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REPORT OF THE INTERNATIONAL WORKSHOP ON OPPORTUNITIES FOR ECOSYSTEM APPROACHES TO FISHERIES MANAGEMENT IN THE PACIFIC OCEAN TUNA FISHERIES

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Report of the international workshop on opportunities for Ecosystem Approaches to Fisheries Management in the Pacific Ocean tuna fisheries

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Background

During the past few decades several international initiatives have been adopted to promote the implementation of an Ecosystem Approach to Fisheries Management (EAFM). The 1995 FAO Code of Conduct for Responsible Fisheries has been developed as a reference framework for sustainable fisheries addressing ecosystem considerations, principles and goals needed for EAFM (Garcia & Cochrane, 2005). The FAO code states that fisheries management should ensure the conservation not only of target species, but also sympatric non-target species. This resolution is now explicit in most Regional Fisheries Management Organisation (RFMO) conventions including, in the Pacific, the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), the South Pacific Regional Fisheries Management Organisation (SPRFMO) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMRL). Moreover, for marine ecosystems and populations of non-target, associated and dependent species, the WCPFC, IATTC, SPRFMO and CCAMRL conventions state that improved knowledge should be acquired, the impacts of natural factors and human activities should be assessed, monitoring should be continued or implemented, and conservation and management measures and recommendations should be adopted.

Implementing EAFM requires measurements against criteria that can be used to assess overall ecosystem status and the impacts of human exploitation and climate variation. In single-species management these decision criteria are measurable quantities (e.g. species abundance, F_{Msy}), primarily based on stock assessment model outcomes. They are intended to prompt management action. Analogous decision criteria with a broader focus on community- and ecosystem-level attributes are in a nascent stage of development (Samhouri *et al.*, 2010). New analytical models (multispecies, ecosystem models) and management tools (indicators) appear as essential tools for the quantification of these ecosystem attributes and implementation of EAFM (Pikitch *et al.*, 2004). Ecosystem models help to understand the complex direct and indirect interactions between species, fisheries and the environment, but need to be strengthened and should include uncertainty (deYoung *et al.*, 2004) to improve their representation of the ecosystem and reliability of outcomes that can be used by managers for decision-making. Ideally, indicators should characterise the structure and dynamics of ecosystems, provide information on the state of the ecosystem, be sensitive to changes due to the impact of environmental variability and fisheries, as well as serve as a communication tool for managers and stakeholders. Among the many ecological indicators proposed, few can be measured directly from the ecosystem as a whole, but are mainly derived from species-specific information (Fulton *et al.*, 2005; Powers & Monk, 2010).

The tuna fisheries of the tropical Pacific Ocean (Fig. 1) are the largest in the world, providing more than 50% of the global catch and with more than 25% of the global catch being taken from the national territorial waters and exclusive economic zones of Pacific Island countries and territories (PICTs). These tuna fisheries are also extraordinarily important for the economic development of the region. In particular, they provide several PICTs with a significant source of government revenue, through the sale of licence fees to distant water fishing nations (DWFNs), and employment opportunities for both men and women, through direct involvement in the catching and onshore processing sectors and associated businesses. For example, licence fees from DWFNs provide between 10% and 42% of all government revenue in five PICTs; in another two PICTs, fishing or processing operations for tuna alone contribute approximately with 20% to gross domestic product; and, across the region, tuna fishing and processing operations employ more than 14,000 people (Gillett 2009, Bell *et al.* 2011). Tuna fisheries also play an extremely important role in food security. Most Pacific Island communities are largely dependent on fish for protein (Gillett 2009). There is a consensus that no further increases in coastal demersal fisheries production are possible and therefore oceanic resources are viewed as one of the solutions to provide food security in the Pacific in the face of fast growing populations (Bell *et al.* 2009).

