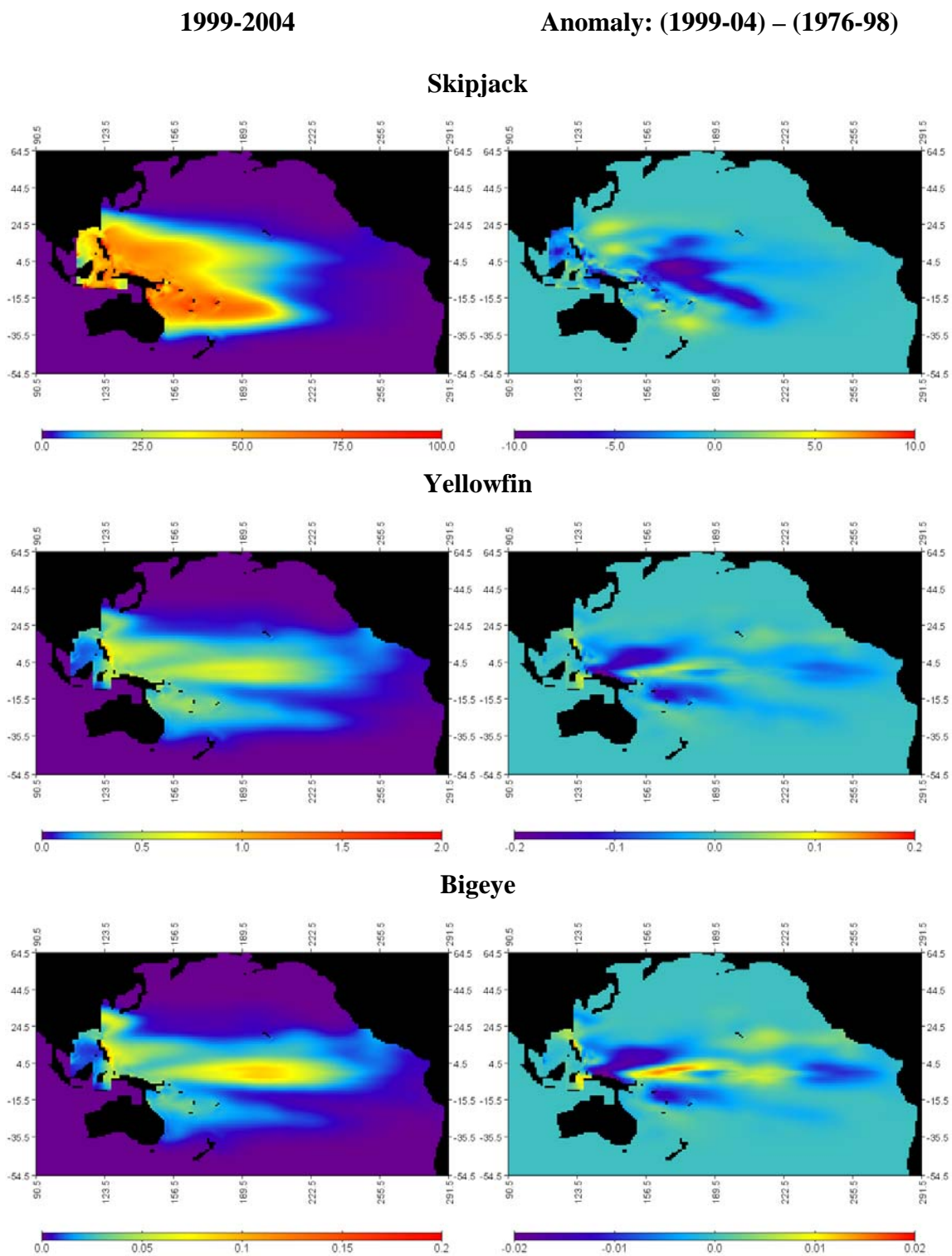
1999-2004   **Anomaly: (1999-04) – (1976-98)**

Skipjack

Yellowfin

Bigeye

Figure 15. Average predicted spatial distribution of juvenile (age 1 and 2 months) biomass (mg.m^{-2}) of skipjack, yellowfin and bigeye for the period 1999-2004 (left) and its anomaly relatively to the previous period 1976-98 (right).

Conclusion

There is still a large possibility to improve the predictions for these three tuna species with SEAPODYM. Nevertheless, the results appear coherent together, capture the main features described from (limited) observations for the pelagic micronekton and tuna larvae distribution (Nishikawa et al. 1985), converge fairly well with statistical estimates, and produce relatively high levels of correlation of spatial catch distributions. Parameterization for albacore still needs to be developed and multi-species simulations compared to single-species simulations to investigate how forage predation affects the spatial distribution and the recruitment of these species. In parallel, implementation of an optimization function for a statistical estimation of the parameters remains a priority.

Previous conclusions on the impact of ENSO on the recruitment (Lehodey et al. 2003) are confirmed and point to a clear link between tuna recruitment and climatic fluctuations. Recruitment in the last 5 years for the three species is predicted to be lower than the average of the highly productive period 1976-1998. It is still difficult to assert that this trend is due to a shift to a new decadal climate regime, though evidence for such a shift in the North Pacific is increasing. In addition, even if this decadal climate regime shift is actually occurring, it does not mean necessarily that the situation will return to the one existing in the period 1950-1975, especially since the global warming due to greenhouse effect can substantially modify the physical oceanic environment and then the pelagic ecosystem (Loukos et al. 2003).

