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EcoSEA workshop: Ecosystem modelling in the WCPO: current status and future directions

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EXECUTIVE SUMMARY

1. Developing ecosystem models and using their outputs in decision-making processes is one course of action to implement the ecosystem approach to fisheries management (EAFM).
2. The EcoSEA workshop was co-convened by SPC and IATTC in October 2019 to draw together expertise to progress the development of ecosystem modelling in the WCPO.
3. A series of presentations was given on different themes: overview of existing ecosystem model platforms, the latest WCPO Ecopath model, the best data available to update ecosystem models, spatial considerations, new developments in the SEAPODYM model, ecosystem and Management Strategy Evaluation, ecological indicators.
4. The presentations sparked vibrant discussion from participants, and a series of focussed 'group discussion' and 'working group' sessions facilitated knowledge transfer on recent developments across the abovementioned themes.
5. Prior to the workshop a questionnaire was sent to the fisheries department of the PICTs to capture their views on the development of ecosystem modelling for the region. Participants highlighted:
    a. The need for ecosystem models to support management and to not only address the impact of fisheries but also of climate variability.
    b. The need for consultation to align ecosystem work with other issues discussed at the WCPFC.
    c. The need for national and sub-regional level work.
    d. The need to consider bycatch species also caught by small-scale fisheries.
    e. The need for training and good communication to fully engage in this work.
    f. The species they considered the most important to include in future models.
6. The existing Ecopath model for the region is undergoing significant modification to maximise its characterisation of the ecosystem and utility for potential use as a tool for WCPFC resource managers to progress an ecosystem approach to fisheries management. The key features of the revised model are:
    a. Extension of the spatial extent of the model to the eastern boundary of the WCPFC Convention Area (150°W) to provide a continuous modelling surface with a similar model of the eastern Pacific Ocean built by the IATTC.
    b. Inclusion of additional species of conservation importance (e.g. seabirds, rays) and increasing importance as edible bycatch (e.g. barracuda, wahoo).
    c. Integration of 7118 stomachs from 38 species collected throughout the WCPO and 262 data time series of target, bycatch and forage species to further improve the realism of the model structure and reliability of model predictions under defined fishing and environmental scenarios.
7. We invite WCPFC-SC16 to:
    a. Highlight the need for availability of better data on non-target species collected by fisheries observers on purse seine and longline vessels.
    b. Support on-going research developments into trophic-structured ecosystem models to describe the holistic functioning of the WCPO pelagic ecosystem, including the development of the Pacific Marine Specimen Bank.
    c. Note the development and progress of a new Ecopath model for the WCPO.
    d. Encourage active participation by fisheries managers of the WCPO on the development of ecosystem models and EAFM for the region.

1. INTRODUCTION

The WCPFC convention specifically calls for an ecosystem approach to fisheries management (EAFM) (WCPFC, 2000, article 5 and 6), taking into account the context of climate change (WCPFC, 2019). Developing ecosystem models and using their outputs in decision-making processes is one course of action to meeting these mandates. Ecosystem models differ from single species models (e.g. the MULTIFAN model used to assess the stock status of bigeye tuna) in that they represent the prey-predator relationships between a broad spectrum of taxa. Ecosystem models can be complex by characterising the trophic pathways from primary producers to top predators, but provide a holistic view of the system. Therefore, they can provide opportunities to monitor the status of an ecosystem using indicators, or to predict fishing and/or environmental impacts on individual species (e.g. bycatch, target species) or the structure and function of the ecosystem as a whole.

SPC has led the development of two ecosystem models for the western and central Pacific Ocean (WCPO) over the past 25 years: SEAPODYM and the Warm Pool Ecopath model.

The Spatially Ecosystem and Populations Dynamics Model (SEAPODYM) has been continuously developed by SPC and CLS since 1995, with the aim of describing the distribution and dynamics of tuna, tuna-like species, and mid-trophic level species using advection-diffusion-reaction equations:

- The original model aimed to incorporate the effect of environmental variability on the distribution of skipjack tuna in the WCPO area, (SEPODYM, Lehodey et al., 1998).
- Over a fifteen year period SEAPODYM then developed into a full life cycle model for tuna and tuna-like species (Lehodey et al., 2008), including data assimilating mid-trophic tuna forage sub-models (Lehodey et al., 2010) and projections into the future using various climate scenarios (Lehodey et al., 2013).
- Now SEAPODYM is applied to modelling each key tuna species in the Pacific and other ocean basins individually (Senina et al., 2018), providing abundance and distribution estimates for other studies (Miller et al., 2018), and including mark-recapture tagging data to directly inform movement parameters for target tuna species in the Pacific (Senina et al., 2020).

Since 2002, SPC has led the development of trophic mass balance ecosystem models to describe the dynamics of the WCPO pelagic ecosystem using Ecopath with Ecosim[1] software, which was originally conceptualised by Polovina (1984):

- The first two preliminary models—developed in 2002 and 2007—focused on the Warm Pool province and provided insight into the structure of the ecosystem, prominent information deficiencies, and potential areas of improvement to increase the confidence in the outcomes of the model. However, these iterations of the model were not used for simulating fisheries management options nor the impact of the changing environment (Allain et al., 2007; Godinot and Allain, 2003).

[1] http://www.ecopath.org

- In 2010, a third version of the model was developed using updated biological and ecological parameters and fitted to historical time-series of catch and effort for key species. These improvements provided a more reliable model that allowed the exploration of the potential impacts of climate change on target and non-target species and on the mid-trophic level species included in the model (mesozooplankton and micronekton)(Allain et al., 2012a; Le Borgne et al., 2011)
- In 2011, a workshop was organised at SPC, Noumea, to bring together experts on ecosystem research in the Pacific to synthesize progress and identify future priorities (Allain et al., 2012b). A key conclusion was the need to improve catch time-series of target and non-target species to in order improve the calibration and realism of trophic models in the Pacific.
- Using improved non-target species catch estimates, an updated Warm Pool Ecopath model was built in 2013 and used to explore the impact of hypothetical longline and purse-seine fishing practices (e.g. increase longline effort to increase bycatch species for domestic markets, and reducing purse seine effort on FADs) on the ecosystem (Allain et al., 2015; Griffiths et al., 2019a). The model indicated that the structure of the Warm Pool has considerable stability to increased catches of larger pelagic fishes, but was sensitive to changes in the biomass of the forage groups that comprise the prey for large pelagic fish.

