Report of the 2012 ISSF Stock Assessment Workshop: Understanding Purse Seine CPUE

Rome, Italy, July 16-19, 2012

Summary. A workshop was held to examine various issues that make the use of purse seine catch-per-unit-effort (CPUE) data in stock assessment difficult. The workshop convened a group of international experts from various fields who discussed possible ways to move forward in better understanding how and why purse seine CPUE may vary independent of stock abundance (or, equivalently, how fishing effort may vary independently of fishing mortality). The workshop carried out several preliminary analyses of the available data and made recommendations for future analyses. Recommendations were also made for the collection of information that may be available to industry but not to scientists. In terms of existing data, a number of analyses were recommended to better understand what makes catchability change over time (catchability is the constant of proportionality between stock abundance and CPUE). In addition, data mining of information about when fishing vessels began using various searching tools was viewed as potentially providing relevant information. Recommendations were made to make better use of the area searched during fishing operations, in addition to search time. In terms of future data collection possibilities, the workshop noted that access to information about the use of floating objects (including fish aggregating devices, FADs) for scientific purposes would likely provide useful insight into how to standardize such data with respect to covariates unrelated to fish abundance, and that FADs could potentially become observatories to monitor tuna densities. The Workshop also examined other potential alternatives to using CPUE, such as the biomass of tunas associated with FADs, and data derived from Vessel Monitoring Systems.

1. BACKGROUND, OBJECTIVES AND ORGANIZATION

Most tuna stock assessments rely heavily upon catch-per-unit-effort (CPUE) data from longline fisheries that have been contracting in recent years. In contrast, many purse seine fisheries have been expanding, especially those that target skipjack tuna and also catch yellowfin and bigeye tuna. Therefore, obtaining a better understanding of the factors that affect CPUE in purse seine fisheries could result in improvements to the potential use of these data in stock assessments. The idea behind doing so is to account for covariates that are independent of fish abundance so that a CPUE measure that tracks abundance can be used in the stock assessment as an abundance index (or, equivalently, a measure of fishing effort that is proportional to fishing mortality). ISSF convened a workshop aimed at obtaining a better understanding of how purse seine CPUE varies.

The workshop was held at the Hotel Capo d'Africa. The agenda is included as **Appendix 1**. Participants included members of the ISSF Scientific Advisory Committee, staff from the Tuna RFMO Secretariats, scientists that actively participate in the RFMO scientific committees, and several invited external experts: R. Allen, N. Bez, M. Capello, T. Carruthers, M. Chambers, E. Chassot, G. Compeán, A. Cooper, L. Dagorn, R. Deriso, A. Fonteneau, F. Forrestal, D. Gaertner, S. Harley, S. Jackson, A. Langley, J. Majkowski, A. Maufroy, M. Maunder, H. Murua, H. Okamoto, P. Pallares, J.-F. Pulvenis, V. Restrepo, K. Schaefer, G. Scott, R. Sharma, M. Soto, and D. Squires. The meeting was chaired by Mark Maunder (IATTC). Francesca Forrestal served as Rapporteur.

A number of participants made background presentations intended to inform the discussions. In addition, a number of scientific publications were made available as references (**Appendix 2**), and several participants brought with them data to be analyzed (see **Appendices 3 and 4**). **Section 2** provides summaries of the

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presentations and discussions. **Sections 3 and 4** report the deliberations of various break-out groups in which participants considered different issues and made recommendations.

2. PRESENTATIONS

A comparative overview of observations during two trips on a French purse seiner in the Atlantic and Indian oceans (09/1980 and 01/2001), and global consideration and hierarchy of changes in purse seine fishing efficiency (A. Fonteneau).

Summary. The presentation was based on 40 years of field experience on tropical tuna purse seiners and upon 2 observed trips done in 1980 and 2001 in the Atlantic and the Indian oceans on French purse seiners. It was concluded that vessels in the same category of French purse seiners and their fishing activities have been widely modified, with the introduction of a wide range of interacting factors, most intended to increase the yearly catches and yearly fishing time of the purse seiners. The 2 factors classified as being the most important ones in 2000 are the extensive use of FADs and the use of bird radars during searching. Other new factors are also considered as being very important to increase the efficiency of the vessels, including: use of supply vessels, improved echo sounders, improved sonar (e.g. increased range), intensive use of satellite imagery, deeper and faster nets, knowledge of underwater currents and of net depth, faster unloadings, widespread use of computers and technological improvements of FADs. Other changes may also be important to improve fishing power such as improved positioning of vessels, skippers' improved use of an increasing amount of information, higher bird nests, improved navigation radars, larger brail nets, and increased fish hold capacity. It was concluded that, as a result of these multiple changes, purse seiners are clearly much more efficient in 2001 (and today) than in 1980 (and before). This conclusion probably applies worldwide, although these improvements in fishing power were probably variable between flags and oceans. Unfortunately, the timing of changes in these factors is poorly documented by scientists and the exact effects of the interaction of these multiple factors producing the increase of purse seiner fishing power remain difficult or impossible to measure quantitatively.

Discussion. It was discussed that new technologies are probably adopted somewhat simultaneously by vessels belonging to the same company. It was also discussed that code groups (vessels that share information) would have an effect on the adoption of certain technologies. It was noted that technological advances have slowed down and have perhaps reached an asymptote. The use of echosounders and doppler may not be evident in the data except as a decrease in skunk sets, as information from these technologies may result in the captain not setting.

Behavior of bigeye, yellowfin, and skipjack tunas, and their vulnerability to capture by purse-seine vessels, in the eastern Pacific Ocean (K. Schaefer).

Presentation**.** Behavior of bigeye, yellowfin, and skipjack tunas, based on archival tag data sets collected in the EPO was presented, with respect to how it may be useful for understanding their vulnerability to capture by purse-seine vessels. Analyses of the archival tag data for bigeye clearly indicate restricted movements with regional fidelity to an area of high biological productivity in the equatorial eastern Pacific Ocean. Based on the analyses of time-series data recorded for depths and temperatures, only about 12% of days the fish were at liberty did they exhibit associative behavior with floating objects, and associative events only lasted an average of 2.5 days. There is a significant negative correlation between the time fish exhibit associative behavior and increasing fish size. For yellowfin tuna, analyses of some fairly extensive archival tag data sets, indicate surface oriented behavior during the day is probably a reasonable approximation for the potential detection and vulnerability to capture by purse-seine vessels. There were spatial, temporal, and size/age differences observed in the behavior of yellowfin and thus unequal vulnerability to their capture by purse-seine vessels throughout the EPO. There is only a very limited amount of skipjack tuna archival tag data available. Analyses of those data indicate that skipjack tuna, when not associated with floating objects, spent about 38% of their time below the thermocline during the day. Tagging adequate numbers of skipjack with archival tags could provide estimates of the duration of associative events at floating objects, useful for estimates of vulnerability to capture by purse-seine vessels.

Discussion. It was noted the behavior types were defined statistically through algorithms and that tuna behavior was indicative of schools, and not just individuals. It was also discussed whether data obtained through tunas caught at FADs could represent selection bias and it was suggested that a comparison between the data obtained through tunas caught at FADs and by longline gear be conducted. Tuna feeding behavior at FADs was discussed. It was argued that the reason stomach content studies found a high proportion of empty stomachs was because the samples were collected from purse-seine sets around FADs in the early morning and are not representative of their foraging during the night. Tuna forage on deep scattering layer (DSL) prey organisms that undergo diel vertical migrations to the surface at night. FADs are commonly planted in areas with high biological productivity.