Currently, tuna fisheries are managed on the basis of single-species stock assessments, but with the increasing requirement for sustainable management of co-occurring species (e.g. bycatch, threatened and endangered species), there is increasing effort by a range of organizations to collect detailed data on the structure of the Pacific Ocean pelagic ecosystem. This effort occurs through observer programmes (e.g bycatch composition and quantities), trophic analyses (e.g. stomach contents, stable isotopes), and mid-trophic level sampling (e.g. acoustics and net sampling of micronekton and zooplankton). Despite the highly valuable information they provide on the knowledge of the ecosystem structure and functioning, the collection of observer data is still relatively recent, with low coverage. Moreover, trophic analyses and mid-trophic level sampling are conducted on a project-by-project basis and are not continuous in space and time, thus limiting their use for long-term monitoring and EAFM.

The workshop

The Global Environment Facility Oceanic Fisheries Management project recently brought together scientists who have been leading ecosystem research of the Pacific Ocean pelagic systems, by convening a workshop to synthesize past progress and identify future priorities within the scientific and monitoring component of EAFM. The workshop was hosted by the Secretariat of the Pacific Community at its headquarters in Noumea, New Caledonia in March 2011.

During the workshop, scientific information available from RFMOs and the main scientific organizations were synthesized, including time series of catches (target and non-target), effort, length-frequencies, observer data, potential ecosystem metrics, as well as sporadic information on trophic structure and mid-trophic levels and existing ecosystem models assimilating these data. This overview also included presentations on the IndiSeas project which includes data-based indicators, and on available trophic models and model-based indicator alternatives.

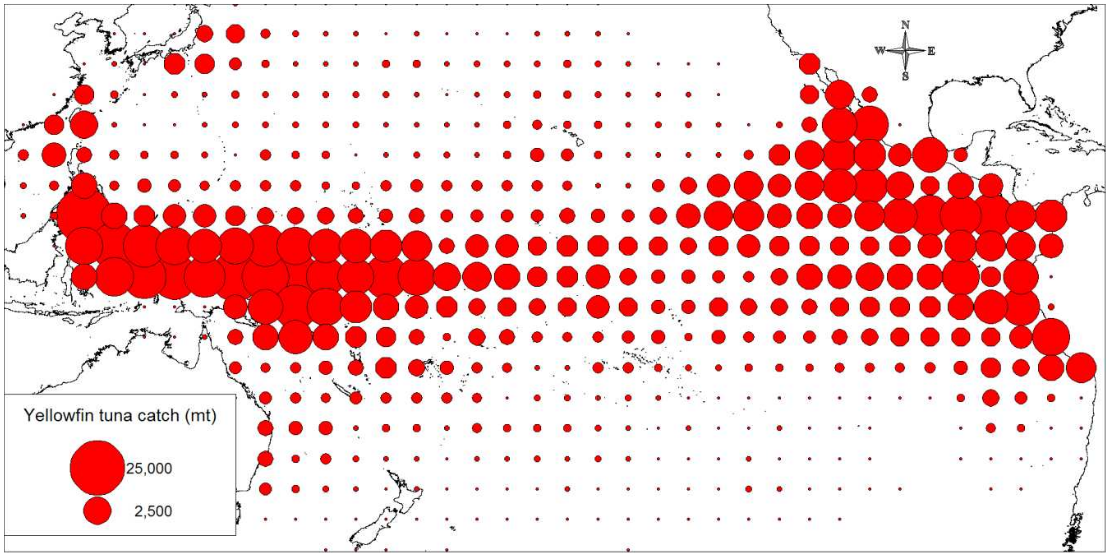

Figure 1. From Allain *et al.* 2011. Average annual yellowfin tuna catch in metric tons from purse seine and longline vessels for the period 2004-2008.

The opening presentation on the first day provided an introduction to ecosystem and by-catch policy for tuna fisheries in the Pacific Ocean. The presentation emphasized that for tuna fisheries management, the ability to differentiate between environmentally driven changes and fishing impacts was fundamental, along with progression towards the development of reference points for the ecosystem and by-catch species.