With the objective of using the Ecopath model to explore and predict the impact of climate change on the non-target species of interest for food security such as mahi mahi or wahoo, SPC, in collaboration with the Inter-American Tropical Tuna Commission (IATTC), convened a workshop on ecosystem modelling (EcoSEA) in October 2019. The aim was to draw together expertise to discuss the various existing ecosystem modelling platforms and to progress the development of the Warm Pool Ecopath model, particularly considering the availability of improved data on non-target species since the implementation of 100% observer coverage on purse seine vessels in 2010.

This paper reports on the progress and outcomes of the EcoSEA workshop, the results of a survey conducted with the Pacific fisheries departments on their views on ecosystem modelling, and new developments in ecosystem modelling for the WCPO. Additionally, we provide some notes for consideration by WCPFC-SC16 on ecosystem modelling in the WCPO.

2. THE EcoSEA WORKSHOP

The EcoSEA workshop, organised by SPC in collaboration with IATTC, took place from 28 October to 1 November 2019 at SPC headquarters in Noumea, New Caledonia. A group of 30 invited experts (Annex 1) participated in the workshop, in person or online. The participants and the content of the workshop focused on technical ecological and modelling expertise. However, to collect the view of the fisheries managers in the region, a questionnaire was distributed before the workshop to ensure modelling objectives aligned with conservation and management needs (see section 4).

The workshop was structured around eight main themes, within which 21 presentations were made, and group discussions conducted (Annex 2).

The first theme introduced the two major ecosystem models used in the WCPO, namely Ecopath and SEAPODYM, and the presentations highlighted the differences in structure of the two models. Ecopath models include numerous species or aggregations of species with similar ecological function (called "functional groups") from phytoplankton to top predators (including fisheries), and as many species as desired in-between (e.g. non-target species), which are linked via predator-prey relationships. Ecopath does not include environmental forcing and has no spatial structure, and for all species/groups—other than principal commercial species—no detailed age-structure of their populations is defined. By contrast, SEAPODYM is spatially-explicit, and integrates environmental parameters but only includes organisms at low and intermediate trophic levels (i.e. phytoplankton, zooplankton, micronekton or tuna prey) and a single top predator species with detailed population dynamics (typically either skipjack, yellowfin, albacore or bigeye tunas). No bycatch species can be included, and there are no interactions between species of top predators (i.e. tunas).

Following these two presentations, the latest Ecopath model developed for the Warm Pool province in the western equatorial Pacific was presented, highlighting the different components of the model and describing the results of simulations involving various fisheries and climate change scenarios. This overview led to a series of eight presentations, each one focusing on one component of the ecosystem (e.g. zooplankton), providing information on available data that could be used to update and improve the reliability of the model.

The presentations were ordered from environmental forcing on the physical oceanography and climate of the region (winds, currents, sea temperature, marine heat waves, convergence zone, El Niño/La Niña), as well as on biogeochemical processes (carbon, oxygen, acidification, chlorophyll) and climate forecasting of these processes to impact biological components from the bottom of the food web towards the top predators. Ocean colour imagery from satellites allow the estimation of phytoplankton biomass, which forms the base of the food web. Assimilated into NPZD models (Nutrients, Phytoplankton, Zooplankton, Detritus), this information can be used to estimate zooplankton biomass for which there are no large-scale observations in the WCPO. Micronekton is a diverse group of small species (2-20 cm) that prey upon zooplankton, comprised of fish, squids, crustaceans and gelatinous organisms, which are difficult to observe or sample across large spatial scales. One presentation described how the SEAPODYM-LMTL model allows the estimation of biomass of 6 micronekton groups defined by their depth range and vertical migratory behaviour. A second presentation compared micronekton biomass proxies estimated by acoustics and SEAPODYM for the New Caledonia region, which demonstrated reasonably good agreement between the two methods for the shallower organisms but discrepancies for organisms occupying depths greater than 200m. Moving up the food web, the trophic structure of the pelagic ecosystem was presented, detailing how the diet matrix (prey-predator relationships) used in Ecopath models was developed for the WCPO using predator stomach content collected and curated within the Pacific Marine Specimen Bank (Macdonald et al., 2020). Non-target species catch estimates—based on observer data—were presented where it was highlighted that low observer coverage (<5%) of the longline fleet resulted in low confidence in catch estimates. While catch estimates were considered more precise for purse-seine given the near 100% observer coverage, catch estimates are uncertain for rarely-caught species. Finally, by-region biomass and fishing mortality estimates of top predators were presented for species for which stock assessments are conducted on a regular basis in the region, namely swordfish, blue marlin, striped marlin, shortfin mako shark, blue shark, silky shark, oceanic whitetip shark,

skipjack, bigeye tuna, yellowfin tuna and albacore. Stocks assessments rely on catch data and, when available, size composition, mark-recapture information (tagging) and biological parameters, such as growth and reproductive dynamics.

The subsequent session comprised of three presentations focused on spatial aspects of modelling. The first presentation described modelling tuna movements based on mark-recapture conventional tagging data in the region and information on the vertical behaviour of fish derived from archival tags. The second presentation described the improvement of the movement parameterisation of SEAPODYM using tagging data. The final presentation highlighted the utility of the Ecospace model as a spatially-explicit extension to Ecopath with Ecosim (EwE) models. The Ecospace model accounts for the spatial distribution of marine species and fishing effort, allowing the exploration of spatial management options that may temper the impacts of fishing, environmental and habitat changes on individual species as well as ecosystem integrity.

