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SEAPODYM perspectives as management tool for albacore (*Thunnus alalunga*) in the South Pacific Ocean..

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Executive Summary

1. SEAPODYM provides a general framework for the integration of biological and ecological knowledge of tuna species and their responses to fishing pressure within a maximum likelihood approach for parameter estimation. It incorporates several types of forcing for modeling tuna population dynamics, including, environmental data, forage data and fisheries data. The model is age-structured and the spatial and vertical migrations are modeled based on a set of diffusion-advection reaction equations and habitat quality indices. It is assumed that migration, reproduction and mortality are influenced by physical and biogeo-chemical conditions. The environmental data series are used to build habitat suitability indices (thermal habitat index, spawning habitat index, feeding habitat index and migration index) that control the population dynamic processes.

2. The environmental forcing of SEAPODYM allows the spatial resolution of the models it generates to be user defined and consequently, with data permitting, the spatial distribution of tuna abundance can be modelled at high resolution. An example of the higher resolution capabilities of SEAPODYM is provided for South Pacific albacore (*Thunus alalunga*) where the spatial distribution of tuna abundance is modelled at 2 degree resolution. Comparisons are made with the results generated by MULTIFAN-CL, which was used for the 2009 stock assessment for South Pacific albacore, to evaluate the performance of the model.

3. During initial evaluations the biomass estimates from SEAPODYM were an order of magnitude higher than those predicted by MULTIFAN-CL for the same period. Initial exploration of potential causes for this discrepancy indicated that the initial age structure was responsible. A multiplier was added to force the SEAPODYM initial age structure from the spin-up to resemble the initial age-structure from MULTIFAN-CL.

4. Our results and examination of model diagnostics indicate that the population dynamics of South Pacific albacore was satisfactorily described by SEAPODYM. The estimated catch and size composition data estimated by SEAPODYM corresponded closely with the observed data. The estimated biomass had a decreasing tendency and was in the same order of magnitude as the MULTIFAN-CL estimate once the multiplier was implemented; the majority of the differences between these two estimates were smaller than 25%. Similarly, for recruitment, both estimates followed the same trend in the same order of magnitude. Results suggest that the estimates of the predation mortality slope coefficient, the maximum aging mortality, the dissolved oxygen threshold value and a multiplier factor used in the model produced a consistent population dynamics for albacore in the south Pacific. The maximum aging mortality and several fisheries parameters (catchability and selectivities) were highly correlated. Similarly, some catchability and selectivity parameters were correlated. SEAPODYM reproduced the main features observed in the annual albacore migration and the juvenile distribution in New Zealand.

5. After the model fitting was completed simulations were undertaken to explore how South Pacific albacore spatial population dynamics change under different fishing effort

scenarios by projecting the population into the future. For the future fishing mortality, we defined the reference effort (E_{ref}) as the average of the last five years. We explored five scenarios of alternative fishing effort, including 50%, 100%, 150%, 200% of the E_{ref} and a no-fishing scenario. We projected the population for 20 years with 2003 set as the first year of the simulation. All of the scenarios predicted a future decreasing biomass except for the scenario of no-fishing mortality where the biomass was 111% of the starting adult biomass. The lowest projected adult biomass corresponded to the 200% E_{ref} level. In this scenario, the estimated biomass was 33% of the starting biomass. When the future effort was reduced to 50% E_{ref} the simulated biomass in the last year was 63% of the biomass in 2003. Maintaining the current levels of effort produced a biomass that was 56% of the 2003 biomass. Recruitment under these scenarios was dependent on the fishing mortality simulated. Different levels of effort produced different trajectories of recruitment. The lowest recruitment corresponded to the 200% E_{ref} level and the highest recruitment corresponded to the no fishing scenario where recruitment remained almost constant through the years.

6. Zooming at the EEZ scale suggested the average (1971-2003) percentage of biomass available in the French Polynesia EEZ was 6.1% of the total available biomass in the region. Our simulations on fishing effort suggested a decrease of the percentage biomass available in that EEZ with increasing effort. The average available biomass for the New Zealand EEZ was 6.3%. Contrary to the French Polynesia an increase in the percentage of biomass available was observed under alternative fishing efforts within the New Zealand EEZ. Cook Islands (2.0%) and New Caledonia (1.9%) had similar average percentage of biomass available within their EEZs. The projections suggested the biomass available in the Cook Islands EEZ will remain mostly constant and an increase in the New Caledonia EEZ was predicted. The rest of the Pacific Islands analyzed had smaller percentage of biomass available in their EEZs. The average available biomass in Tokelau, Nuie, Tonga, Samoa were 0.21%, 0.63%, 1.0% and 0.1% respectively. In the projections, all these countries had a slight increase in their respective average biomass. Regarding the average monthly availability of adult biomass, for French Polynesia, Cook Islands, Tonga, Niue and New Caledonia, the highest availability of biomass within their EEZ is found in the second part of the year. On the contrary for New Zealand there is a decrease. The availability of monthly biomass remains almost constant through the year for Tókelau and Samoa.

7. Our results suggest that SEAPODYM is a complementary and useful tool in the ecosystem approach to fisheries management, providing additional information to assure sustainable exploitation of tuna populations and avoiding pelagic ecosystem degradation. In regard to model development the following areas would benefit from further investigation of:

    a. The influence of the albacore initial age-structure used as input data. We noted that the initial age structure generated by SEAPODYM and that generated by MULTIFAN-CL were different. When we applied a multiplier to the SEAPODYM initial age structure to force it to replicate the MULTIFAN-CL initial age structure our biomass estimates between the two models were comparable. We recommend a review of the approach adopted to generate the initial age structure in SEAPODYM to avoid the potential for overestimation. Options worth exploring include: (1) the addition of fishing mortality in the estimation process; and (2) applying the MULTIFAN-CL approach, where the initial younger age class is estimated statistically and the subsequent age classes are estimated assuming equilibrium.

b. The use of higher resolution data. Current efforts are also focused in the use of environmental and fishing data with higher resolution, preliminary results suggest that the likelihood value improves and that discrepancy in biomass estimates between SEAPODYM and MULTIFAN-CL is reduced (see SC7-EB-WP-06). The application of methods that adjust the catch data for non-modeled effects such as vessel could also prove beneficial (see SC7-EB-IP-05).

c. Understanding the interaction between recruitment and effort. We noted that when we projected the population the estimated recruitment was effort dependent. The level of recruitment decreased when the effort augmented. Analysing the effects of changing the values in the Beverton-Holt recruitment parameters is recommended. In addition, the projected environmental forcing is the monthly average forcing repeated for each year. This might be one of the potentials causes for the lack of variability observed in the recruitment projected. A potential solution could be the use of the standard IPCC emission scenarios used in the exploration of the effects of Global warming. A second approach to this problem could be the use of the historical environmental forcing already used in the model.