This was followed by a presentation that overviewed progress on the International IndiSeas project (Shin & Shannon 2010; www.indiseas.org), which has developed and continues to develop data-based indicators on the status of exploited marine ecosystems. The pelagic ecosystems of the Pacific Ocean are currently not included in the IndiSeas project; however, there is opportunity for involvement in the near future under a new phase of the project starting in 2011. According to this project, ecosystem indicators should be (i) measurable (i.e. the potential data to calculate the indicators need to be available across the ecosystems to be compared), (ii) sensitive (i.e. there should be a high correlation between the indicator and the driver), (iii) ecologically meaningful (i.e. the indicator should be based on strong scientific and theoretical knowledge) and (iv) widely understood (i.e. the meaning and link of the indicator with the driver should be intuitively understood by a wide range of stakeholders) (Shin *et al.* 2010). The lessons learned from IndiSeas should be followed for those indicators developed for application on the tuna fisheries in the Pacific.

The third presentation summarized the observer data available for analyses in the western and central Pacific Ocean. Those data have been used to estimate annual catches of non-target species, initially concentrated on five key shark species, providing standardized CPUE (Catch Per Unit Effort). However, the use of standardised CPUE as an indicator of population abundance is complicated by operational changes in the fishery due to regulations and targeting changes. While observer coverage of the purse-seine fleet has been representative of the whole fleet, coverage of the longline fleet has not, with important gaps for distant-water longline fleets. Deficiencies in the spatial and temporal coverage of these data presents significant challenges for this type of analysis, and the provision of longline observer data from commercial, research and training vessels held by DWFNs would improve these analyses. It is worth noting that 100% observer coverage for the approximately 200 large purse seiners has been implemented since 2010, and from 2012 a 5% observer coverage across nearly 850 longliners will be implemented. This should greatly improve the data collection on the interaction between tuna fisheries and non-target species.

The next presentation illustrated some changes over the past decade at both the bottom and top of the central North Pacific subtropical pelagic ecosystem. At the base of the ecosystem, SeaWiFS cholorophyll data was used to show that the most oligotrophic centers of the subtropical gyres in the North and South Pacific and North and South Atlantic have expanded in area by 2-4%/yr over the past decade (Polovina *et al*. 2008). At the top of the ecosystem, observer and logbook data from the Hawaii-based longline fishery were used to describe possible top-down ecosystem responses. Time series showed an increase in catch rates of mid-trophic fishes occurred concurrent with the declines in catch rates of apex predators (Polovina *et al.* 2009).

The final presentation for the first day was an overview of three potential ecosystem metrics applied to purse-seine catches and bycatch undertaken by the IATTC in the Eastern Pacific Ocean. The metrics were mean trophic level, replacement time, and diversity of the catch. The presentation raised the important point that examining the impacts of fishing on the ecosystem requires an assessment of the total removals (i.e. retained and discarded catch), contrary to previous studies that focused only on the discards. In this example, however, the metrics were strongly influenced by the target tuna species in the catch, which may have masked community-level implications. Vessel operating behaviors have influences on catch composition and the ecosystem metrics can be confounded with this factor. For metrics based on catch composition, examination of the discards was more informative than landings examination.

The second day of the workshop commenced with a presentation about a decadal-scale diet shift in yellowfin tuna in the eastern Pacific Ocean (EPO) through comparison of data collected in the early 1990s and the early 2000s. During the intervening decade, a suite of epipelagic fishes declined from dietary dominance and were largely replaced by mesopelagic fishes and cephalopods. Previous modeling efforts demonstrated separate epipelagic and mesopelagic trophic pathways in the pelagic EPO (Watters *et al.* 2003) and system-wide sensitivity to model parameters for a dominant epipelagic prey species and mesopelagic-migrating cephalopods (Olson and Watters 2003). The key concept was whether the diet composition of a ubiquitous generalist pelagic predator can be representative of community-level species composition and changes over time. Two important issues raised by this presentation for future trophic studies were i) the spatial definition of the study, and ii) the adequacy of the temporal duration to detect changes. Identification of pelagic habitat biomes may be a useful approach in the future. Examples of the efficacy of this biome approach have been demonstrated in eastern Australia using satellite-derived oceanographic information and proved to be effective at identifying specific habitat types that are relevant to trophodynamics and species composition of pelagic communities. Ensuring that the temporal period for measuring diet is representative is also important to make sure that differences observed between time periods (e.g. decades) are associated with actual diet change rather than sampling error.