To place the presented information in perspective for developing an updated Ecopath model, the remaining presentations provided information on other models and platforms that run in parallel to the development of the Ecopath model. New developments in SEAPODYM were presented focusing on proposed improvements characterising seasonal migrations of albacore tuna (Senina et al., 2019). Advances in data assimilation and developments in operational oceanography were also presented providing realistic forecasts of tuna habitat at 1-week and seasonal temporal scales. The author of a review of SEAPODYM shared suggestions for the future development of the model for the region that were discussed by the group (Dunn and Webber, 2020). A presentation was given on Management Strategy Evaluation (MSE), which were developed in the region to be used with single-species stock assessments, and ideas were mentioned on how to extend MSEs to consider ecosystem interactions. The Spatial Population Model (SPM) was presented, which is a spatial, age-structured population model that characterises the movements of individual fish of a single species, but has the potential to include prey-predator relationships for a limited number of prey species (Dunn et al., 2018). SPM was used to assess the impact of the implementation of a marine protected area on fisheries. Finally, the EASI-Fish tool (Ecological Assessment of the Sustainable Impacts by Fisheries) was presented; an approach for quantifying the cumulative impacts of fisheries on data-poor bycatch species (Griffiths et al., 2019b). Based on a limited number of parameters for each species of interest (e.g. spatial distribution of the species relative to fishing effort, encounterability and selectivity), a proxy for fishing mortality for each species is estimated and compared to traditional biological reference points (e.g. F_{MSY}) derived from a simple length-based yield per recruit model . This allows the classification of each species as “most vulnerable” or “least vulnerable”, guiding fishery managers as to which species to prioritise for immediate mitigation or further monitoring and research.

The final presentation of the workshop described ecological indicators, particularly those derived from the EwE software. These include biomass-based indicators (e.g. biomass of predators in the ecosystem), catch-based indicators (e.g. total discarded catch), trophic-based indicators (e.g. trophic level of the catch), size-based indicators (e.g. mean length of fish in the catch), and species-based indicators (e.g. the biomass of endangered species in the ecosystem).

3. GROUP DISCUSSION AND WORKING GROUP SESSIONS

Interspersed throughout the workshop presentations were seven 'group discussion' sessions, designed both to provide participants an opportunity to expand upon questions arising during the presentations, and to foster dialogue around specific workshop themes (see Annex 2 for details). These sessions saw strong involvement from attendees.

Following overview presentations on Ecopath and SEAPODYM, the first group discussion session provided a forum for queries and comments on each of the modelling frameworks, and how they may complement one another. The need to establish the aims of the work prior to deciding how to proceed and which model to use was stressed at the outset. The discussion then evolved around the differences in focus and scale of Ecopath (i.e. ecosystem-level) versus SEAPODYM (i.e. single-species, though species-coupled estimation possible), while outlining the strengths and weaknesses of each approach in relation to the different questions we want to address. The group then touched on how uncertainty was estimated in both models. Though handled vastly differently, it was suggested that uncertainty measures around SEAPODYM parameter estimates could be used to simulate a suite of alternative predictions for Ecopath. There was general agreement that when prediction is the goal, we need to work to minimise complexity whilst providing good predictive skill.

The group discussion sessions on day two focussed on the selection of datasets for parameterising the new Ecopath model; specifically, data type, quantity, quality and the spatial and temporal scales required. In the first session the issue of scale arose as particularly important in the context of biomass data for key tuna and billfish groups for which stock assessments are available, as the stock assessment regions often do not overlap with the new, proposed Ecopath model box. The question of if and how best to propagate uncertainty in Ecopath projections, both ecological and socio-economic, was also raised. This is possible with the EwE framework, for example through bootstrapping, and processes for capturing and reporting it are improving. The importance of including lower trophic-level groups and bycatch group into Ecopath models was demonstrated, and ideas for improving bycatch data coverage (e.g. through electronic monitoring – EM) tabled.

The discussion then turned towards if/how the new model might be used to provide management advice in a climate-fisheries change context. Reporting on ecosystem indicators, both those routinely output from Ecopath models, and new indicators derived from SEAPODYM, was highlighted as one useful approach. Developing empirical indicators, using information from the WCPFC Tuna Tissue Bank and fisheries datasets stored in house at SPC, may also be productive and provide opportunities for comparison with model-based indicators (Allain et al., 2020). The need to identify the temporal scale of most interest for our climate change projections, and how our data requirements relate, occupied the final part of this group discussion session. It was generally agreed that different time frames for projections are informative. For example, the next 5-10-20 years are relevant for immediate management needs and business decisions, but 50 year to end-of-century projections provide longer-term planning options and essential context.

Finally, it was asked whether the goals of this modelling exercise were to incorporate economic as well as ecological scenarios? Ecology was confirmed as the focus for this new

Ecopath model, but it was stressed that economic aspects should be integrated into a future iteration.

The last group discussion session on day two began with a presentation and subsequent dialogue on the outcomes of the stakeholder survey, as detailed in Section 4. A detailed appraisal of which species should be included in the model, the limitations and benefits of inclusion/exclusion and the desired trophic structure of the new model followed.

Participants continued the exchange under this theme in the first group discussion session on day three. The dialogue centred on decisions around the spatial and temporal scales of the new Ecopath model, in terms of the size and location of the model box (agreed to encompass the region between 140E to 150W, and 20N to 20S, the desired resolution of data within this area, the 'reference year' to be selected (agreed on 2013), and the length of the time series needed for parameterisation. In the second group discussion session of the day, the group returned to the climate change and fishery scenario theme touched on earlier in the workshop. A presentation on climate change scenarios and SEAPODYM simulations on tuna sparked discussion around the priorities for planned simulations in Ecosim and what data are required.

The group discussion sessions on day four of the EcoSEA workshop were focussed largely around new developments in SEAPODYM, and a review of the SEAPODYM modelling framework, including its potential for current and future integration with Ecopath and other spatial populations dynamics models (Dunn and Webber, 2020). Lively discussion also stemmed from the presentation on management strategy evaluation (MSE) in the WCPO, and the potential for linking MSE models with other (possibly ecosystem) models in the future. Presentations on alternative models for the WCPO ecosystem (e.g. SPM and CASAL2 – Dunn and Webber 2020) and an overview of the 'EASI-Fish' tool for ecological risk assessment also drew strong interest from workshop participants, and were discussed in terms of implementing the best-possible modelling strategies to guide management decision-making in the WCPO.