Current use of Purse seine CPUE in IATTC tuna assessments (M. Maunder).

Presentation. An overview of the treatment of purse seine CPUE data in the IATTC eastern Pacific Ocean (EPO) tuna assessments was given. The EPO stock assessments are conducted with Stock Synthesis and the purse seine fisheries are split spatially, temporally, and by purse seine set types. No attempt at all is made to standardize the purse seine CPUE for known important factors that relate to changes in efficiency and. the assessments use raw catch-per-day fished as an index of abundance. A complication is that vessels may make multiple set types (floating object, dolphin associated, and unassociated) on a single trip. Therefore, days fished by set type is estimated by regressing days fished against number of sets by each set type and the coefficients represent the number of days fished per set for each set type. These coefficients are then multiplied by the number of sets for the respective set type to calculate the number of days fished by set type. In the assessment model, the coefficient of variation (CV) used in the likelihood function for the southern longline CPUE based index of abundance is fixed at 0.15 and the CVs estimated for the purse seine CPUE based indices of abundance. Generally, these CVs are high and therefore the purse seine CPUE based indices of abundance have a minor influence on the results.

Discussion. It was discussed whether unobserved differences between vessels could be detected through regression analysis and if analyses took into account whether particular vessels were operating in a certain year. It was noted that serial correlation in CPUE is partially accounted for because the standard errors from the CPUE analysis were not used to weight purse seine CPUE based indices of abundance in the stock assessment. This was not considered a large concern as purse seine CPUE data had more pressing issues. It was also noted that vessel searching trajectories can be used to determine target species.

Purse seine fishery in the Western and Central Pacific Ocean and use of CPUE data (S. Harley).

Presentation. An overview of the purse seine fishery in the western and central Pacific Ocean (WCPO) and the treatment of purse seine CPUE data in the assessments was given. The purse seine fishery is comprised of over 250 large purse seine vessels with the main fleets being the USA, Taiwan, Korea, and Japan. The total catch has been over 1.5 million metric tons since 2006 and is dominated by skipjack. The dominant mode of fishing is on unassociated schools, but there is also a large drifting FAD fishery and smaller localized anchored FAD fisheries. The WCPO stock assessments are conducted with MULTIFAN-CL and the purse seine fisheries are split spatially and into associated and unassociated set types. No attempt at all is made to standardise the catch per unit effort data for known important factors that relate to changes in efficiency. Instead the assessment model estimates temporal trends in catchability so to as minimize the impact of these data on trends in abundance. Presently, the penalty on changes in catchability is low – the development of better estimates of effective effort may allow for these penalties to be tightened and allow the purse seine CPUE to provide more information on trends in abundance. Important future work areas should include the analysis of VMS data to better understand vessel behavior, FAD tracking data, and taking advantage of the WCPFC FAD closures to observe purse seine fishing behavior in the absence of drifting FADs.

Discussion. It was discussed that thermocline depth could have a significant effect on the amount of fish that are available to the fishery. Additionally, catch and effort are combined across the entire stock and different fleets enter the fishery at dissimilar times. It was noted that if the data were standardized, it will not be feasible to correct for every variable occurring but the CV could be lowered due to a higher confidence. It was noted that the yellowfin CPUE data looked more reasonable than other species and this was discussed as possibly the result of mechanistic reasons.

Indian Ocean Tuna Commission- Type and Quality of data used in Assessments (R. Sharma).

Presentation. An overview of species, and data collected for the Indian Ocean Tuna Commission was given. The data are currently collected by the member countries, analyzed and then sent to IOTC for archiving. Essentially, Type-II data is collated by the IOTC, as the Secretariat does not have access to the raw data. An overview of catch and effort distributions by the Eastern and Western Indian Ocean region were presented by species. Finally, the IOTC Secretariat has done some CPUE standardization for some countries, e.g. Maldives pole and line fishery, and can assist other countries in similar analysis for Purse Seine fleets. Currently, the assessment models are weighted towards CPUE data from the long-line fleets operated by Japan and Taiwan at a 1° resolution. Purse seine CPUEs are used in the assessment model, but these fisheries are modeled with time varying catchability and hence their CPUE series have marginal influence on the overall model fit.

Discussion. It was noted the dramatic spatial separation between where the longline and purse seine fleets operated was artificial and a result of the presence of pirates. Typically, these fleets have overlap in Indian Ocean.

CPUE data utilization at ICCAT (P. Pallares).

Presentation. An overview of CPUE data utilization in the Atlantic ICATT tuna assessments was given. Assessments are conducted by the Scientific Committee (SCRS) and not by the Secretariat. Input data are provided from ICCAT Task I (annual catch) and Task II data (catch-effort and size) and other information such as standardized CPUE series are provided by national scientists. During the assessment meeting, the Species Group analyzes the different indices submitted and decides on the use of each of these indices in the assessment. In order to facilitate the work of the assessment groups, the WG on Stock Assessment Methods (WGSAM) has provided the SCRS with *Protocols for the inclusion or use of CPUE series in assessment models* (ICCAT, 2012).

For tropical tunas, the purse seine indices have been mainly used in the yellowfin (YFT) stock assessment. In the past, production models were fitted to a combined French/Spain PS CPUE index calculated assuming an annual 3% increase in catchability since 1981. Most recently, the following new standardized CPUEs have been used in both surplus production and VPA models:

- Standardized CPUE for adult YFT from PS fleets fishing in the eastern Atlantic. The analysis uses a delta-GLM model considering the catch of large YFT (>30 kg.)/fishing day in the spawning area during the spawning season. In addition to year, a combination of vessel category and flag, the age of the boat, and the SKJ catch were used as explanatory variables.

- Juvenile YFT index from PS fleets fishing on FADs in the eastern Atlantic. The analysis uses a delta- GLM model considering the total catch (YFT, SKJ, and BET) on FADs per day fished and using year, area, quarter and vessel category as explanatory variables.
- Venezuelan PS standardized index. The analysis modlled the catch per day fished with year, quarter and vessel category as explanatory variables.

In addition to the new PS standardized CPUEs provided from the eastern Atlantic, updated indices considering constant annual increase in catchability have been also used in the recent assessment because the species group has considered that the models used in the standardization were not able to fully include changes in catchability. In line with this consideration, the group carried out estimates of the PS catchability from the results of production models and VPA fitted without including the PS indices. The resulting estimates were around a rate of annual increase of 7% for the period 1970-1999 and 1.5% from 2000 to 2006. For skipjack, two standardized PS CPUE indices have been considered for skipjack:

- A SKJ index from PS fleets fishing on FADs in the eastern Atlantic (same model as used for juvenile YFT).
- A SKJ index from Spanish PS fleet fishing on free schools in an area off the Senegalese coast. GLM delta model considering year, quarter and vessel category as explanatory variables.

Discussion. It was noted that it would be interesting to calculate purse seine relative catchability estimates, with and without the assumed 3% adjustment for technological advances. There was then an inconclusive discussion on the origin of the 3% adjustment. The intention of this analysis would be to get estimate of trends in the overall fleet.

The potential application of VMS data in the analysis of purse-seine catch and effort data – a study from the WCPO (A. Langley).