Introduction

Prior to 2001 South Pacific albacore catches ranged between 25,000 – 44,000 t however more recently the catch has increased to between 51,000 and 66,000 t due to the expansion of domestic longline fisheries in the Pacific Island Countries. The economical and ecological importance of tuna requires that their stocks are exploited at sustainable levels. This task requires adequate fishing strategies and good stock assessment tools able to assess the potential effects of different levels of future fishing effort/mortality and environmental variability. Currently MULTIFAN-CL is the main tool used in the stock assessment of albacore in the South Pacific. MULTIFAN-CL is a state-of-the-art single species model that is size based, age-structured model, fitting time series of catch and size composition data (Hampton and Fournier, 2001). However, due to the lack of high spatial resolution, this model cannot provide accurate scientific support for management at national level; thus, it does not respond to recent calls by PCIT for developing tools and strategies to evaluate national impacts from fishing management measures at regional level. This task requires the development and improvement of stock assessment tools.

Assessment of the historical, present and future states of marine ecosystem and the effects that human exploitation and climate variation have on the ecosystems are necessary to implement an ecosystem-based fishery management system (Livingston *et al.*, 2005). In particular, understanding how tuna populations respond to environmental variability and fishing pressure is a major challenge for developing this approach. Thus, the modeling of tuna population dynamics should be focused on mechanisms linking the biological and physical components of marine ecosystems and exploring their responses to different types of physical forcing, biological interactions, exploitation and their potential synergies and uncertainties. In the Pacific Ocean, a spatial ecosystem and population dynamics model (SEAPODYM) has been developed for providing a general framework for the integration of biological and ecological knowledge of tuna species and other oceanic top predators and their responses to fishing pressure (Lehodey et al. 2008). SEAPODYM has been used to assess the population dynamics of bigeye *Thunnus obesus* and skipjack *Katsuwonus pelamis* (Lehodey *et al.* 2008; Senina *et al.* 2008) and is also being applied for sword fish and turtles in the North Pacific and sardine and anchovies off the Peruvian coast. Previous work with this model has been focused on describing the spatial dynamics of tuna species driven by bio-physical environmental forcing and spatially allocated fishing effort (Lehodey et al. 2008) and the validation of the model through the use of statistical parameter estimation in a maximum likelihood estimate framework.

In this work, we present preliminary results of the potential use of SEAPODYM as a management tool for assessing the status of the stock and the potential consequences of different levels of fishing mortality and environmental variability in the future population dynamics of South Pacific albacore at regional and national levels. This approach will contribute to establish an ecosystem approach to fisheries management in the south Pacific region through providing additional information to fisheries managers, useful in the decision making process for assuring a sustainable exploitation of tuna resources.

Methods

SEAPODYM is a 2D coupled physical-biological-fisheries model at ocean basin scale with a maximum likelihood estimate approach for the estimation of model parameters and fitting fisheries data (Senina et al. 2008). In contrast to several fisheries models, SEAPODYM incorporates several types of forcing for modeling the spatial tuna population dynamics, including, environmental data (temperature, currents velocity, dissolved oxygen, euphotic depth and primary productivity), forage data (derived from a SEAPODYM sub-model) and fisheries data. The model is age-structured and the spatial and vertical migrations are modeled based on a set of diffusion-advection reaction equations (ADR) and habitat quality indices. It is assumed that migration, reproduction and mortality are influenced by physical and biogeo-chemical conditions; thus the environmental data series are used to build habitat suitability indices (thermal habitat index, spawning habitat index, feeding habitat index and migration index) controlling the population dynamical processes.

The current SEAPODYM version assumes only observation error on fisheries data and the maximum likelihood estimate approach is used for fitting the model to observed spatially distributed catch data and size composition. For the spatially scattered catch, the model assumes a Poisson distribution; However if the catch contains many zeros the negative binomial with zero inflation could be used. For the size composition a log-normal distribution was assumed (Senina *et al.*, 2008). The main assumptions and the equations from the SEAPODYM model are described in detail in Lehodey *et al*. (2008) and Senina *et al*. (2008). SEAPODYM is implemented in C++ and uses the library AUTODIF from ADModel builder (Fournier 1996) pre-compiled with gcc3.4.6 for Linux 64-bit. Due to the availability of forcing data, the model was set up monthly from January of 1971 to December 2003 and it was restricted by the coordinates: 59.75 $^{\circ}$ latitude south, 9.75° latitude north, 142.25° longitude east, and 111.75°

longitude west with a 2 degrees resolution. The forcing fields used were provided by a coupled biogeochemical-physical model that reproduces the ecosystem dynamics at seasonal and interannual scales (Christian et al. 2002; Wang et al. 2005). Twelve fisheries were defined with assumed constant catchability coefficients and selectivity parameters (Table 1). The albacore catch spatial distribution is shown below (Figure 1). The initial age-structure was generated by a "spin-up" process (Senina et al. 2008). It is important to mention that during initial runs, although the model fit the observed data well, the biomass estimates were an order of magnitude higher than the MULTIFAN-CL estimates. Initial exploration of potential causes for this discrepancy suggested that the initial age structure was potentially responsible; therefore, a multiplier was added to force the SEAPODYM initial age structure from the spin-up to resemble the initial age-structure from MULTIFAN-CL.

Forty three parameters and their uncertainties were estimated including 11 catchability coefficients, 21 selectivity parameters, three parameters for natural mortality, one parameter for the juveniles optimal surface temperature, two parameters for the adults optimal temperature, one parameter for the threshold value for dissolved oxygen, one for the maximum sustainable speed, one for the half saturation constant for the predator's food, multiplier for diffusion, one for the coefficient of fish diffusion (Senina *et al.*, 2008). Although SEAPODYM has an important number of outputs, we focus on estimated parameters, recruitment and adult biomass.

After the model fitting was done, exploring management options required projections of the albacore spatial population dynamics with assumptions regarding future fishing effort, recruitment and environmental forcing. These projections were carried out using SEAPODYM in simulation model. For the future fishing mortality, we defined the reference effort (E_{ref}) as the average of the last five years. We explored five scenarios of future fishing effort, including 50%, 100%, 150%, 200% of the reference effort and a no-fishing scenario. Currently, the only option implemented for the future environmental forcing is the monthly average of the environmental forcing for the period of time provided as input. Therefore the same monthly average values were repeated for each year in the projection. Thus the environmental forcing projection lacks interannual variability. Future recruitment was modeled as in the SEAPODYM stock assessment module, where is assumed that recruitment follows the Beverton-Holt equation and it is modified by the spawning habitat index H_s that constrains the larval production and its mortality:

$$R = \frac{aN}{1+bN} H_s$$

This index depends on the surface layer temperature, the micronekton biomass in the surface and the primary production. More details for this index are found in (Lehodey *et al.*, 2008).