In addition, to the group discussion sessions, six 'working group' sessions were built into the workshop schedule. These had a more practical focus around the availability and selection of datasets, data collation and processing, and assignment of tasks for undertaking these critical steps.

4. SURVEY ON THE ECOSYSTEM WORK TO BE CONDUCTED IN THE WCPO

In order to capture the views of the fisheries managers of the WCPO on the development of ecosystem models for the region, a survey was on October 19, 2019 to 49 staff of the fisheries departments from 18 PICTs[2] and from 2 regional agencies (FFA and WCPFC). One to three persons were contacted in each organisation to answer a short questionnaire (Annex 3). A total of 27 answers were received giving a response rate of 55%.

[2] All PICTs except Pitcairn, Niue, Guam, Northern Mariana Islands

Through the questions and the comments provided by the participants to the survey, we gained a better understanding on the needs of the fisheries managers and their expectations in terms of ecosystem studies and modelling.

The need to **support management** was strongly expressed through the selection of "Ecosystem indicators to inform management" as the most frequently chosen topic of interest (Figure 1; and see in Figure 2 "Training on ecosystem approach to fisheries management"). Comments highlighted that ecosystem modelling should help to inform management to ensure the good health of all fisheries, including small-scale practises. A strong interest was also communicated on the need to not only assess the **impacts of fisheries but also of environmental variability, habitat degradation and climate change** (see in Figure 1, "Early warning signs for fundamental changes in the ecosystem", "Future climate and fishing impacts on ecosystem" and "Future climate and fishing impacts on bycatch species").

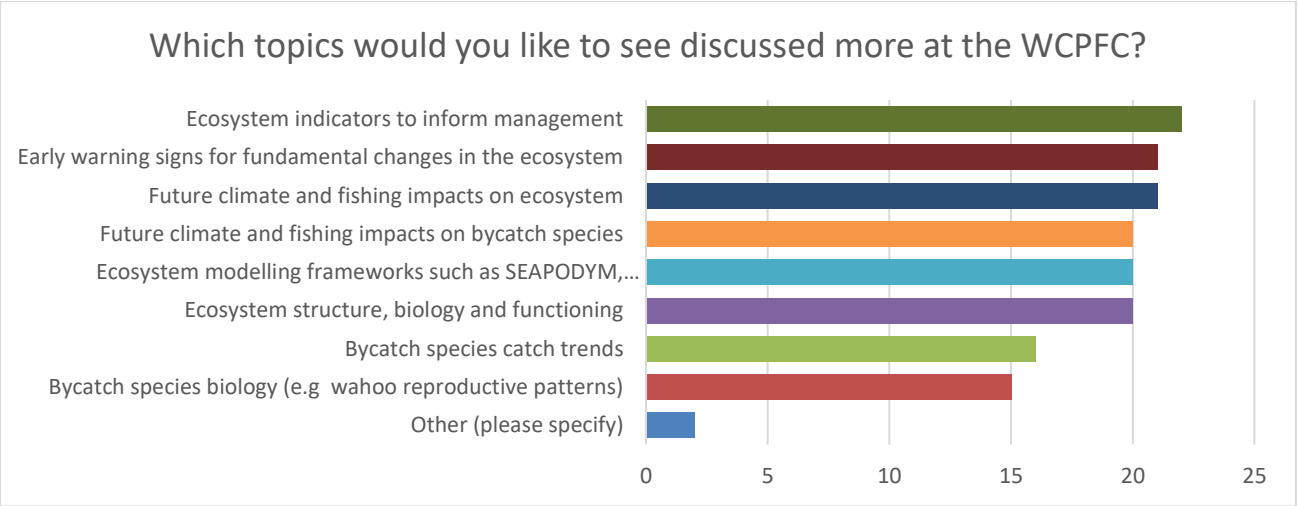

Figure 1. Number of answers (over 27 participants) to the question: "Which topics would you like to see discussed more at the WCPFC?

Several participants highlighted the **need for consultation** to ensure that ecosystem work aligns with current issues discussed at the WCPFC and that new projects related to ecosystem studies do not undermine other core work. A streamlined and focussed approach is deemed necessary, as well as a close work with stakeholders in the design and application of EAFM.

Ecosystem work at the **national or sub-regional levels** is seen as important to demonstrate the effectiveness of the ecosystem approach and it was suggested that specific studies on ecosystem interactions should be developed and information updated on the SPC country pages (see in Figure 2 "Information available on SPC website").

If detailed information on **bycatch** did not come up as the first topics of interest (see in Figure 1, "Bycatch species catch trends" and "Bycatch species biology"), it was commented that the ecosystem modelling work should help develop strategies to consider the small-scale fisheries which rely on species such as barracudas, marlins, wahoo, mahi mahi. Electronic reporting and monitoring for bycatch species, or android apps providing information on species habitat of biology were seen as potential useful tools to improve bycatch information. Species of

special interest, and particularly turtles and marine mammals were also mentioned as species of strong cultural and conservation values.

It was highlighted in the comments that SPC members need to understand the ecosystem work before they can fully **engage** at the WCPFC level, and training and capacity-building, through workshop or career development opportunities, were seen as the preferred way to engage (see in Figure 2 "Training on ecosystem approach to fisheries management" and "Training on ecosystem structure, biology and functioning"). It was also suggested to collaborate with the University of the South Pacific to develop new programs focusing on fisheries science. The communication on outputs of the modelling work needs to be easy to comprehend for people to be able to use this information for management; preferred way to receive information is through the WCPFC scientific committee and SPC website (see in Figure 2 "Information received at the WCPFC scientific committee", "Information available on SPC website" and "Information forwarded via newsletters, email, Twitter").

In terms of the **implementation** of the EAFM, the elaboration of a multispecies harvest strategy approach was suggested and several participants indicated the importance of the multi-model comparative approach.