Presentation. Data obtained through Vessel Monitory System (VMS) was presented. Since 2001, VMS data have been collected from the New Zealand purse seine vessels operating in the western central equatorial Pacific tuna fishery. VMS data have been collected from the entire WCPFC fleet since 2008, generally at the 2-hour temporal resolution. An analysis of the data from the NZ fleet was conducted to characterize the main modes of operation of the fleet. The analysis applied statistical approaches developed for the analysis of wildlife tracking data sets to partition periods of vessel activity based on the distance moved between successive VMS locations. The analysis based solely on VMS data was not able to discriminate between unassociated (free school) and associated (FAD-based) fishing activities. Additional information from the associated logsheet records (including set type) was necessary to discriminate a range of different fishing behaviors. The analysis revealed some trends in the operation of the NZ fleet, in particular the nature of the FAD fishing operation. An increasing proportion of the fishing days were solely directed at fishing on FAD sets, while the level of searching activity previously conducted in association with FAD based fishing declined.

Discussion. It was discussed whether the use of helicopters would impact the amount of steaming by vessels as it is less expensive sometimes to search with helicopters instead of using the vessels. It was also noted that VMS would allow pressure to be removed from observers to record whether or not a FAD set had occurred.

Electronic Monitoring System trials on purse seiners (V. Restrepo).

Presentation. Results of three preliminary pilot studies done in the Atlantic Ocean, Indian Ocean and western Pacific Ocean were presented. These used an integrated electronic monitoring system that combines cameras with tracking of a vessels' position, speed and gear usage every 10 seconds. The cameras are only on during fishing activities, which is important to maintain crew privacy. The system's use of the positions, speed and gear such as hydraulic pressure is of very fine resolution (recorded every 10 seconds on a hard disk for later analyses) and it should permit the splitting of days into various components (set time, search time, cruising time, etc.) with high accuracy relative to a VMS system, which only has positions.

Discussion. It was also discussed that a similar system was used in Canadian fisheries for compliance purposes as random checks in logbooks. The system could also be combined with observers to obtain spatio-temporal length data. It was noted that the system could be much less expensive if it did not include the cameras.

VMS data in the Indian Ocean (N. Bez).

Presentation. The use of data on vessel trajectories as a method to determine effort and an index of abundance was presented. Indices of abundance are supposed to vary following the true unknown abundance. Catch rates have long been questioned especially with regards to the need to use effective fishing effort rather than nominal fishing effort. The use of vessels' trajectories for i) quantifying more adequately effective fishing effort and ii) producing tuna potential distribution maps with a high spatial resolution and indices of abundance. A state-based model was used to estimate vessels' foraging activities from vessel tracks of French purse seiners in the Indian Ocean (Walker and Bez, 2010). The model showed that this fleet spent 78% of its time prospecting (i.e. daytime minus the fishing operations). The prospecting phase broke down into 34% cruising, 61% tracking schools in areas of aggregations, and 5% being stationary. Effort corresponding to tracking phases in aggregations should be down weighted in some way to represent an effective effort (weights yet to be determined). Vessel effect is explained by different allocation of time in the different prospecting modes with a common proportion of time (22%) devoted to setting operations (Bez et al., 2011). After an ad hoc geostatistical interpolation procedure (e.g. co-kriging), foraging activities were linked to classes of tuna presence and merged into one map of tuna potential distribution (Walker et al., in prep). This analysis showed that monthly spatial structures were remarkably stable over the study period (2006-2010). Time series of indices of abundance were produced, together with their estimation variance, and highlighted the strong dynamics of tropical tuna in the Indian Ocean. The truth will never be available for such an ecosystem, so complete validation of the traditional catch rates versus this new index is not possible. The validity of the method is thus considered with regards to its internal consistency (e.g. validation with observers' data, emerging characteristics that are biologically relevant).

Discussion. It was discussed how to ensure double-counting was not occurring and what is a useful time period of observation. It was noted that this approach was very interesting, representing an index between presence and catch and if coupled with vulnerability, could yield a relative abundance in the area. It was also noted that if the number of schools and observations remain the same while size of schools were decreasing, the decreasing stock size would not be detected (as this is essentially an index of presence). However, fishermen tend not to set on small schools so the catch rate would strongly decrease and the vessel behavior would reflect that.

Identifying purse-seiner cooperative fishing from vessel movements (M. Maunder for Cleridy Lennert-Cody).

Presentation. Mark Maunder presented research by Cleridy Lennert-Cody on cooperation between fishing vessels. The analysis was based on IATTC onboard observer data and was validated using anecdotal information on vessel associations. A daily "interaction" between any two trips was defined as a distance between daily traces < 2 degrees and agglomerative hierarchical clustering was used to group vessels. The dendrogram structure suggests a range of levels of interaction among vessels and possibly group sizes. There was often a dominant purse-seine set type associated with certain types of clusters: distinct small clusters were often vessels that made mostly floating object sets; distinct large clusters tended to be dominated by vessels making unassociated or dolphin sets. Several (but not all) vessel groups identified in the anecdotal information were distinct within the dendrogram.

Efficiency of the tuna purse seiners and effective efforts (ESTHER) (D. Gaertner).