This was followed by a presentation examining decadal changes in diet of tuna species in New Caledonia and French Polynesia. As observed in the EPO there appeared to be a change in broad categories of diet composition and in fish family diversity between 1960-1970 and 2001-2011 in New Caledonia, and between 1995-1997 and 2001-2011 in French Polynesia. The results provided some support for hypotheses that a significant shift in tuna diets occurred in the late 1990s in French Polynesia and highlighted the difficulties of recovering historical data and comparing non-standardised studies with varying levels of prey taxonomic identification.

The next presentation evaluated the suitability of population biological parameters for measuring ecosystem change. Tuna condition measured by fat content was examined and showed important variability. However trends observed were primarily due to differences in fish length. Other factors influencing the fat content were space and time. Stable isotope analysis was also discussed and proved to provide valuable information as biogeographic tracer with a very strong potential to explore trophic structure given that new data analysis techniques have been developed recently (Jackson *et al.* 2011). It was estimated that biological parameters could potentially be informative on the status of populations and ecosystems; however, it was recognized that more exploration was needed (e.g. detailed data analysis, tank experiments) to understand the mechanisms underlying these parameters (e.g. including density-dependant effect, tissue and metabolic turnover and physiology) before being able to use biological parameters as indicators in the management context.

The last presentation of the second day focused on biomass estimation and identification of the mid-trophic component of oceanic ecosystems using acoustics and opening-closing midwater nets (Kloser *et al.* 2009) and its input to estimates of secondary production, the latter required for ocean-scale production models (Lehodey *et al.* 2008). Also discussed was the potential for video and photography in species recognition, particularly soft bodied species that are usually not well represented in net tows. The point was made for the need for repeated surveys to estimate and identify interannual variability, particularly relevant in monitoring potential changes due to ocean warming. The Australian Government through the Integrated Marine Observing System (IMOS, www.imos.org.au) is now supporting annual cross-Tasman Sea acoustic transects via research vessel and ships of opportunity. More validation is required and an important issue is to ensure that sampling strategies are comparable with those presently being developed elsewhere in the Pacific.

The third day concentrated on model-based structural, functional and trophodynamic indicators of ecosystem change. Based on diet data, four food-web models (ETP-Eastern Tropical Pacific (Olson and Watters 2003), CNP-Central North Pacific (Howell pers. com.), Pacific Warm pool (Allain *et al.* 2007), and ETBF-Australian Eastern Tuna and Billfish Fisheries (Griffiths *et al.* 2010) developed with the Ecopath with Ecosim (EwE) modelling tool (Christensen and Walters 2004) and three qualitative models (Dambacher at al. 2010) have been constructed to characterise pelagic ecosystems in specific regions throughout the Pacific Ocean.

The first presentation described qualitative evaluation of food-web structure and ecosystem dynamics. Predictions from qualitative models can be used to identify ecological indicators that are robust to model-structure uncertainty and also able to distinguish between multiple simultaneous pressures (e.g., fishing and environmental). This approach provides a useful way to create syntheses across multiple disciplines and identify potential ecosystem drivers, and also a complement to quantitative EwE models. Comparison between the approaches could be highly beneficial.