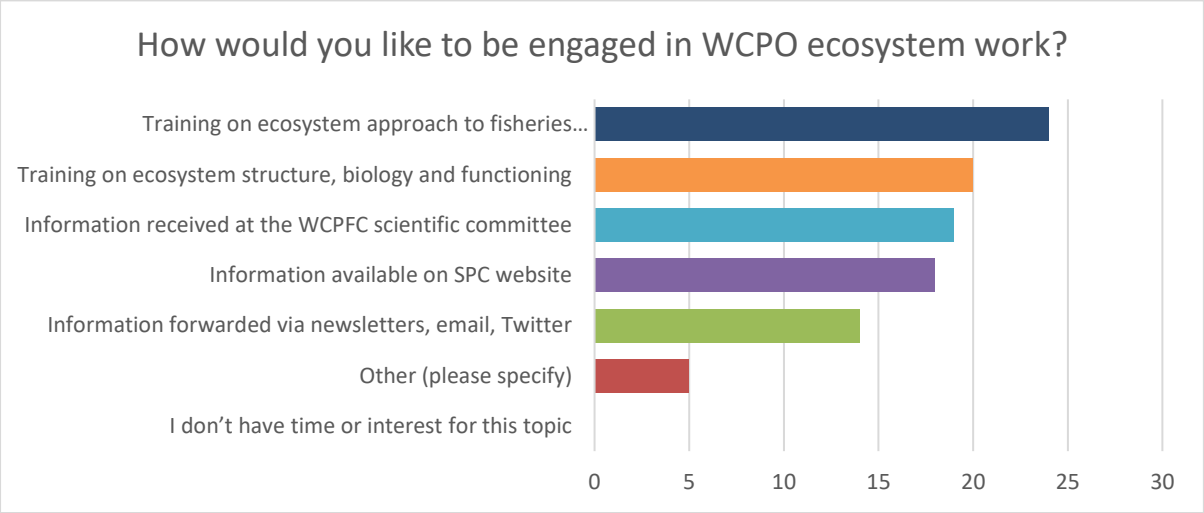

Figure 2. Number of answers (over 27 participants) to the question: "How would you like to be engaged in WCPO ecosystem work?

With the objective of developing a new Ecopath model, we asked the participants of the survey to indicate, within a **list of species**, which species were important to include and to suggest other species not listed.

The species classified as highly important to include in ecosystem models were the 4 target tuna species and the turtles (Table 1). Billfish, sharks, species of special interest (seabirds and marine mammals), and edible bycatch (wahoo, mahi mahi, rainbow runner, opah) were considered important to include in the ecosystem models. The species that raised the lowest interest were small tuna, and bycatch species, non-edible (escolars and oilfish, lancetfish) or with a very marginal economical interest (pomfrets). Results highlight the interest of fisheries managers for commercially-important species (target and non-target

species), but also their awareness in taking into account species of special interest such as turtles and shark.

Group	Species	Index of importance
TUNA	Yellowfin tuna	3.9
TUNA	Bigeye tuna	3.6
SSI	Turtles as a group not differentiating species	3.1
TUNA	Skipjack tuna	3.1
TUNA	Albacore tuna	3.1
SSI	Marine mammals as a group not differentiating species	2.9
BYCATCH	Wahoo	2.8
BYCATCH	Dolphinfish/mahi mahi	2.7
BILLFISH	Swordfish	2.7
SSI	Seabirds as a group not differentiating species	2.5
SHARK	Mako sharks as a group, not differentiating species	2.5
SHARK	Oceanic whitetip shark	2.5
BYCATCH	Rainbow runner	2.5
SHARK	Silky shark	2.5
BILLFISH	Striped marlin	2.5
SHARK	All other sharks as a group not differentiating species	2.5
BILLFISH	Blue marlin	2.5
SHARK	Blue shark	2.4
BILLFISH	All other billfish as a group not differentiating species	2.3
BYCATCH	Opah	2.1
TUNA	Small tuna (e.g. frigate, bullet), as a group, not differentiating species	2.0
BYCATCH	Escolars and oilfish as a group not differentiating species	1.6
BYCATCH	Pomfrets as a group not differentiating species	1.6
BYCATCH	Lancetfish as a group not differentiating species	1.4

Table 1. Species to be included in the Ecopath model in order of importance for a suggested list of species or group of species. The index of importance was calculated based on the proportion of participants indicating for each species if they were "very important", "fairly important", "important", "slightly important", "not at all important", "no opinion".

Seven participants to the survey suggested additional species to be included in ecosystem models:

- Rays (e.g. manta rays, pelagic sting-ray) were mentioned by 2 participants
- Food species for tuna
- Great barracuda and other barracuda species
- Snapper and diamondback squid
- Some of the endangered fish species
- Humans

The suggested species underlined some gaps in the previous model that did not consider the rays and the barracudas for example; those 2 groups will be added to the new Ecopath model (see section 5). Suggestions provided also highlighted the good understanding of the ecosystem functioning with the mention of the tuna food species which were actually included in the previous model, as well as the mention of the human dimension which is also considered in the model through the fisheries. Our knowledge of the tuna pelagic ecosystem indicates little to no interaction with the deep-snapper species and it is not envisioned to include this group into the present model. Deep-snappers ecosystem is strongly linked to the bottom of the ocean and those species have strong interactions with benthic organisms and their ecosystem; they evolve in an ecosystem very different from the tuna. The diamondback squid is a pelagic species and as such could be included in the pelagic ecosystem model; it is actually included into the group of tuna prey, but not as a stand-alone species. Considering the diamondback squid as a specific component of the model would require the acquisition of more knowledge on its biology (diet, growth), but also on catch and biomass estimations, data which are likely not available at the scale of the WCPO at the moment.

5. PROGRESS ON DEVELOPING AN UPDATED ECOPATH MODEL FOR THE WCPO

The workshop participants contributed to several substantial changes in the structure of the existing Warm Pool model, as well as the input data for parameterization. The existing model covered an important biogeographical and tuna fishery region in the WCPO, but it failed to capture the full spatial extent of the ecosystem and fisheries for which the WCPFC is responsible. Therefore, the model boundaries were extended to 150°W and latitudinally to span 20°N to 20°S to encompass a total area of 38,000,040 km^2; this new model is named Western Tropical Pacific (WTP). This was also seen as a strategic decision, providing an option to link (spatially) with an existing Ecopath model of the eastern Pacific Ocean (EPO), the Eastern Tropical Pacific (ETP), built by the IATTC staff (Olson and Watters, 2003) (Figure 3), and to create a tropical Pacific-wide model more easily in future, should the opportunity arise.