To analyze the potential effects of regional policies in PCIT EEZ we zoom in the SEAPODYM results using a mask of 2 degrees x 2 degrees resolution. The biomass in SEAPODYM is the product of the density times the area times the weight. Therefore, we also used a correction factor for the estimate of biomass at the EEZ:

$$Correction \quad factor = \frac{A_R}{A_M}$$

Where A_R is the area estimated with Mapinfo version 5.5 for Windows, and A_M is the area used in the 2 degrees x 2 degrees mask mentioned. As an example, we explore the implications on the following PCIT: Cook Islands, French Polynesia, New Caledonia, New Zealand, Niue, Samoa, Tokelau and Tonga. We projected the albacore population for twenty years and we used the ratio of adult biomass in 2023 to the biomass in 2003 and the recruitment as performance indices.

Results

SEAPODYM fitted the observed albacore catch from twelve fisheries from 1971 to 2003 well (Fig. 2). However, SEAPODYM had difficulties fitting the last part of the catch data series for some fisheries (4, 6 and 10). The residuals analysis for each fishery suggested lack of homocedasticity for some fisheries and the inability of SEAPODYM to predict large catch values. Regarding the observed size composition data, SEAPODYM shows a good fit to the observed values (Figure 3). Parameter estimates and their standard error are shown below (Table 2). In particular, the maximum aging mortality was 0.22 ± 0.001months^{-1}; the optimum temperature for juveniles and adults were 25.31 ± 0.01°C and 6.00 ± 0.01°C respectively, the threshold value for dissolved oxygen was 2.71± 0.01 ml/l, and the maximum sustainable speed was 1.92 ± 0.01 body lengths per second.

The SEAPODYM estimated adult biomass in the region defined had a decreasing tendency from 1971 to 2003, with the highest estimated biomass in1971 (6.6×10^5 t) and the smallest estimate in 2000 (2.8×10^5 t). As shown, the adult biomass estimates were in the same order of magnitude as the MULTIFAN-CL estimates but most of the time the SEAPODYM estimates were smaller than the MULTIFAN-CL estimates (Fig. 4). The largest percentage change between these estimates was 71% in 1971; however, the majority of the changes were smaller than 25%. It is important to point out that for the last year of the SEAPODYM assessment (2003) the percentage difference between the SEAPODYM and MFCL estimates was only 6%.

The highest annual estimated recruitment occurred also in 1971 (8.64×10^{10} individuals) and the lowest in 2001 (4.77×10^{10} individuals). In general, the SEAPODYM recruitment estimates were in the same order of magnitude as the MULTIFAN-CL estimates (Figure 6). They had a slight decreasing trend from the beginning of the 70's to the mid 90's and a slight increasing recruitment up to 2003. It is important to point out that SEAPODYM recruitment had less variability than the MULTIFAN-CL estimates with corresponding coefficients of variation of 0.17 and 0.30 respectively. Monthly SEAPODYM recruitment estimates suggested seasonality within a year with a maximum recruitment generally occurring from April to June and a minimum recruitment occurring from November to January.

Regarding the projections, most of the scenarios predicted a future decreasing biomass; the lowest projected adult biomass corresponded to the 200% E_{ref} level. In this scenario, in 2023 the biomass was only 33% of the biomass in the first year of the projection (2003). On the contrary when the future effort was reduced to 50% E_{ref} the simulated biomass in the last year was 63% of the biomass in 2003. It is important to point out that SEAPODYM results suggest that keeping the current levels of effort would produce a biomass in 2023 that is 56% of the 2003 biomass. A scenario of no-fishing mortality was the only producing an increasing biomass. After

20 years of simulation, the biomass was 111% of the adult biomass at the starting year of the simulation.

The projected recruitment presented patterns that are dependent on the fishing mortality. Different levels of effort produced different trajectories of recruitment. Once again the lowest recruitment corresponded to the 200% E_{ref} level and the highest recruitment corresponded to the no fishing scenario where apparently recruitment remained almost constant through the years. It is important to point out that the recruitment used in the projections lacks of variability observed in the results from the MULTIFAN-CL stock assessment and SEAPODYM (Figure 7).

Zooming in the PCIT EEZ suggested the average (1971-2003) percentage of biomass available in the French Polynesia EEZ was 6.1% of the total available biomass in the region under analysis. The SEAPODYM projection suggested a decrease of the percentage biomass available in that EEZ (Figure 8a). The average available biomass for the New Zealand EEZ was 6.3%. Contrary to the French Polynesia case, for New Zealand an increase in the percentage of biomass available was observed. Cook Islands (2.0%) and New Caledonia (1.9%) had similar average percentage of biomass available at their EEZ. The projections suggested the biomass available in the Cook Islands EEZ will remain mostly constant and an increase for New Caledonia. The rest of the IPCT analyzed had smaller percentage of biomass available in their EEZ. The average available biomass in Tokelau, Nuie, Tonga, Samoa were 0.21%, 0.63%, 1.0% and 0.1% respectively. In the projections, all these countries had a slight increase in their respective average biomass (Figure 8b). Regarding the average monthly availability of adult biomass, for French Polynesia, Cook Islands, Tonga, Niue and New Caledonia, the highest availability of biomass within their EEZ is found in the second part of the year. On the contrary for New Zealand there is a decrease (Figures 8c and 8d). The availability of monthly biomass remains almost constant through the year for Tókelau and Samoa.

Discussion

Model performance was assessed statistically with the fitting to observed data but also by meaningful biological results. SEAPODYM fit suggested there is a good agreement between the model and the observed data. Further statistics tests also suggest good performance for the model. Initial runs provided estimates that were significantly higher than MULTIFAN-CL estimates and contradicted biomass trends, SEAPODYM suggested increasing trends in periods of time (2000-2004) where the stock assessment results from MULTIFAN-CL estimated that the biomass decreased (Hoyle and Davis, 2009). Therefore, it was important to explore the origin of these differences. One potential cause is the influence of the albacore initial age-structure used as input data. In SEAPODYM these parameters are not statistically estimated; this initial age structure is the result of running a “spin-up” process in SEAPODYM that starts with uniform null spatial distribution; later, the population is modelled with the ADR and population equations and forced by the climatological environment where every month a new larval recruitment is computed using only the temperature. Fishing mortality is not included in the spin-up process; therefore, there might be an overestimation of the initial age-structure. To compensate this problem in the present SEAPODYM run, we multiply the initial age structure from the “spin-up” by a scaling factor to mimic the initial age structure from MULTIFAN-CL. It seems that this temporal solution worked out and suggests that is recommendable to review the spin-up process to include fishing mortality to avoid overestimation in the initial age structure. Other possibility would be exploring the potential use of the approach taken in the MULTIFAN-CL stock assessment, where the initial younger age class is estimated statistically and the subsequent age classes are estimated assuming equilibrium; with this approach the environmental forcing would be used only for the period of time without being used to estimate the initial age structure. Current efforts for improvement of SEAPODYM are also focused in the use of environmental and fishing data with higher resolution, preliminary results suggest that the likelihood value improves and that the biomass estimate discrepancy is reduced (see SC7-EB-WP-06).