Presentation. Results of the IRD-IEO project 'Efficiency of Tuna Purse-seiners and Real Effort' were presented**.** The main objectives of this study were to review the technological factors that may have contributed to the increase in the 'fishing power' of the European tuna fleet, to observe their use patterns on board purse-seiners and a supply vessel and then to quantify their impact on catch per unit of effort (CPUE). The individual variability in the dates of introduction of any particular piece of equipment and the many interactions between these factors give the impression that these developments occurred as a continuous process. It is therefore difficult to accurately gauge the causes of significant changes in yields. Another constraint on analysis is linked to the fact that the impact of a particular piece of equipment can only be measured at a specific phase of the school capture process (detection of aggregations, location of school, deployment of purse-seine, etc.), while the analysis is carried out on overall CPUE figures, which can make interpretations of results inaccurate. As with many examples of the numerical analysis of data, the existence of interactions between the various factors can lead to the development of complex statistical models that may be accurate in terms of fit but are difficult to interpret because they appear to be over-parameterised. An insight into these difficulties is given in the analysis made to standardise the CPUEs, where, despite a deliberately limited number of explanatory variables, we obtain significant interactions between the age of the purse-seiner, the country category to which it belongs and the time period over which observations were recorded. It would therefore seem that, depending on the period analysed and the nationality and size class of the purse-seiner, the ageing effect will show varying degrees of intensity (it can even be positive for some size groups, which permits supposition that technological progress has been introduced on board). In practice, the combined effects of certain innovations (e.g. sonar and echo-sounder when fishing around FADs) do not make it possible to differentiate the individual effects of any piece of equipment or what might be due to synergy between them. In some cases, synergy is not automatically developed between the various technological innovations, because one replaces another. It is possible, for example, that a helicopter may have been replaced by bird radar in the aggregation detection phase and as the aid to decision-making in the pursuit of a school. Similarly, the dual use of certain pieces of equipment (e.g. sonar, bird radar), more frequently indicating the preference of the captain or first officer rather than simultaneous use, would not necessarily lead to a doubling in the boat's efficiency (even if this could reduce the risk of failure of one of the pieces of equipment). Lastly, in some cases, the positive impact of a form of technological progress can be negated by a change in the fisher's behaviour resulting from its use (for example, the bending of FAD antennae, so as to avoid thefts). In another area, the efficiency gain resulting from the deepening of purse-seines (reduction of nil set returns) would have been greater if this development had not prompted fishers to explore new fishing grounds further offshore, releasing them from some of the constraints imposed by the thermocline. These considerations illustrate quite clearly the complexity of the interactions that exist between all these technological and behavioural factors. Despite the need to conduct more thorough research, this research programme enabled the identification of major factors in the development of purse-seiner fishing efficiency. The switch by the French boats to an 'opening ring' system in the second half of the 1980s made it possible to virtually double in 20 years the time spent on searching for aggregations and locating schools. However, this gain is only really substantial in a situation of large school density. The intensification of FAD fishing since the late 1980s is a major factor in the increase in purse-seiners' fishing efficiency. The adoption of FAD fishing made it possible to minimise the risk of having totally unproductive fishing days (direct effect on increases in CPUE), but also to exploit new fishing grounds (indirect effect). However, real progress only occurred when fishers were able to instrument their FADs in such a way as to find them easily from a long distance. The use of GPS buoys, the Ariane type in particular, can be considered as a significant step forward in the development of purse-seiners' fishing power. In such cases the efficiency gain mostly concerns skipjack and juveniles of the other two target species (yellowfin and bigeye), as fish caught on FADs are usually small in size. The time spent on this fishing method reduces by the same amount the time spent seeking free-swimming schools, so the effect would be the opposite one for large yellowfin taken from unassociated schools. Together with FAD use, the assistance provided by fishery support vessels is also an illustration of the increase in the efficiency of the purse-seiners receiving such assistance. The Esther project made it possible to acquire valuable information on the operating methods of this kind of boat and to appraise the impact of such support on Spanish purse-seine yield. The importance of bird radars during fishing was unanimously recognised by all fishers to whom the question was put. This device would appear mostly to be used to detect aggregations, then to select potentially promising indications. It enables the purse-seiner to avoid having to sail the place of detection every time to check if an indication is worth pursuing and thus to avoid unproductive use of time. Sonar has been used on board tuna boats for a long time now but its productive use, especially to take a decision on net setting and to guide the captain during the encircling of the school, would appear to come with gradually increasing familiarity over the analysis period. Here again, skippers responding to questions on this point recognise the fundamental role that this device plays, particularly when fishing on free schools. The deeper the net is closed, the lower the risk of a zero catch, as demonstrated by this project. However, deepening of nets over time has made it possible to catch deeper schools and has probably contributed to the redistribution of fishing effort in offshore grounds, which were unfavourable in the past due to the depth of the thermocline. Many other factors such as top speed (competition between boats on the same aggregation), the modernisation of winches and of the power block (less downtime when setting), etc., have also contributed to increasing individual fishing power of community purse-seiners. It must however be borne in mind that the on-board use of a technological innovation can be justified both by a reduction in operating costs for the vessel and by an observable positive effect on changes in CPUEs.

Discussion. It was discussed whether the age of the vessel was an important variable and it was noted that many of the technological innovations are small and can be placed on older vessels. The best and most experienced captains tend to move to newest and most up to date vessels, however, the captain and vessel could be separated out as new boat designs do not always function well in practice and a steep learning curve can be associated with new or unfamiliar vessels.

Measures of effort and covariates, data collected in IATTC database (M. Maunder)

Presentation. There are a number of measures of effort from basic quantities such as number of sets, days fished or trips to more refined measures such as vessel search time and FAD search time. The measure chosen will differ based on the data available and the characteristics of the relationship between CPUE and abundance. Refined measures may include the elimination of non-fishing time such as steaming to and from fishing areas and setting and retrieving. Locators on FADs have made tradition measures of effort meaningless for FAD fisheries and catch-per-set may be just an indication of school size. The search time of the FAD may be a better measure of effort. FAD density may also be an important consideration. CPUE is often standardized using covariates that are hypothesized to modify the relationship between CPUE and abundance (i.e. catchability). Common covariates include vessel and crew characteristics, spatial and temporal characteristics, characteristics of the fishing gear, technology such as fish finders, and environmental variables.

Discussion. It was discussed how search times and set time are related and that it becomes difficult to aggregate the three sets into a common search time. A question was raised on how tagging data could be utilized as a validation method and it was noted that tagging data greatly varied in scope across ocean basin and time periods. It is not known whether the available tagging data could be useful for abundance or to directly validate CPUE.

Statistical approaches for deriving indices of abundance from CPUE data (A. Cooper).

Presentation. When attempting to standardize CPUE estimates, researchers face a number of statistical issues, and the choice of statistical modeling approach will depend on the importance of these issues for their particular dataset. In particular, the choice of statistical approach will depend on whether catch is in numbers or weight, the importance of non-linear relationships, the prevalence of interactions, the hierarchical nature of the data, and the processes that generated the zeros in the data. Generalized linear models (GLMs) are one of the most common CPUE standardization approaches; however, it has problems handling many of these statistical issues. Zero-inflated models (typically Poisson and negative binomial) are well suited for when the data contain more zeros than one might expect and the process generating those zeros is uncertain. If the source of the zeros is fairly certain (e.g., habitat quality), then delta methods (e.g., delta-lognormal) work quite well. Generalized additive models (GAMs) are powerful when dealing with non-linearities, however they do not handle interactions well. Mixed-effects models are designed specifically for repeated-measures data (e.g., multiple observations of the same skipper) and are more flexible in handling variance and correlation structures than the standard GLMs. Regression trees perform well when there are many variables with many high-order interactions and non-linearities. Random Forests (an extension of regression trees) are extremely well-suited for prediction modeling in the face of high-order interactions and non-linearities.

Discussion. There was a discussion on the appropriate types of models for different data, mixed or random models and what effect should be fixed or designated as random effects. There was further discussion on the historical reasons for ICCAT utilizing mixed models. It was noted that the order of variables did not matter but rather how they were nested in hierarchical models. It was also discussed how one could model extreme events rather than the variability of average events and how skunk sets could be treated.

Estimates of Catchability and fishing efficiency and it's effect on purse seine CPUE estimates (M. Soto).

Presentation. The European purse seine fleet in the Indian Ocean has been continuously improving the detection systems to increase tropical tuna catches. Data related to abundance and catchability such as skipper, sonar, radar, net and vessel speed are analyzed for the period 1984-1995 using the Delta-Lognormal GLM approach. Abundance effects are identified with the GLM delta approach for effort standardization; a skipper effect is also identified, but sonar, radar and net characteristics could be better analyzed by relating them with a more representative measure of effort and must be investigated at the individual vessel level.

Discussion. It was noted that only positive sets were used in the model and there was a discussion on how to include covariates in the model as estimates of area or spatial extent. It was also noted that it was difficult to detect technological changes in other fields, notably manufacturing and it was not surprising that it was also challenging to discern these changes in fisheries. It was suggested the skipper effect may be masking some of the technological upticks; however it was hard to explain even with detailed skipper data. A point was raised that instead of considering technological advances as an increase in catches they could instead be considered as a cost saving device and this may explain why technical advances are difficult to detect in catch rate models. It was also noted that even though the technology existed, it did not mean the skipper or crew was utilizing it to the full potential. Additionally, the economics (i.e. profitability) may cause bad skippers to exit the fishery while good economics may result in an influx of poor skippers.

How do tunas distribute among floating objects? And, using FADs (objects) to obtain scientific information on indices of abundance (L. Dagorn and M Capello).