The second presentation provided an overview of potential metrics derived from single species analyses, ecological risk assessment, and Ecopath with Ecosim models. Size-spectra (number of fish per size class) has the advantage of being easily computed and uses observer data without the need for any data assimilation in external models. Sustainability for Fishing Effects (SAFE) is a quantitative ecological risk assessment tool that allows the status of non-target or data-deficient species to be determined against commonly used fishery reference points. Several structural and trophodynamic indicators can be derived from EwE models, with examples provided from the ETBF model (Griffiths *et al.* 2010). Structural indicators characterise the physical network, particularly the trophic level (TL) of the catch and the Marine Trophic Impact (TL of the catch of groups with TL>3.25), the trophic level of the whole community and the transfer efficiency. Other trophodynamic indicators such as the keystone index, the Mixed Trophic Impact, the Fishing-in-balance index and the Loss-in-production index can be used to detect and measure the magnitude and direction of change and identify key drivers (Libralato *et al.* 2006, 2008, Christensen 2000, Christensen and Walters 2004, Cury *et al.* 2005, Pauly and Watson 2005). There is still further work required to determine which of the several EwE-based indicators may be more suitable for oceanic pelagic ecosystems. Formal comparison of the existing four EwE models may improve our understanding of the utility of these indicators. However, it is likely that no single indicator would be a panacea or 'silver bullet' for all marine ecosystems, and a combination of structural and trophodynamic indicators may be required. Although food-web models can produce various quantitative indicators and suggest future states of ecosystems following specific perturbations, the validity of results is highly dependent upon the extent to which the balanced model represents the system, which require species-specific and regionally-specific dietary and biological information and biomass estimates. The third presentation also addressed the metrics that can be derived from EwE models, with reference to multi-model comparisons both in terms of snapshots in time (using static models) and dynamic simulations (using time dynamic modelling) (Coll & Libralato, in press, Coll *et al.* 2010).

The final presentation outlined the current progress of the dynamic system model SEAPODYM- Spatial Ecosystem And Populations Dynamics Model (Lehodey *et al.* 2008) application to the albacore fisheries in the South Pacific. The model has the potential to provide additional information for the management of tuna species. In particular, due to the spatial characteristic of the model, SEAPODYM could provide information of percentage of available biomass and average monthly biomass available at EEZ level as well as results on recruitment. Future work will be focused on improving the forecasting module of SEAPODYM to assess the potential consequences and robustness of different fishing policies under different scenarios of climate variability at global and national level.

The fourth day had a presentation on the use of a climate model to examine possible ecosystem changes in the North Pacific over this century with a biome approach. Three biomes (temperate, subtropical, and equatorial upwelling) were defined based on model-estimated depth-integrated phytoplankton. Over the 21^{st} century the model predicts a 30% expansion of the subtropical biome and 34 and 28% declines in the temperate and equatorial upwelling biomes respectively (Polovina *et al.* 2011).

On the fifth day a presentation showed large-scale spatial patterns in the sizes of yellowfin, bigeye, and skipjack tuna across the Pacific. Larger average sizes were associated with locations further east for all species, and there were significant latitudinal size differences as well as finer scale patterns. The causes of these patterns are not understood, but spatial patterns of sex ratio at length suggest biological causes, with differences in growth, natural mortality, and/or movement between regions.

Discussion

The discussion following the presentations recognized uncertainty issues in the interpretation of the ecosystem indicators, which require an in-depth knowledge of the ecosystem functioning before being able to use these indicators in the EAFM context. It was emphasized that indicator trends should always be interpreted along with fishing and environmental indicators, the two major drivers of marine ecosystems, and that local expertise with extended knowledge of the ecosystem functioning was critical for separating fishing from environmental effects.

During the workshop we identified that a real opportunity exists to complete a basin wide ocean monitoring system to support ecosystem based fisheries management across the pelagic tropical and subtropical Pacific Ocean. Monitoring systems to measure physical and biological oceanography such as remote sensing or Tropical Atmosphere Ocean (TAO) weather buoy array have been established to measure bottom-up processes; however, measurement of top-down processes are limited at the basin scale. There are currently 421 large purse-seine vessels and 2025 longline vessels licensed to operate in the Pacific Ocean. Observer coverage on all large purse-seine vessels is already mandatory thorough the Pacific and in 2012 the mandatory coverage for longline vessels in the jurisdiction of the WCPFC will be 5%. In the EPO the longline coverage is considered very low. This observer coverage which can provide a spatially explicit catch time-series of target and non-target species and operational level information would supply comprehensive catch information for the upper trophic levels. In addition, many of the DWFNs (Japan, Taiwan, China, Korea and United States of America) have historical observer data beyond that supplied to the RFMOs. A significant challenge for the management of tuna resources in the Pacific Ocean is the differentiation of the influences of environment and fishing on the changes in abundance of target and non-target species. Ongoing ecological analyses of these observer data would improve the ability for fisheries managers to assess the impacts of fishing on non-target species and the indirect impacts on target species. These analyses would also improve the design of protocols for the observer programs through the provision of feedback on the data critical to such analyses.