Another potential source for the SEAPODYM – MFCL differences is the type of data used in the fitting process. Multifan CL uses twelve standardized CPUE indices (Bigelow and Hoyle, 2009), resulting from the combinations of four regions and three distant – water fleets (Japan, Korea and Taiwan). It is important to keep in mind that the primary objective of standardizing catch and effort data is to detect trends over time of abundance and remove most of the annual variation in the data not attributable to changes in abundance (Maunder and Punt, 2004). On the other hand, currently, SEAPODYM uses nominal catch spatially distributed in the fitting process. This type of data is important in SEAPODYM for estimating the tuna spatial distribution and migration patterns but does not provide unbiased information for estimating the temporal trend of albacore abundance. Currently we are developing and adjusted CPUE. This index includes information from the distant-water fleets (Japan, Korea and Taiwan) and domestic fleets (American Samoa, French Polynesia, New Caledonia, Tonga and Western Samoa) targeting only albacore. There have been temporal changes in the catchability of the distant-water long line fisheries. Since 1975, the entire Japan and large portion of the Korean fleet have changed the geographic area fished and the configuration of the fishing gear to target yellowfin and bigeye tuna (Bigelow and Hoyle, 2008); therefore it is important to include in the index only data from fleets targeting albacore. The new index is not a standardized CPUE because it retains the spatial variability but it will remove the bias caused by the boat factor and targeting (see SC7-EB-IP-05).

In addition to the initial age structure and the use of an index, the environmental forcing and assumptions on natural mortality could also contribute to the SEAPODYM – MFCL differences of abundance estimates. At this moment is difficult to assess which of these factors are more important in explaining the variability in the SEAPODYM results.

Current management of South Pacific albacore is based on the length-based age-structured model MULTIFAN-CL that incorporates spatial heterogeneity, age-dependent natural mortality, migration rates, and seasonal variation in catchability and density dependent growth (Fournier et al. 1998). Although MULTIFAN -CL provides the majority of the information required for the albacore management in the South Pacific, some issues require a different approach. For example, it may be convenient to assess the effects of fishing on tuna populations in the context of climate and ecosystem variation and to investigate the potential changes due to anthropogenic activities including global warming; phenomena that could potentially affect the distribution and abundance of the tuna species in the future. In this respect, SEAPODYM is an ideal platform to explore these scenarios. In addition, recently WCPO managers have suggested the development of methodologies that allow assessing self determined effort limits (TAEs) and catch limits (TACs) in respect of the economic performances of in-country domestic tuna fisheries. SEAPODYM is able to estimate the available biomass for each country without assumptions about homogeneity in tuna distributions that would be required if the same analysis was to be performed with MULTIFAN-CL. SEAPODYM estimates the tuna migration patterns (Lehodey et al., 2008) and this is taken into account when the available biomass is estimated in each EEZ.

We implemented the projection of the albacore population dynamics at different levels of fishing mortality and also we zoomed in the EEZ to explore the percentage of biomass available in their corresponding EEZ, together with the average monthly biomass availability. Regarding the projections, it is important to point out that some results suggest that after 2003 the population decreases except for the no-fishing scenario; however, the current MULTIFAN-CL stock assessment runs up to 2007 and its results suggested that the biomass increased slightly in 2006 and 2007 despite the fishing effort in those years. Even the SEAPODYM no-fishing scenario did not project this level of biomass. Therefore is important to explore the potential causes of this discrepancy. Recruitment is a potential cause, in addition to the lack of variability; the recruitment scenarios projected suggested that the recruitment is effort dependent. The level of recruitment decreases when the effort augmented. Therefore is important to analyze the effects of changing the values in the Beverton-Holt recruitment parameters. The inclusion of process error could increase recruitment variability. In addition, the projected environmental forcing is the monthly average forcing repeated for each year. This might be one of the potentials causes for the lack of variability observed in the recruitment project. A potential solution could be the use of the standard IPCC emission scenarios (Nakicenovic et al. 2000) used in the exploration of the effects of Global warming. A second approach to this problem could be the use of the historical environmental forcing already used in the model. It is important to point out that the main goal for this approach is not predicting the future albacore population dynamics but to assess the robustness of the proposed fishing policies regarding this particular scenario.

These preliminary results suggest that SEAPODYM has a great potential as a future management tool. It can be used to project the future dynamics and zoom to EEZ scales. These capabilities are important to assess the robustness of different future fishing policies under different scenarios of levels of fishing effort and environmental forcing at regional and local level. SEAPODYM is built with a statistical framework therefore all recent state-of-the-art statistics tools could be implemented, including Bayesian methods with Monte Carlo Markov Chains (MCMC) and the inclusion of process error.

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Table 1. Albacore fisheries data used in the SEAPODYM model, * - period of time for which catch and size composition data is available. L – longline, T – troll fishery and G – drift fishery.