Presentation. The opportunity of using FADs as fishery-independent indices of the abundance of tuna and other associated species was discussed. The principle is very simple: the abundance of tuna (or other fish) associated with FADs within a region is related to the total abundance of tuna (or other fish) in the same region. However, this relationship is unknown. Here, we presented a model of the behavior of tuna associated with FADs that could give insights on the ratio between the associated and free biomass, based on experimental measurements. First, we stressed that the amount of associated fish with FADs depends not only on abundance but also on other factors, like species characteristics (social/non-social), fish response to environmental variables and number of FADs. Therefore, interpreting relative variations of the tuna-associated biomass demands further understanding of tuna associative behavior. Then, based on the behavioral models that we developed, we provided local indices of exploitation and abundance based on the amount of time spent by fish at FADs and outside the FADs. We discussed how the parameters of the model can be estimated through future experiments based on echosounder buoys and tagging.

Discussion. There was a discussion about the reasons driving the associations at FADs, noting that different size classes of tuna show different behavior. It was noted that a common assumption (when individuals do not interact with each other) is that higher density of FADs in an area tend to increase the proportion of the tuna population associated with FADs, but social interactions between individuals complicate the system and modify this pattern. It is assumed that the attractive power of a FAD is low when the FAD is new and increases quickly (within a few weeks), then becomes constant after a certain point. It was also discussed how instrumented FAD arrays could be used to determine relative indices of abundance, stratified by time and space.

Dynamics of FAD use in the Indian and the Atlantic oceans (A. Maufroy).

Presentation**.** Using the first available dataset for the French purse seine fleet, the dynamics of Fishing Aggregating Devices (FADs) in the Indian and the Atlantic Oceans were analyzed. GPS buoys positions allowed us to follow FADs trajectories between November 2006 and December 2010. These positions were first separated into two categories: *at sea* positions and *on board* positions. To do so, five classification methods (velocity filter, k nearest neighbors, Multiple Logistic Regression, Artificial Neural Network and Random Forest) were compared using an already classified subset of the buoys positions. On the basis of several performance indicators (e.g. accuracy and precision), we chose the Random Forest model as the best classifier and predicted the class of the rest of the buoys positions. *At sea* positions provided an estimate of FADs use in time and space. In particular, we demonstrated that the use of FADs concerned wide zones in both oceans although some areas appeared as higher FADs use zones. We proposed various methods to measure FADs nominal effort that could serve to build CPUE indices.

Discussion. It was discussed how changing FAD ownership would affect the results and it was noted that the methods utilized in this project would be ideal for getting short-term snapshots of the fishery. It was requested that the group consider ways in which FADs could be utilized to measure effort, for example: number of fads at sea, number of fads within fishing grounds, cumulated surface explored by FADs (isolated fads, network fads, echosounders).

Decomposing purse seine CPUE for improving abundance indices: The case study of tropical tuna free-swimming schools in the Indian Ocean (E. Chassot).

Presentation. Three indices of catch per unit effort (CPUE) were considered for purse seine fishing on free-swimming schools during 1981-2010 so as to decompose vessel fishing power. The overall objective of the analysis was to assess whether temporal changes in yellowfin population abundance in the Indian Ocean could be related to changes in the number or/and the size of tuna schools. First, the number of sets per searching day was considered to model the ability to detect tuna schools. Second, the proportion of successful sets was used to model the ability to succeed in the set. Third, the yellowfin catch per positive set was used as a proxy of the ability to maximise the catch from the school. GLM analyses were performed to standardize the CPUE time series by considering a vessel effect and a spatio-temporal effect. Model results suggested a significant decrease in the number of free-swimming schools of yellowfin since the early 1980s. Meanwhile, the size of the schools did not show any temporal pattern although it was characterized by high interannual variability, e.g. very large schools having been caught during 2003-2005 which could be due to high concentrations of prey. More recent vessels appeared to favour school detection while the purse seiner length or carrying capacity resulted in better ability to catch larger schools.

Discussion. It was noted in 2009 all the French purse seine vessels fished in pairs due to security and that the exchange of information and size of fleet is quite important when considering effort. It was also noted that data was not split into months and this was due to the fishing occurring at the equator and months do not mean the same thing in terms of seasonality.

Spatial considerations in the standardization of CPUE data (T. Carruthers).

Presentation. The presentation focused on how population dynamics and observation processes affect the type of CPUE standardization model that can be logically applied. If there are differences in regional trends in abundance, it may be necessary to estimate time x area interaction effects. Where systematic changes in distribution of fishing have occurred it is necessary to impute the missing time x area observations to avoid introducing bias. Increased spatial targeting of species over time can mask genuine declines in abundance (hyperstability). Spatial avoidance of species over time can exaggerate genuine declines in abundance (hyperdepletion). Bias may also be introduced by unbalanced sampling (different number of observations in each spatial strata) and failing to account for the size of the area from which observations of CPUE are made (since CPUE is a measure of density). It is relatively simple to implement an ad-hoc approach to spatial imputation and adjust for unbalanced sampling design. It should be noted that a principle concern for the standardization of purse seine data is hyperstability due to the targeting of localised aggregations. In such a case CPUE may remain high at low relative abundance. Since the phenomenon driving this are likely to occur over a relatively small spatial scale and exhibit high temporal variability it may be difficult to correct for using spatial standardization and imputation. In order to estimate the effect of stock depletion on catchability (sometimes referred to as the 'beta' parameter) auxiliary information is required.

Discussion. It was noted that it would be useful if the same means were used in comparisons with the time-area ad hoc imputation method. A question was raised if spatial correlation was taken into account and this was not done.

Tuna concentration as a factor conditioning yearly PS CPUE (A. Fonteneau).

Presentation. Tuna concentrations at a small spatial and temporal scale are often actively exploited by large fleets of purse seiners (PS) in the Atlantic and Indian oceans. These tuna and PS concentrations are easily identified by set by set log book data. It can be concluded that the potential of PS fleets to identify these hot spots and to exploit them quickly and efficiently, most often under intense competition between vessels fishing on the spot (importance of good radar and good sonar), is very important to produce high yearly catches. Some examples of these localized hot spots exploited by purse seiners in the Atlantic and Indian Ocean, and analysed by EU scientists, were presented. The most notable concentration, probably a historical world record, was exploited in the western Indian Ocean in February 2005. It took place during a period of only 12 days and in an area of about 3500 nautical miles^2, producing a total catch of 22,000 tons. This catch corresponds to 6.5 % of the total fishing mortality on all adult yellowfin (*Thunnus albacares*) in the entire Indian Ocean in 2005. The average CPUE and the average catch per set were very large, 65 tons (per fishing day) and 85 tons respectively, but surprisingly 30% of the fishing days during the best period were unsuccessful. This fishing event took place exactly in an area where high concentration of chlorophyll was localized 18 days before the fishing event. There is no doubt that 20 years ago the same tuna concentration would have produced less catch than today due to the major improvement in the current fishing technology and to the larger size of purse seiners.

Discussion. It was noted that it would be useful to quantify the exchange of information between the purse seiners that are exploiting a concentration.

An economic perspective on CPUE (D. Squires).