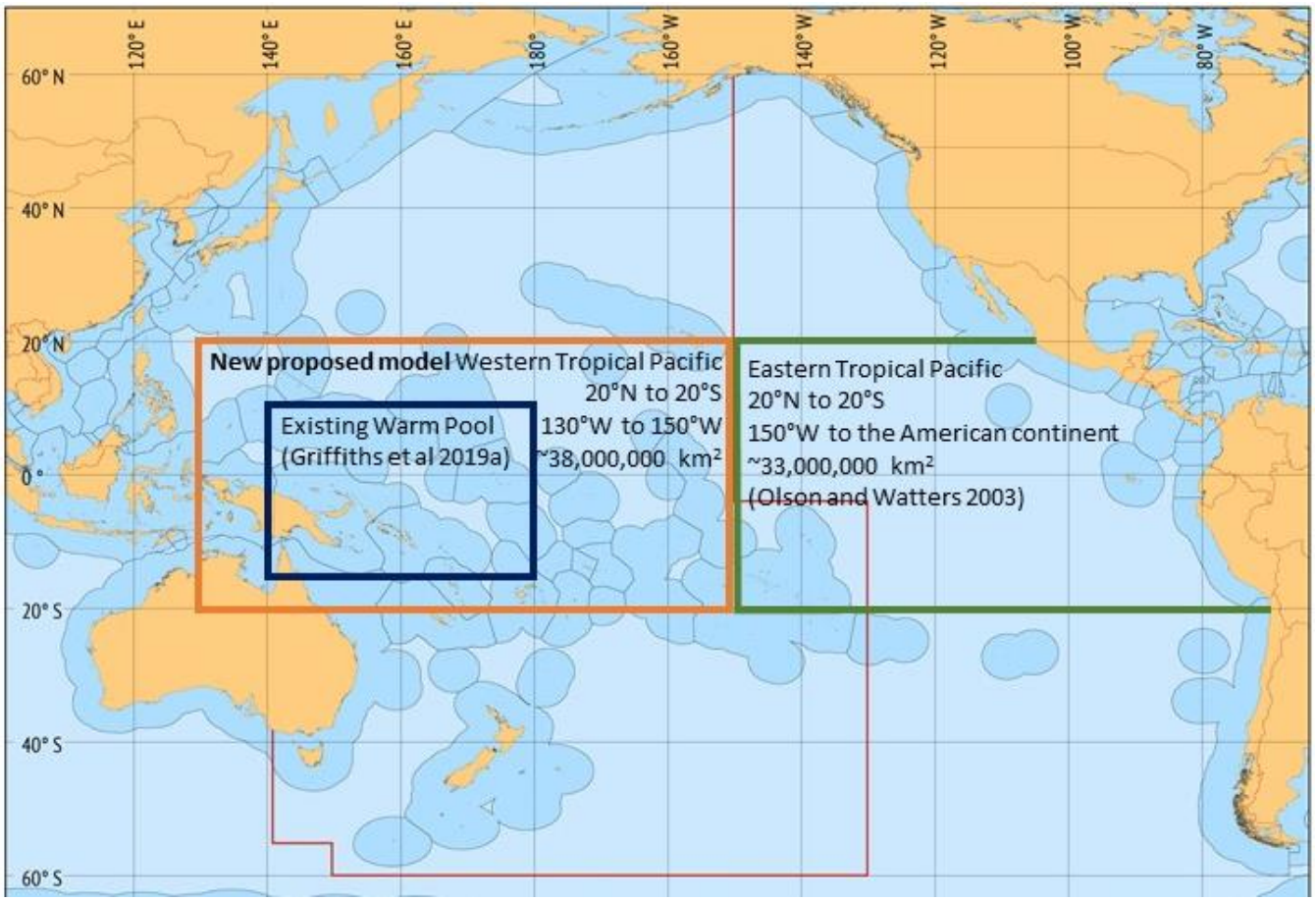

Figure 3. Map of the Pacific showing the previous model area for the warm pool area and the new proposed area (WTP: Western Tropical Pacific), as well as the existing Eastern Pacific model (ETP).

The structure of the new WTP model was also modified to align functional groups in the WTP and ETP models to facilitate comparisons of ecosystem processes, but also to assess the similarities and differences in the impacts by specific simulated fishing and environmental scenarios (e.g. increased FAD effort). Additional species or functional groups were also added to the model to maximise its relevance to the WCPO and to resource managers. For example, the results of the questionnaire sent to WCPFC Members indicated that seabirds, marine mammals, numerous sharks, billfishes and opah were important bycatch species, and they suggested that rays and barracudas be added. Stakeholders present at the workshop also identified mobulids, pelagic stingray, whale shark and barracudas as species that should be explicitly included in the model. At the conclusion of the workshop, a total of 65 functional groups were agreed upon by participants to characterize the WCPO model.

The base year of the model—the period for which the structure and trophic connections and flows define the ecosystem—was also changed from 2005 to 2013. This was implemented to not only take advantage of the increasing amount of bycatch and predator diet data available to parameterize the model, but to also characterize the model for a reasonably 'stable' environmental period, that is, a period lacking strong ENSO events. A particularly significant modification of the model was to the underlying diet matrix, which defines the trophic relationships and the magnitude of energy flow through the ecosystem.

This was possible due to over 19 years of sampling predator diets throughout the WCPO, which has yielded a total of 7118 stomachs from 38 species directly relevant to the model.

The workshop was attended by several SPC stock assessment scientists and ecological modellers who provided valuable input into the species and fisheries for which time series of biomass, catch, discard, fishing mortality or effort data were available for the model region. In total, the group identified and collated 245 data time series for 46 functional groups of target and non-target species, 4 time series of effort data for longline, purse-seine (associated and unassociated sets), and pole-and-line. An additional 13 time series that exceeded 10 years were derived for forage species and zooplankton from the SEAPODYM-LMTL model, since field-based estimates of biomass are notoriously difficult—and expensive—to obtain.