Fishery	**Region**	**Country**	**Catch***	**Size composition***
L1/12	50S-0; 140E-110W	Japan	1/1952-12/2006	3/1964-3/2005
L2	50S-0; 140E-110W	Korea	3/1962-12/2008	1/1966-2/2006
L3	50S-0; 140E-110W	Chinese Taipei	7/1964-12/2008	3/1964-2/2007
L4	50S-10S; 140E-175E	Australia	3/1985-12/2007	2/2002-2/2007
L5	25S-0; 150E-180E	New Caledonia	11/1983-12/2007	1/1993-4/2007
L6/ L10	50S-0; 140E-110W	Other	11/1957-12/2008	3/1963-3/2005
L7	50S-25S; 145E-180E	New Zealand	8/1989-12/2007	2/1992-4/2006
L8	25S-0; 150E-180E	Fiji	8/1989-12/2007	3/1992-3/2007
L11	25S-0; 180E-155W	American Samoa,	1/1993-5/2008	1/1998-3/2007
L7	25S-5S; 180E-140W	Tonga	2/1982-3/2008	3/1995-242006
L7	25S-0; 180E-110W	French Polynesia	1/1992-5/2007	2/1991-4/2007
T8	50S-25S; 140E-110W	New Zealand, USA	1/1967-12/2007	4/1986-2/2006
G9	45S-25S; 140E-125W	Japan, Chinese Taipei	11/1983-1/1991	4/1988-1/1990

Table 2. Maximum likelihood estimates of parameter and standard errors from the SEAPODYM model for albacore in the South Pacific. MLE – maximum likelihood estimate,

Parameter	MLE	Parameter	MLE
Predation mortality slope coeff.	0.67 ± 0.01	Fish length threshold (type II)	17.35 ± 0.01
Maximum aging mortality	0.22 ± 0.001	Select. std. deviation (type II)	86.47 ± 0.01
Threshold age for aging mortality	120.0 ± 0.03	Fish length threshold (type I)	99.22 ± 0.01
Half saturation constant	7.12 ± 0.04	Steepness of the select. type I	0.19 ± 0.01
Std. deviation in the temp. function	4.0 ± 0.01	Fish length threshold (type II)	80.13 ± 0.01
Optimum temp. for juveniles	25.31 ± 0.01	Select. std. deviation (type II)	14.37 ± 0.01
Optimum temp. for older tuna	6.0 ± 0.01	Fish length threshold (type II)	65.64 ± 0.01
Threshold for dissolved oxygen	2.71 ± 0.01	Select. std. deviation (type II)	14.88 ± 0.01
Tuna maximum sustainable speed	1.92 ± 0.01	Fish length threshold (type II)	66.11 ± 0.01
Fish diffusion coeff.	2.0 ± 0.01	Select. std. deviation (type II)	8.63 ± 0.01
Multiplier for D_{max}	0.19 ± 0.01	Fishery 1 catchability coeff.	3.12E-05 ± 0.00112
Fish length threshold (type I)	107.55 ± 0.02	Fishery 2 catchability coeff.	0.00017 ± 0.00425
Steepness of the select. type I	0.12 ± 0.01	Fishery 3 catchability coeff.	0.00044 ± 0.00969
Fish length threshold (type I)	91.73 ± 0.01	Fishery 4 catchability coeff.	1.88E-05 ± 0.00140
Fish length threshold (type I)	94.95 ± 0.01	Fishery 5 catchability coeff.	0.000204 ± 0.006317
Steepness of the select. type I	0.25 ± 0.01	Fishery 7 catchability coeff.	6.90E-05 ± 0.00173
Fish length threshold (type II)	95.98 ± 0.01	Fishery 8 catchability coeff.	0.00214 ± 0.00224
Select. std. deviation (type II)	23.97 ± 0.02	Fishery 9 catchability coeff.	0.00076 ± 0.00164
Fish length threshold (type I)	97.13 ± 0.01	Fishery 10 catchability coeff.	9.33E-05 ± 0.01554
Steepness of the select. type I	0.20 ± 0.01	Fishery 11 catchability coeff.	0.00057 ± 0.00864
Fish length threshold (type I)	99.56 ± 0.01	Fishery 12 catchability coeff.	5.02E-05 ± 0.00188
Steepness of the select. type I	0.16 ± 0.01		

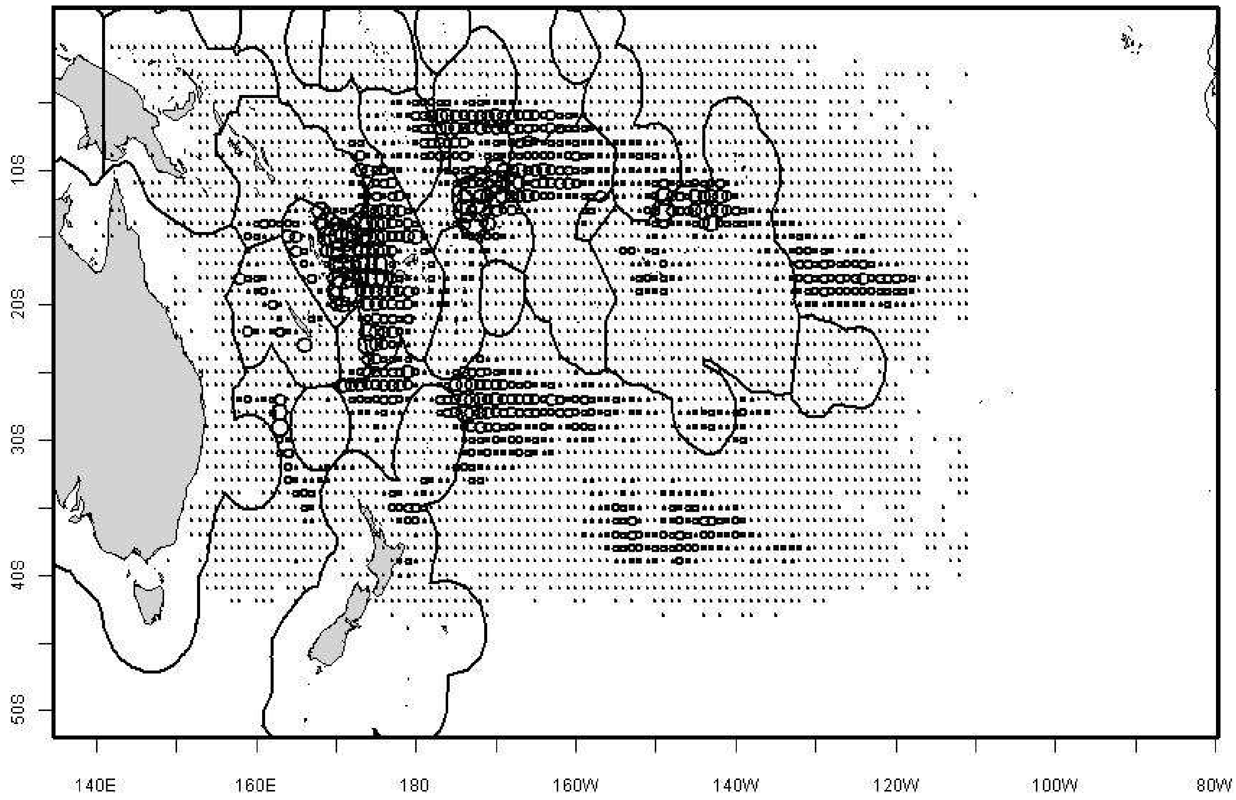

Figure 1. Albacore’s spatial catch distribution in the south Pacific.