Presentation. Fishing effort is an unobserved intellectual construct that is a composite of individual inputs such as skipper skill, labor, fuel, gear, equipment (including FADs), and the vessel. Accurate measurement of CPUE requires an accurate specification of effort. Under the assumption that days and capital are in fixed proportions and days is the binding input, then days is a suitable measure of effort. When capital (vessel) is the binding input, vessel is the suitable measure of effort. Under more general conditions, effort as a composite of all inputs (say days and vessel) should be combined into a composite input using an aggregator function. The theory of economic index numbers informs the specification of this aggregator function. So, the first message is largely to use the available input information on days and capital to inform a GLM. The second message is that changes in fishing power are due to many reasons, the most important being changes in technology. Changes in technology are either disembodied technical change (learning by doing) and that in principle can be captured by a time trend (including time trend squared and time trend interacting with the other covariates to capture biases in the direction of disembodied technical change) or technical change that is embodied in the capital stock (e.g. bird radar or FADs). Both of these types of technological change should be accounted for in a GLM.

Discussion. It was also noted that in a given year, different boats will have different numbers of FAD and free sets due to different efficiencies. It was also discussed that because there existed dissimilarity between effort and how biomass was estimated, a relative trajectory may be the result. It was noted that it may be possible to work with purse seiners to conduct a randomized trial with different levels of technology.

Including Oceanographic Data (M. Maunder).

Presentation. Oceanographic processes can have an influence on both population and fishing processes. In particular, oceanographic conditions can determine the spatial distribution of a stock. Tuna and other species have particular habitat preferences and matching the oceanographic conditions with these habitat preferences can be used to interpret CPUE data. Archival tag data provides information on the habitat preference of the species and has been used for interpreting longline CPUE data (Hinton and Nakano 1996, Maunder et al. 2006). Oceanographic processes can also influence the performance of the gear. For example strong currents may distort the shape of the purse seine net. A shallow thermocline may keep the fish closer to the surface making them more vulnerable to the purse seine gear. Currents will determine where FADs drift and their “search” area. Some commonly used oceanographic variables include temperature, oxygen, thermocline depth, and currents. Despite the promise of using oceanographic data to interpret CPUE, many analyses find that when latitude and longitude are included, oceanographic variables are no longer important. These results suggest that large scale spatial variability in oceanographic processes is stable over time.

Discussion. It was discussed that estimations are reliant on large-scale oceanographic models that are not as helpful as assumed and habitat preference on archival tagging does predict understanding of future CPUE.

Alternative models (M. Maunder).

Presentation. Due to the issues with relating purse seine CPUE with abundance, innovative methods may need to be developed. Several novel methods have been suggested and some preliminary investigations have been applied. One suggestion is that due to the inability for most species to keep up with an association of dolphin and yellowfin tuna that is chased by speedboats, a dolphin associated set can be treated as a random sample in the ocean. Unfortunately, the catch rates of most species in dolphin associated sets are low and therefore an index of abundance using this data would be imprecise. This approach has been applied to silky shark in the EPO (pers. com. Cleridy E. Lennert-Cody). The method may also be useful for skipjack tuna and sailfish. Another method uses the ratio of the species of interest in the purse seine catch to a reference species of known abundance (e.g. one that has a reliable stock assessment). The method assumes that relative catchability for the species of interest is similar to the reference species. Maunder and Hoyle (2006) applied this method to skipjack tuna in the EPO. Innovative methods using FADs also show promise. The abundance of tuna around anchored TOA buoys in the EPO has been investigated as a possible index of population abundance (pers. com. Shelton Harley). The analysis was aided by the ability to associate purse seine sets with the TAO buoys due to knowledge of their daily locations. These types of analyses would be facilitated by individual identification of FADs so all sets can be associated with individual FADS. New technology on FADs such as echo sounders may provide additional information that can be used to improve these analyses.

Discussion. There was a discussion on using dolphin sets as a random sample of non-target species, particularly silky sharks. It was suggested that a "stock assessment" on FADs should be conducted as FADs have greatly affected purse seine CPUE over the last 20 years. Understanding the densities, trajectories and attractiveness of FADs could be using to connect assessment on species of interest.

3. DATA NEEDS

The Workshop devoted considerable time to the types of data that could give more insight into why purse seine CPUE may vary independent of stock abundance. This includes both data related to historical changes in technological equipment and fishing operations, as well as data on current fishing operations that would help improve analyses if they were made available to scientists, as explained below.

3.1 Historical changes in fishing

Since 1980, many changes in fishing technology and operations have occurred, potentially affecting the fishing power of tropical purse seiners. **Table 3.1** lists 23 elements that the Workshop considered to be more or less important in this respect. The table also comments on the likely (1) geographical scale of the influence of each factor, (2) year when the change was first introduced, (3) relative cost of the factor (low, medium or high), (4) magnitude of the factor's effect on fishing efficiency (and on Fishing mortality), and (5) rate of annual change in each factor after its introduction.

Table 3.1. Initial list[+] of 23 factors that have changed historically in purse seine fisheries and their likely importance in affecting fishing power.

Factor	Scale	Year	Cost	Impact	Annual change
Use of FADs *	Global	1990	Low	Major	Steep increase
Use of supply vessels *	Global**	1992	High	Major	Steep increase
Faster unloadings	Global	1980	Low	Significant	Slow increase
Use of computers	Global	1990	Low	Significant	Slow increase
Technological improvement of FADs *	Global	1990	Low	Major	Steep increase
Improved GPS positioning of vessels	Global	1994	Low	Marginal	Stable
Improved fishing memory of fisheries	Global	1990	Low	Marginal	Stable

Increased freezing capacity	Global	1990	Moderate	Significant	Slow increase
Increasing vessel size and capacity	Global	1980	High	Significant	Slow increase
Ageing of fleets	Global	1980		Marginal	Slow increase
Use of satellite imagery	Localized	1997	Low	Significant	Slow increase
Bird radars	Localized	1985	Low	Major	Slow increase
Helicopters	Localized	1980	High	Significant	Stable
Improved Sonar/long range	Localized	2002	Low	Significant	Stable
Higher, improved crow nests	Localized	1985	Moderate	Marginal	Slow increase
Improved navigation radars	Localized	1995	Low	Significant	Stable
Real-time private radio communication	Localized		Low	Significant	Stable
Improved lateral echo sounders *	Set-specific	1990	Low	Significant	Stable
Deeper and faster nets	Set-specific	1985	High	Significant	Slow increase
Canon vs opening rings	Set-specific	1985	Low	Marginal	Stable
Larger skimming nets and mast	Set-specific	1987	Moderate	Marginal	Stable
Underwater current meters	Set-specific	1991	Low	Marginal	Slow increase
Monitoring of net fishing depth	Set-specific	1990	Low	Marginal	Slow increase

[+] This is a preliminary list and likely to be improved (see Recommendation 1, below).

* Factor directly related to FADs.

** But note that supply vessels are now prohibited in some RFMO areas.

Table 3.1 is semi-quantitative, being mostly based on expert knowledge and not on data analyses, as these data are most often unavailable to scientists (see **Appendix 3** for an example where data is available). The 23 elements highlighted have contributed to an increase in the fishing pressure on all tropical tuna resources during the past three decades. This increase has not been constant, though, as there have been periods of major changes and periods of limited changes (as is perhaps the case in recent years). In the Indian and Atlantic oceans, changes appear to have been nearly identical because the European fleets have driven many of these changes simultaneously. Other fleets may have assimilated the changes in different years. Changes in purse seine fishing power have also occurred at different spatial scales: Globally or at an oceanic scale, at a localized scale (for instance, during the exploitation of large tuna concentrations), and at the set-by-set level.