As of June 30, 2020, model building is underway. All data has now been included, namely the diet matrix, catch and discard biomass for each species by fishery, and the 262 time series of data that will be used for calibration to ensure the model can reproduce known data trends. The model is currently in the 'balancing' stage, where the biomass production of each of the functional groups due to growth is balanced against the loss of biomass to predators, biological processes and fishing mortality.

Over the coming months, once the model is balanced, various scenarios will be simulated regarding changes to fishing activities and/or the environment. The model will produce outputs of the changes in biomass (and catch where relevant) in individual species (e.g. target and non-target species) as well as ecological indicators, such as those described in a previous SPC ecosystem workshop (Allain et al., 2020, 2015, 2012a), for e.g. trophic level of the catch and the fishing in balance index. Together, such indicators can allow for the identification of changes to the structure and dynamics of the WCPO ecosystem.

6. NOTES TO THE WCPFC-SC16

We invite WCPFC-SC16 to:

- Highlight the need for availability of better data on non-target species collected by fisheries observers on purse seine and longline vessels.
- Support on-going research developments into trophic-structured ecosystem models to describe the holistic functioning of the WCPO pelagic ecosystem, including the development of the Pacific Marine Specimen Bank.
- Note the development and progress of a new Ecopath model for the WCPO.
- Encourage active participation by fisheries managers of the WCPO on the development of ecosystem models and EAFM for the region.

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9. ANNEXES

Annex 1 – List of EcoSEA workshop attendees

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Annex 2 – Agenda of the EcoSEA workshop.

EcoSEA: Ecosystem modelling in the WCPO using Ecopath and SEAPODYM: current status and future directions

Date and location: 28 October to 1 November 2019, SPC (IT training room), Nouméa, New Caledonia

Talks/presentations	Group discussions	Working groups

Time	Monday 28 Oct	Tuesday 29 Oct	Wednesday 30 Oct	Thursday 31 Oct	Friday 1 Nov
8:00 **8:30**	Coffee/tea available at the coffee machine next to the conference room (IT training room by the Social Club area) Collect your per diem				
8:30 **10:00**	***Theme: EcoSEA, Ecopath and SEAPODYM***	***Theme: Specific data to support ecosystem modelling in the WCPO (continue)***	***Theme: Desired model structure (continue) and Working groups***	***Theme: SEAPODYM – new developments and applications***	***Theme: Where are we headed?***
	8:30 Introduction and overview of ecosystem modelling in the WCPO: current status and ecological questions of interest to SPC (V. Allain / N. Smith)	**8:30** SPC bycatch monitoring and abundance indices for key species (T. Peatman via Skype)	**8:30** Ecospace: potential application and modelling framework (J. Steenbeek via Skype)	**8:30** New developments in SEAPODYM and future plans in the WCPO – albacore case study (I. Senina)	**8:30** Ecological indicators (M. Coll via Skype)
	8:45 Overview of Ecopath - history, structure, processes and equations (C. Wabnitz / M. Coll)	**9:00** SPC stock assessment estimates II: target species (M. Vincent / T. Cunningham)			**9:00** Can ecosystem models provide the sensitivity we need for managing our oceans? Is there a silver bullet in the form of a 'dream' model? (S. Nicol)

	9:20 Overview of SEAPODYM – history, structure, processes and equations (P. Lehodey / I. Senina)	**9:30** Group discussion 'Dataset quality and availability for the new Ecopath model' (led by J. MacDonald Rapporteurs: Valerie/Joe)	**9:15** Working groups Working groups to discuss and decide which datasets are to be used, data collation and processing in required formats; • Define working groups and begin tasks. (Led by S. Griffiths)	**9:15** Presentation from the SEAPODYM review consultant on progress, preliminary findings of the review and remaining tasks (A. Dunn)	**9:30** Flexible time to continue work from the week such as • Continue group work, following on from Wednesday afternoon's sessions • Continue discussions on SEAPODYM development
10:00 10:30	Morning tea				
10:30 12:00	***Theme: Model appraisal the Warm Pool Ecopath model***	***Theme: Specific data to support ecosystem modelling in the WCPO (continue)***	***Theme: Working groups con...***	***Theme: SEAPODYM – new developments and applications***	***Theme: Working groups con...***
	10:30 Group discussion 'Questions, queries and comments on the Ecopath and SEAPODYM frameworks' (Led by S. Griffiths Rapporteurs: Jed/Joe)	**10:30** Group discussion (continue) 'Dataset quality and availability for the new Ecopath model' (led by S. Griffiths Rapporteurs: Valerie/Joe)	**10:30** Working groups Break into defined groups and begin tasks (Rapporteurs: Nan/ Joe/Colette)	**10:30** Group discussion 'SEAPODYM developments, review findings and what these mean in the context of SEAPODYM's future direction' (led by N. Smith Rapporteurs: Valerie/Shane).	**10:30** Flexible time to continue work from the week such as • Continue group work, following on from Wednesday afternoon's sessions • Continue discussions on SEAPODYM development
		Theme: Spatial possibilities			
	11:10 The Warm Pool Ecopath model (S. Griffiths)	**11:00** Tagging and movement data (J. Scutt Phillips)			**11:30** Wrap up and conclusions (V. Allain / N. Smith / S. Griffiths)
		11:30 Incorporating movement dynamics in SEAPODYM (I. Senina)			
12:00 13:30	Lunch				
13:30 15:00	***Theme: Specific data to support ecosystem modelling in the WCPO***	***Theme: Desired model structure***	***Theme: Desired model structure (continue) and Working groups (continue)***	***Theme: Ecosystem models and MSE for WCPO tuna fisheries (continue)***	***END OF WORKSHOP***
	13:30 The physical ocean environment and climate change scenarios (M. Wandres)	**13:30** Group discussion 'Desired structure and utility of the new Ecopath model':- 1. Stakeholder views.	**13:30** Group discussion 'Desired structure and utility of the new Ecopath model':- 3. Climate change and fishery scenarios;	**13:30** MSE in the WCPO – overview, current applications and the potential for incorporating ecosystem models (F. Scott / N. Yao)	Free time – continue group work or extracurricular activities