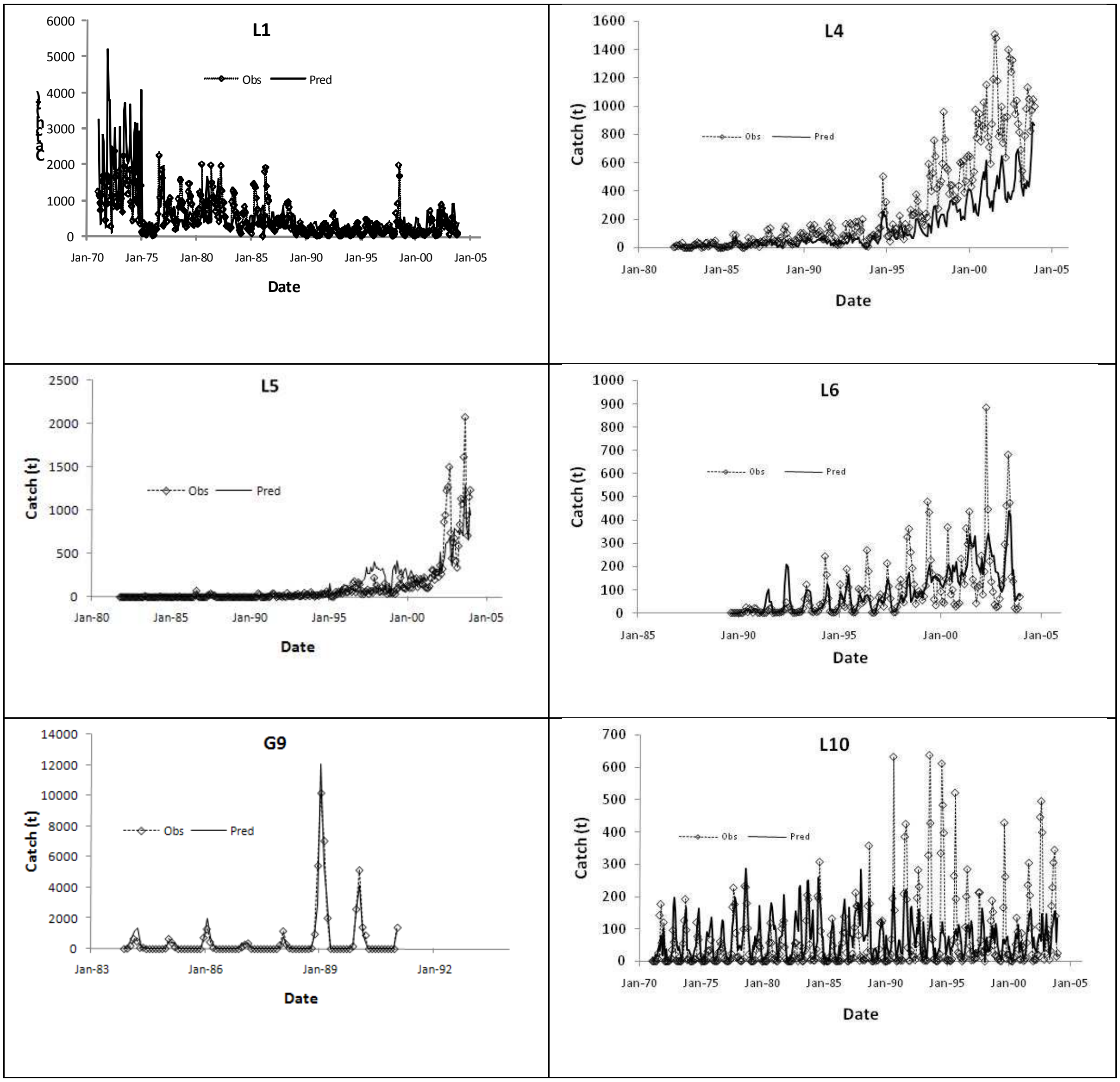

Figure 2. SEAPODYM fit to the observed albacore catch (by fishery) in the south Pacific. Obs – observed catch, Pred – SEAPODYM estimated catch, L – long line fishery, G – drift fishery,