In-depth analyses of spatial distributions and time series of catch and catch rates of non-target species could also contribute significantly to the improvement of the four trophic models (ETP, CNP, Pacific Warm Pool, ETBF) that have been constructed using the Ecopath with Ecosim framework. The validation and application of these models has been constrained by the absence of time-series of abundance for the non-target species by some fleets. More thorough analyses of the observer data would alleviate many of these constraints. Comparison of trophic models and development of spatial models would be highly beneficial to ascertain the degree of difference in the function and structure of the ecosystems described in the Eastern, Central, Western and Southern Pacific Ocean. This comparison, which requires some degree of standardization, would also assist in developing a candidate list of indices that could be used by fisheries managers to assess the status of the Pacific Ocean ecosystems and the differential traits of Pacific Ocean marine food webs. A comparative approach among ecosystems and development of multiple models and indicators were envisaged as the most appropriate approach toward EAFM.

The models would also significantly benefit from time series of the composition and quantities of mid-trophic level organisms. Although these data can be determined by independent surveys of predator forage, which are developing and should be encouraged, surveys are extremely expensive and logistically difficult to carry out. Predatory fishes, however, are effective samplers of this forage and the expanding temporal and spatial coverage of observers across all tuna fleets operating in the Pacific Ocean provides an opportunity for the systematic sampling of mid-trophic levels via the stomach contents. In order to evaluate the most efficient design for such a sampling regime, analyses of the dynamic oceanographic biomes (Hobday *et al.* 2011) is an immediate priority followed by a subsequent analysis to associate these biomes with tuna size patterns, growth rates, bycatch composition, diet composition and stable isotope signatures. Such analyses would provide the spatial template necessary for future sampling programs. Hence, ecosystem models enhanced by detailed mid-trophic level information based on taxonomic groups rather than functional groups will allow a better understanding of the impacts of fishing and environmental variability on key non-target species. In addition to updating and improving the suite of ecosystem models in existence, ongoing collection of predator diet information of sufficient taxonomic resolution will allow the construction of mid-trophic level long time series necessary for the identification of indicator species and the monitoring of community-level changes. Hence, based on these long time-series and a good knowledge of the oceanography and environmental variability, the development of new multispecies model for the region will allow the detection of significant changes in the distribution and abundance of species that are the consequence of environmental variability and change (e.g. climate change). Monitoring changes in the distribution and abundance at lower trophic levels could potentially provide an early warning system for pending large scale changes in pelagic ecosystems, thereby providing fisheries managers with the cues for implementing adaptive strategies within realistic timeframes.

Future directions

From discussion on research activities and needs in regards to the implementation of EAFM of the Pacific pelagic ecosystem, a number of suggestions were outlined to move further into this approach. Detailed ecological analyses of observer data available in the region should be implemented to understand the influence of environmental and fishing effects and to identify potential trophic changes in the upper trophic levels. The identification of biomes based on cluster analyses of oceanographic parameters appears as a priority that should be enhanced by subsequent analyses of other parameters such as stable isotope signatures, bycatch and diet composition. A comparison of the existing pelagic ecosystem models developed in the Pacific should be encouraged, with the potential of extending this exercise to the spatial modelling and to other oceans, to elucidate structural traits and functionality, and to identify suitable indicators of the ecosystem state. Enhanced collection of mid-trophic level organisms will be promoted to RFMOs and funding agencies demonstrating the importance of extending standardised acoustic surveys and implementing ongoing predator stomach sampling along with the relevance of developing a central facility to analyse trophic samples. The ecological links between inshore and offshore ecosystems and their roles on pelagic species was also identified as a question to tackle in the future, although this issue is currently limited by data availability. Participation in the IndiSeas programme was viewed as a valuable future direction.

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