The ageing of the purse seine fleets, which has occurred worldwide, is probably the only factor on the list that potentially reduces fishing power (although any real decline in efficiency appears to be limited). The most important changes were introduced since the early 1990s in relation to FAD fishing: This major change in fishing technique produced major increases in the global catches of skipjack, but also resulted in increased catches of small yellowfin and bigeye, and on the by-catches of species such as sharks, mahi-mahi, etc. The changes in Table 3.1 have affected both free school and floating object sets, but to varying degrees for each factor. Overall, the introduction of these changes tends to produce increasing or stable CPUEs, even when the stock biomasses may decline.

There is an increasing recognition by scientists of these technological changes and of their potential effects. However, it is difficult to analyze these in the absence of detailed knowledge of the adoption of these changes by individual skippers or fleets (see Appendix 3 for an example). An additional difficulty is that the use of many of these factors is largely unobservable by scientists in most fleets, as they are not easily visible and are often kept in secrecy by fishers/owners.

Recommendation 1: Data Mining of historical changes in fishing technology and operations. An active data-mining program should be developed, in order to identify as much as possible the modalities and dates of changes of the major factors that have likely affected the fishing efficiency of purse seine vessels. This project requires active cooperation with industry, via in-depth systematic interviews with skippers (especially retired and experienced skippers) as well as with vessel-owning companies. It also needs some social science advice on how best to capture some of the information, noting that there will be large differences between countries.

3.2 Other data needed to address technological change

The Workshop considered that obtaining the following information is critical for improving the understanding of purse seine CPUE.

Information on FADs and other floating objects ("FOBs"):

- Number of FADs deployed
- Number of Floating Objects (FOBs) observed (i.e. visited)
- Numberof FOBs monitored
- FOB trajectory and echo-sounder information

Information on vessel fishing operations:

- Detailed (hourly or more frequent) VMS data that can help split days into search time and fishing time, or:
- Data from Electronic Monitoring systems which include:
    - High resolution GPS data (e.g. at intervals of 10 sec) and VMS (1 hour frequency) sensor data from hydraulic system monitors to identify type and frequency of fishing operations
    - Imagery of catch process.
- Consider experimental designs using old technology fishing to compare against current technology fishing to measure technology effects on “q”
- Evaluation of effect of vessels acting as FOBs

It was noted that several Tuna RFMOs have already adopted or are considering the adoption of so-called "FAD Management Plans". The Workshop noted that the introduction of these plans provide an opportunity to compile some the data above if they require unique identification systems for individual FADs and mandatory reporting of such information to RFMO scientific bodies.

The investment by vessel owners in various technological improvements (see Section 3.1) probably would not have happened at the pace it has if it did not result in improved catch rates. However, scientists usually do not have available to them information on the addition of, or changes to, equipment and fishing operations. A 2012 Workshop to harmonize the data types collected by purse seine observer programs worldwide (Sukarrieta, March 2012) summarized data elements available across tRFMOs relative to purse seine fleets: To the degree possible, data collections should be harmonized and jointly analyzed, across ocean areas, to evaluate the possibility for quantifying changes in catchability over time. Considerable knowledge on efficiency gains with technological advancement likely exists with skippers that have/had long involvement in the fishery. Seeking industry assistance in identifying change in technology resulting in improved efficiencies could provide a basis for modeling changes in catchability over time. In addition, it would be useful to estimate floating object (both natural and man-made) density making use of observer data.

Recommendation 2: Collection of information on fishing operations and floating objects. Comprehensive data on floating object sets (especially on FADs) and on fishing operations, should be made available to scientific bodies. Cooperation with industry should be promoted for obtaining this information in support of the scientific analyses, including running analysis on industry databases. Mechanisms to assure data confidentiality should be reinforced, if needed.

4. DATA ANALYSES

The workshop discussed a number of potentially useful analyses that should be undertaken. In some cases, these would utilize existing data (which in some cases will be limited to a few fisheries or regions).

4.1 Analysis of catchability changes and other variables

If estimates of changes in catchability over time become available, it would be possible to compare these changes against various covariates with the aim of identifying likely drivers of technical change. It would then be possible to standardize CPUE to obtain a more reliable index of abundance. One way of achieving this is to use the estimates of catchability from the stock assessment. Ideally, the assessment should be conducted without the CPUE series that will be analyzed so that these data will not influence the catchability estimates. However, it is also possible to use the results of the assessment with the CPUE series down-weighted to the degree possible. The Workshop undertook these analyses for yellowfin and bigeye tuna in the EPO (Appendix 3). It is difficult to correlate changes in residuals with changes in the characteristics of the fisheries since the changes in characteristics are often monotonic trends over time (e.g. net length) or abrupt changes (e.g. bird radar).

Recommendation 3: Detailed analysis of technical change on the trip/vessel level. Analyses of technical change should be carried out on detailed data (e.g. trip or vessel level) to allow the evaluation of vessel level changes in technology. Abundance estimated by stock assessment models (or other methods) should be considered as a covariate to eliminate the influence of abundance on the analysis and allow for a nonlinear relationship between CPUE and abundance. Code should be produced and shared with other RFMOs so the analysis can be repeated for other stocks. It may be necessary to aggregate data across trips within vessel or other categories to improve the analysis. The analysis can include multiple measures of effort, but special attention should be given to ensure that the use of effort is appropriate (e.g. days fished may not be appropriate for data at the trip level).

Recommendation 4: Analyze purse seine catchability residuals from stock assessments (or other "reliable" estimates of abundance). Stock assessment models can be used to estimate the expected catch rates for fisheries used in the assessment. These estimates can be compared to the observed catch rates to calculate changes in catchability. Information from current stock assessment of the main tuna species of each RFMO should be used to calculate changes in catchability and compared to information about technical change and other factors that might influence catchability. The stock assessments could be recalculated without the PS CPUE indices to avoid any confounding of the abundance estimates with the PS CPUE indices. Other estimates of relative abundance (e.g. SBT survey, tagging data, and longline CPUE) could be used. It might be possible to combine the results into a meta-analysis.

CPUE standardization for use in stock assessments typically uses only one measure of fishing effort (e.g., fishing days, searching days, etc.). In contrast, economic analyses often use a function to aggregate individual components that affect productivity into a composite measure of effort. Economic index numbers deal with situations in which vessel catch and inputs (individual components of effort) are too diverse to measure simply by weighing or counting or there are too many to simply include into an equation such as a GLM. (Collectively, their aggregate index may be statistically significant, but individually the individual components may not be due to multicollinearity or too small of an individual effect.) Economic index numbers combine the individual inputs, such as crew, fuel, vessel, gear, and equipment into a single composite index of effort. Similarly to the analyses outlined above, various candidate composite measures of effort could be examined conditional on the results of a stock assessment. For example, regression techniques could be used to predict catch per vessel per trip as a function of stock size and the composite measures of effort. Such analyses were not initiated during the workshop but it was recommended that they be carried out.

> **Recommendation 5: Compare and contrast stock assessment and economic methods to determine technical change.** A report should be developed that compares and contrasts the methods used in fisheries stock assessment and economics to estimate technical change in fishing fleets. The approaches share many commonalities, but different terminology makes comparisons difficult. Therefore, the report should contain a guide to terminology.