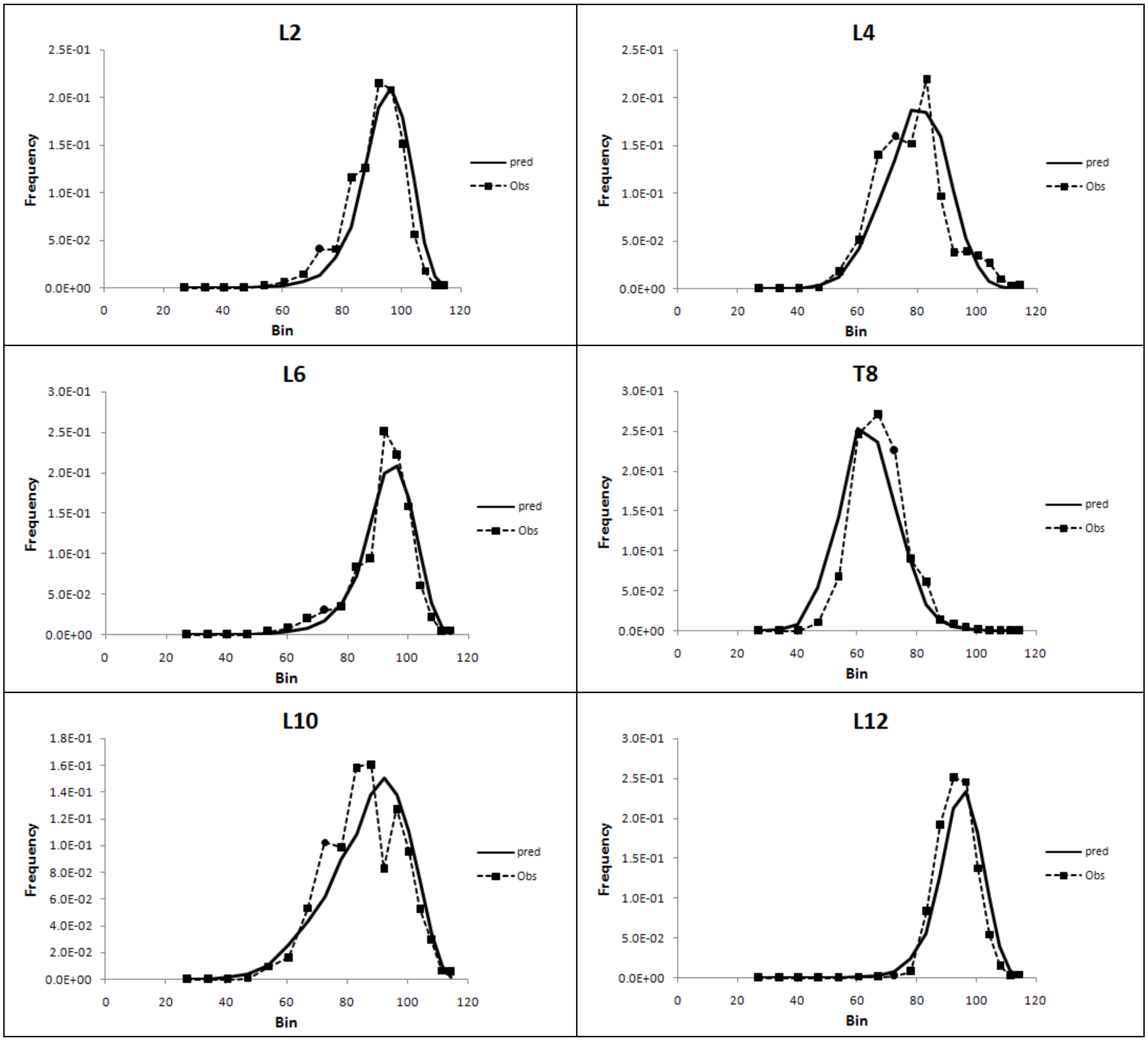

Figure 3. SEAPODYM fit to albacore size composition data in the south pacific by fishery. Pred – estimated size composition, Obs – observed size composition, L – long line fishery, T troll fishery.

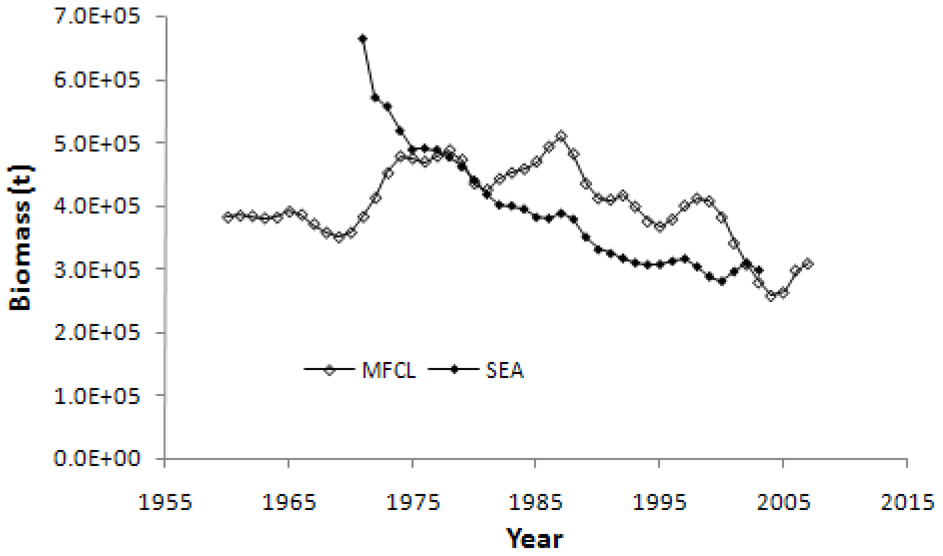

Figure 4. Comparison of the adult albacore biomass estimates in the region defined for MFCL in the south pacific. MFCL – Multifan CL, SEA – SEAPODYM.

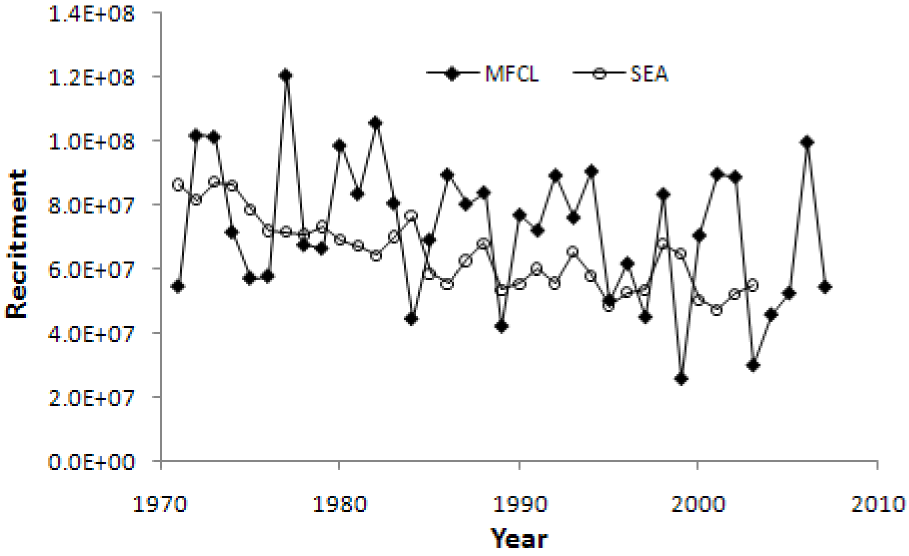

Figure 5. Comparison of albacore recruitment estimates in the region defined for MFCL in the south pacific. MFCL – Multifan CL, SEA – SEAPODYM.

Taken from processing results21_04_2010

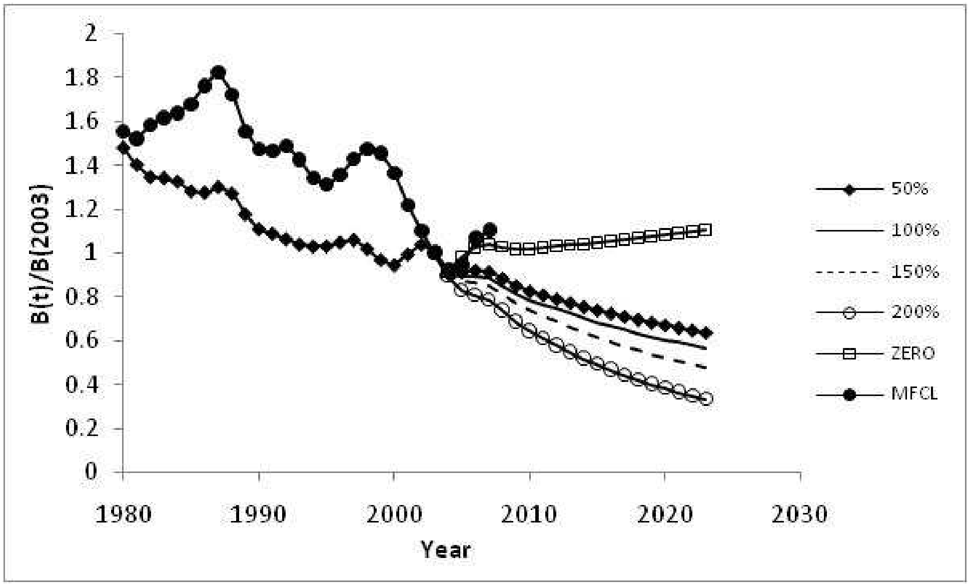

Figure 6. Albacore biomass SEAPODYM projections in the south Pacific from 2004 to 2023, ZERO – no fishing mortality scenario, MFCL – Multifan CL results.