	14:00 Climate change forecasting and primary and secondary production (R. Matear)	2. Species and trophic structure; (Led by V. Allain / S. Griffiths Rapporteurs: Colette/Jed)	(Led by V. Allain Rapporteurs: Colette/Shane)	**13:50** <u>Group discussion</u> 'What modelling tools and which outputs are required to optimise future MSE in the WCPO' (Led by F. Scott / N. Yao Rapporteurs: Tiffany/Joe)	
			<u>Working groups</u> Continue group work	***Theme: Alternative models for the WCPO ecosystem***	
	14:30 The SEAPODYM-LMTL model: dynamics of low- and mid-trophic level organisms (P. Lehodey)			**14:30** The Spatial Population Model (SPM) and CASAL2: overviews and applications in NZ (A. Dunn)	
15:00 **15:20**	Afternoon tea				
15:20 **16:50**	***Theme: Specific data to support ecosystem modelling in the WCPO (continue)***	***Theme: Desired model structure (continue)***	***Theme: Working groups summaries and next steps***	***Theme: Alternative models for the WCPO ecosystem cont...***	Free time – continue group work or extracurricular activities
	15:20 Micronekton acoustic measurements and comparisons with SEAPODYM (A. Receveur)	**15:20** <u>Group discussion</u> 'Desired structure and utility of the new Ecopath model':- 3. Spatial and temporal aspects; (Led by J. Scutt Phillips Rapporteurs: Shane/Jed)	<u>Working groups</u> Continue group work Short summary presentations on progress from each of the working groups (All)	**15:20** EASI-Fish: overview and applications for Ecological Risk Assessment in the EPO (S. Griffiths)	
	15:50 Predator stomach contents analysis (V. Allain)		Summary, next steps and logistics for progressing the Ecopath model for the WCPO, What will this model give us in terms of outputs? (S. Griffiths)	**15:50** <u>Group discussion</u> 'How can ecosystem models borrow strength from one other to inform management directives in the WCPO?' (Led by S. Nicol Rapporteurs: Colette/Jed)	
	16:20 SPC stock assessment estimates I: billfish and sharks (N. Ducharme-Barth)				

Annex 3 – Questionnaire sent to staff of the fisheries department of the Pacific countries and territories in October 2019.

EcoSEA workshop, SPC, Noumea, 28 Oct-1 Nov 2019
Pre-workshop questionnaire for Pacific Island's fisheries service's/managers

CONTEXT

The WCPFC convention specifically calls for an ecosystem approach to fisheries management (articles 5 and 6). Developing ecosystem models is one course of action toward this approach. Ecosystem models differ from single species models (e.g. the bigeye MULTIFAN model used to assess the stock of bigeye tuna) in that they incorporate several species interacting with each other (prey-predator relationships). Ecosystem models can be complex, but they provide a more realistic view of the system and can be used to monitor the status of the ecosystem using indicators, or to predict the impact of fisheries management measures or environmental changes such as climate change, on the different species included in the model (e.g. bycatch, target species).

SPC is organising a workshop on Ecosystem modelling (EcoSEA), 28 Oct-1 Nov 2019. We are bringing together experts to build an ecosystem model describing the pelagic ecosystem that supports the tuna production in the western and central Pacific (WCPO). We will also discuss the different ecosystem frameworks that exist or need to be developed in the region.

Capturing the views of all stakeholders in the WCPO is essential for making these models relevant and useful and we would highly value your inputs into this work. Please take a moment to fill out this short questionnaire, which will help inform the model development and help us customize information and training materials to best support your country's priorities.

Thank you in advance for your kind cooperation.

QUESTIONS

1. Which country do you represent?
2. Which organisation do you represent?
3. Below is a list of species (individual species or groups of species) under consideration to be included in the ecosystem models. Please indicate how important they are for you.

Group/Species	Rate level of importance to your country					
	Not at all important	Slightly important	Important	Fairly important	Very important	No opinion
TUNA						
Albacore tuna						
Bigeye tuna						
Yellowfin tuna						
Skipjack tuna						
Small tuna (e.g. frigate, bullet), as a group, not differentiating species						
BILLFISH						
Blue marlin						
Striped marlin						
Swordfish						
All other billfish as a group not differentiating species						
SHARKS						
Blue shark						
Mako sharks as a group, not differentiating species						
Oceanic whitetip shark						
Silky shark						
All other sharks as a group not differentiating species						
BYCATCH SPECIES						
Wahoo						
Rainbow runner						
Opah						
Dolphinfish/mahi mahi						
Escolars and oilfish as a group not differentiating species						
Pomfrets as a group not differentiating species						
Lancetfish as a group not differentiating species						
SPECIES OF SPECIAL INTEREST						
Marine mammals as a group not differentiating species						
Turtles as a group not differentiating species						
Seabirds as a group not differentiating species						
Please specify other species to be included as individual species or groups						

4. Please specify any additional species or groups that would be important to include in the model
5. How would you like to be engaged in WCPO ecosystem work?
    a. I don't have time or interest for this topic
    b. Training on ecosystem structure, biology and functioning
    c. Training on ecosystem approach to fisheries management
    d. Information received at the WCPFC scientific committee
    e. Information available on SPC website
    f. Information forwarded via newsletters, email, Twitter
    g. Other, please specify…

6. Which topics would you like to see discussed more at the WCPFC
    a. Ecosystem structure, biology and functioning
    b. Ecosystem modelling frameworks such as SEAPODYM, ECOPATH…
    c. Ecosystem indicators to inform management
    d. Bycatch species biology (for example wahoo reproductive patterns…)
    e. Bycatch species catch trends
    f. Future climate and fishing impacts on ecosystem
    g. Future climate and fishing impacts on bycatch species
    h. Early warning signs for fundamental changes in the ecosystem
    i. Other, please specify…
7. Do you have any other comments or suggestions?