The potential impact of global warming on tuna population will be explored by running a simulation with SEAPODYM using the last simulation output available for the time period 1860-2100 (based on the IPCC SRESA2 scenario for 2000-2100) at a global scale with a monthly resolution of 2° square (IPSL, France). This simulation should supply discussions and analyses in the different working groups of the GLOBEC CLIOTOP project (Maury and Lehodey, 2005) to identify potential key-mechanisms in the model, responsible of major changes observed in the simulation, and that would require better definition, parameterization and evaluation.

References

Chen, D., L.M. Rothstein and A.J. Busalacchi, 1994. A hybrid vertical mixing scheme and its application to tropical ocean models. J. Phys. Oceanog., **24**: 2156-2179.

Christian, J., M. Verschell, R. Murtugudde, A. Busalacchi, and C. McClain, 2002. Biogeochemical modeling of the tropical Pacific Ocean I: Seasonal and interannual variability. Deep Sea Res. II, **49**: 509-543

Gent, P. R., and M. A. Cane, 1989. A reduced gravity, primitive equation model of the upper equatorial ocean. Comp. Phys., **81**: 444-480.

Grandperrin R., 1975. Structures trophiques aboutissant aux thons de longues lignes dans le Pacifique sud-ouest tropical. Thèse de Doctorat, Université de Marseille.

Hackert, E., A. Busalacchi, R. Murtugudde, 2001. A wind comparison study using an ocean general circulation model for the 1997-98 El Niño. J. Geophys. Res., **106**: 2345-2362.

Hampton J., Kleiber P., Langley A., Takeuchi Y., Ichinokawa M., 2005a. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **SA WP–1**

Hampton J., Kleiber P., Langley A., Takeuchi Y., Ichinokawa M., Maunder M., 2005b. Stock assessment of bigeye tuna in the western and central Pacific Ocean, with comparisons to a Pacific-wide assessment. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **SA WP–2**.

Lehodey P., 2000. Impacts of the El Niño Southern Oscillation on tuna populations and fisheries in the tropical Pacific Ocean. Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia. 13th SCTB, Noumea New Caledonia, 5-12 July 2000. Working Paper **RG-1**: 32 pp

Lehodey P., 2004a. A Spatial Ecosystem And Populations Dynamics Model (SEAPODYM) for tuna and associated oceanic top-predator species: Part I – Lower and intermediate trophic components. 17th meeting of the Standing Committee on Tuna and Billfish, Majuro, Republic of Marshall Islands, 9-18 Aug. 2004, Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia, *Working Paper*: **ECO-1**: 26 pp.

Lehodey P., 2004b. A Spatial Ecosystem And Populations Dynamics Model (SEAPODYM) for tuna and associated oceanic top-predator species: Part II – Tuna populations and fisheries. 17th meeting of the Standing Committee on Tuna and Billfish, Majuro, Republic of Marshall Islands, 9-18 Aug. 2004, Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia, *Working Paper*: **ECO-2**: 36 pp.

Lehodey P., Chai F., Hampton J. 2003. Modelling climate-related variability of tuna populations from a coupled ocean-biogeochemical-populations dynamics model. *Fisheries Oceanography,* **12**(4): 483-494

Lehodey P., 2005a. Reference manual for the Spatial Ecosystem And Populations Dynamics Model SEAPODYM. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME IP–1**

Lehodey P., 2005b. First application of SEAPODYM to Pacific bigeye tuna. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME-WP-1**

Leonard, C.L., C.R. McClain, R. Murtugudde, E. E. Hofmann, and L.W. Harding, Jr., 1999. An iron-based ecosystem model of the central equatorial Pacific. *J. Geophys. Res.* **104**: 1325-1341

Li, X., Chao, Y., McWilliams, J.C. and Fu, L-L (2001) A Comparison of Two Vertical-Mixing Schemes in a Pacific Ocean General Circulation Model. Journal of Climate **14** (7):1377-1398

Loukos H., Monfray P., Bopp L., Lehodey P., 2003. Potential changes in skipjack tuna habitat from a global warming scenario: modeling approach and preliminary results. *Fisheries Oceanography*, **12**(4): 474-482

Maunder, M. 2003. Status of yellowfin tuna in the eastern Pacific Ocean in 2001 and outlook for 2002. Inter-American Tropical Tuna Commission (IATTC), La Jolla, CA. 15th meeting of the Standing Committee on Tuna and Billfish, Honolulu, Hawaii, USA, 22-27 July 2002, *Working Paper:* **YFT-3**.

Maunder M. and Harley S., 2003. Status of bigeye tuna in the eastern Pacific Ocean in 2001 and outlook for 2002. Inter-American Tropical Tuna Commission (IATTC), La Jolla, CA. 15th meeting of the Standing Committee on Tuna and Billfish, Honolulu, Hawaii, USA, 22-27 July 2002, *Working Paper:* B**ET-2**.

Maury O. and Lehodey P. (Eds.), 2005. Climate Impacts on Oceanic Top Predators (CLIOTOP). Science Plan and Implementation Strategy. GLOBEC Report No. 18, ii, 42 pp. (http://www.pml.ac.uk/globec/structure/regional/cliotop/cliotop_science_plan.pdf)

Murtugudde, R., R. Seager and A. Busalacchi, 1996. Simulation of the tropical oceans with an ocean GCM coupled to an atmospheric mixed layer model. *J. Clim.* **9**: 1795-1815.

Nishikawa Y., Honma M., Ueyenagi S., Kikawa S., 1985. Average distribution of larvae of oceanic species of scombrid fishes, 1951-81. Contribution of the Far Seas Fisheries Research Laboratory, Fishery Agency of Japan **236**: 1-99.

Senina, I.N., Sibert, J.R., Lehodey P. 2005. SEAPODYM on a mixed-resolution spatial scale. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME WP–2**.