Taken from forecast_comparison.xls

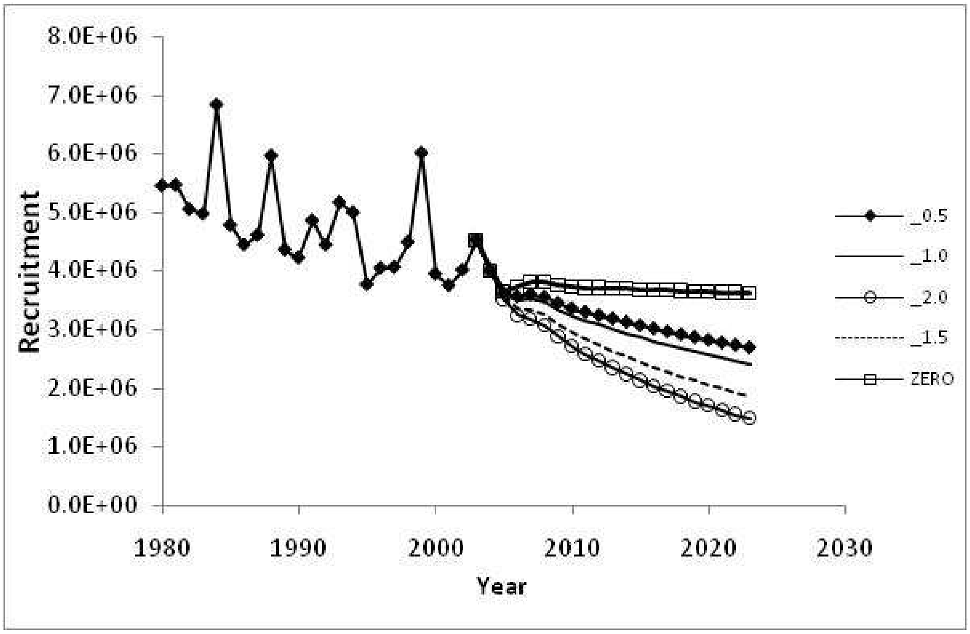

Figure 7. Projection of future albacore recruitment from 2004 to 2023 in the south Pacific.

Taken from forecast_comparison.xls

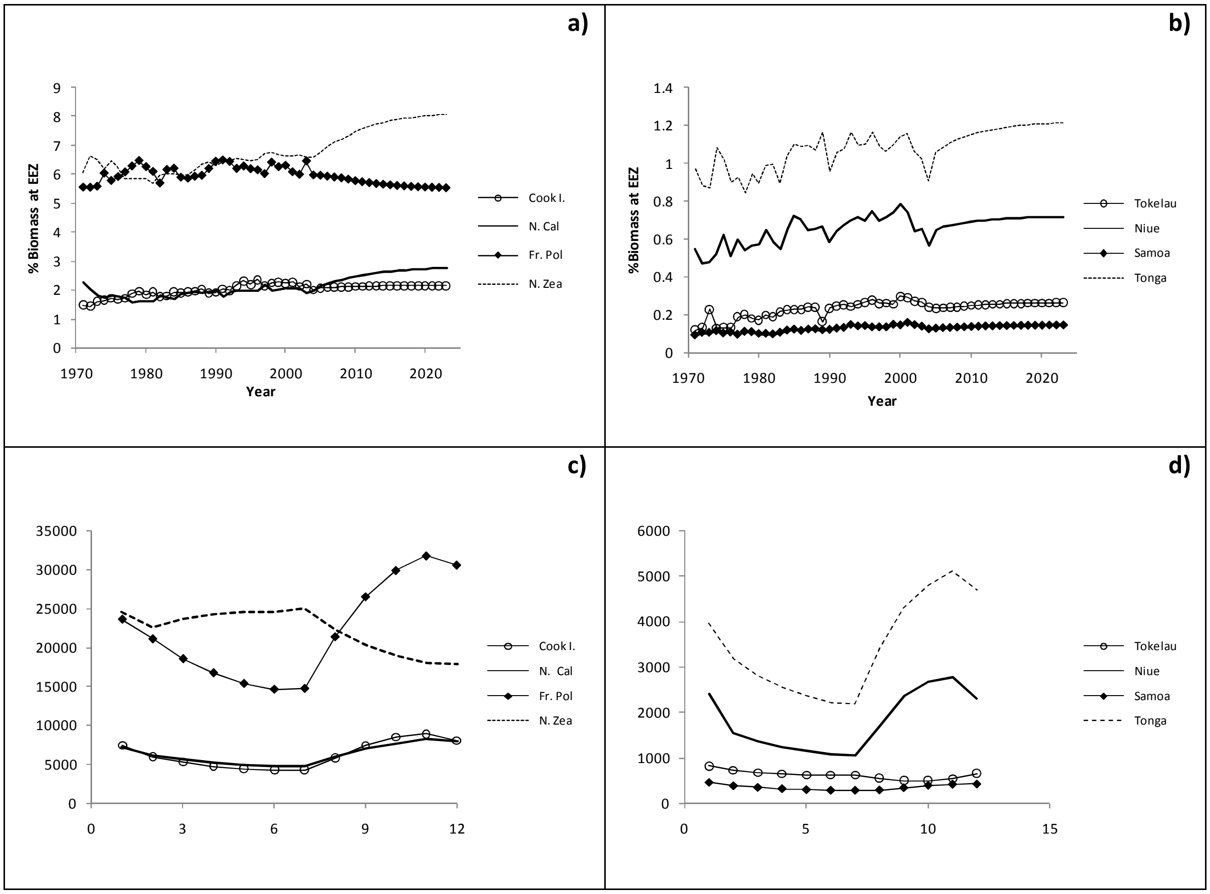

Figure 8. Zooming on EZZ biomass; a) and b) percentage of albacore adult biomass available in the IPCT economical exclusive zone, c) and d) monthly average albacore adult biomass available in the IPCT economical exclusive zone, Fr. Pol – French Polynesia, Cook I. – Cook Islands, N. Zea – New Zealand, N Cal – New Caledonia.