4.2 Quantification of the area searched during purse seine fishing activity

There is potential to improve estimates of purse-seine fishing effort through a more thorough evaluation of the searching behaviour of elements of the purse seine fleets. The quantification of the area searched by a vessel may more explicitly account for changes in fishing power related to the ability to detect tuna schools, for example, the introduction of technology to improve the searching power of a vessel such as bird radar. The area searched is likely to be an important component of the fishing effort for some important modes of purse-seine fishing, most notably of relevance to fishing effort related to skipjack and yellowfin free surface (unassociated) schools.
For some other modes of fishing, search area would appear to be of less importance, for example schools associated with floating objects. Punsly (1987) identified vessel speed as the most important factor in determining CPUE; related to the ability of the vessel to chase dolphin-associated schools.

Visual searching may be important in some aspects of the fishing operation that relates to the FAD associated sets, particularly detecting the location of FADs that belong to other vessels; i.e. FADs that are not being routinely monitored ("owned") by the vessel or the code group. Potentially, the encounter rate and fishing success at these FAD locations may be less biased than fishing on FADs owned by the vessel (or code group). However, CPUE for this component of the fishery will relate to FAD density which may not necessarily be related fish abundance. Current data from the fishery does not identify the owner of the individual FADs and so it would be difficult (or impossible) to undertake an analysis of CPUE based on "pirated" FADs.

Quantification of the area searched during a day requires a consideration of the main components of search activity. A preliminary appraisal of the main elements of the searching activity identified the following range of issues.

1. Distance steamed by vessel, excluding transit.
   • Limit to day light hours only (although technology now allows searching to occur at night in some fisheries). Relate to location of fishing activity (calculate dawn/dusk using celestial

algorithms). Is the effectiveness of searching equivalent through the day or is it necessary to define a diurnal effect in searching activity.

• Can we reliably distinguish between transit and searching activity? Probably just simplify by excluding days of fishing trip prior to first set and post the last set.

• Resolution of the location data. Successive logsheet records (1-3 per day) will grossly under-estimate the distance steamed. The application of VMS data (at 1 or 2 hour intervals) will improve precision of the estimated distance. Potentially, Observer records provide much greater temporal resolution than the logsheet data (high level of PS observer coverage in IATTC and WCPFC).

2. Role of information sharing between code groups.

   • May be less important with respect to daily searching activity although sharing information will direct fleet to the more productive areas.

3. Visual sighting (high powered binoculars).

   • What is the visual sighting range?

   • Experience of key personnel on vessel.

   • Influence of time of the day, weather conditions and sea state – prevailing weather conditions may be available from Observer records but this can probably just be considered as error.

4. Bird radar. Effective detection range of birds. Evolution of the technology.

   • 10-15 n.mile range (Furuno website); dependent on prevailing conditions. What is the practical range of the current generation of bird radar? Compared to earlier generations?

   • Range influenced by height of placement of antennae – height of crow's nest.

5. Helicopter operation.

   • Record of vessel equipment; record of vessel activity (logsheet, observer data sets).

   • Operational range of helicopters. Hughes 500 helicopter has an operation time of two hours and a cruising speed of 90 knots. During searching, the helicopter operates at an altitude of 1000-1800 ft enabling a fish school to be detected at a range of up to 25 miles.

   • Timing of helicopter deployment? Usually earlier in the day?

6. Sonar – limited application during wide area searching.

7. Forecast software (CATSAT, etc). Improvement in the fleet's ability to refine the search area for a day.

Recommendation 6: Carry out analyses of CPUE data using searched area. Conduct a trial study to evaluate data issues associated with determining the effective searching. A prime candidate for the study could be the WCPFC free school skipjack fishery (recent years with VMS and observer data) and select a component of the fleet that has a high proportion of free school fishing activity (especially the Korean fleet and Japanese fleet in recent years). A first step in such an analysis is to compile the VMS and logsheet (and observer) data for individual fishing trips and identify periods of fishing activity that are primarily directed towards unassociated fish schools. The analysis of these elements should be informed through discussions with vessels skippers. This would provide a practical understanding of the application of the technology to the searching behaviour of the fleet and an understanding of the factors that dictate the searching strategy for the day/week.

4.3 Other spatial analyses

Spatial phenomena can generate bias when deriving relative abundance indices from catch rate data. Descriptive analysis of populations and fisheries over large spatial scales indicates that there is spatial heterogeneity in populations and that fisheries may exhibit systematic changes in distribution over time.

Increased spatial targeting of species over time can mask genuine declines in abundance (hyperstability). Spatial avoidance of species over time can exaggerate genuine declines in abundance (hyperdepletion). There is also evidence for important population substructure. Archival tagging of yellowfin off Baja California (Schaefer, et al. 2010) indicates limited diffusion of individuals and therefore the potential for regional abundance trends. There may also be evidence of regional depletion in yellowfin tuna biomass off the east coast of New Zealand (S. Harley, personal communication). These regional depletions may have important implications for management and it may be desirable to standardize data at this resolution (instead of a population-wide index).

Over small spatial scale (smaller than 10° x 10° resolution) there is evidence for the targeting of patchy aggregations. In such cases the sequential depletion of high-density aggregations may lead to strong hyperstability phenomenon (where catch rates decline slower than biomass).

The Workshop undertook (post workshop) preliminary spatial analyses of French purse seine catch-per-unit-effort data for Indian Ocean yellowfin tuna (Appendix 4). Since tagging data indicate that yellowfin tuna mix rapidly in the Indian Ocean, the modeling of time X area interactions may not be important for the reliable determination of a population-wide abundance index. In this application, the similarity in the indices derived from model with marginal area effects and no area effects implies that there have not been important systematic changes in the distribution of fishing. However when fitted, time x area interaction models revealed important spatial inconsistencies that call into question the validity of particular data points and the assumption of an aggregated population.

Recommendation 7: Investigate the impact of spatial assumptions on the use of CPUE based indices of abundance. It may be valuable to evaluate the importance of spatial heterogeneity in tuna populations for the interpretation of purse seine catch rate in terms of abundance.

Recommendation 8: Evaluate the spatial distribution of each species and how the fleet responds to the patchiness. The spatial distribution of the main tuna species targeted by purse-seine fisheries is poorly understood. The development of CPUE approaches to estimate relative abundance is dependent on assumptions regarding the distribution of fishing effort relative to the abundance of the stocks. Simple metrics of purse seine catch rates (e.g. catch/day) are likely to exhibit hyperstability. The analysis of catch and effort data resolved at the temporal and spatial scales of the operation of the fishery that may provide an indication of the spatial structure of the vulnerable population. The analysis should also account for changes in the vulnerability of tuna in the water column. The results of such a study would be applied to appraise the appropriateness of various CPUE metrics and test hypotheses relating to the utility of applying specific measures of CPUE to monitor stock abundance. At a minimum, a range of spatial metrics could be formulated to monitor longer term trends in the spatial structure of the operation of the fisheries (including consideration of set type).

4.4 Modeling of buoys and floating objects

The aim of the Tropical Atmosphere Ocean (TAO) project is to collect real-time data from moored ocean buoys for improved detection, understanding and prediction of El Niño and La Niña. The network of moored buoys is deployed across the equatorial Pacific Ocean. Many of these buoys are located in the prime habitat of tropical tunas and historically purse seine vessels have targeted schools associated with these floating objects. The exact location of these TAO buoys is recorded daily making it easy to determine sets on schools associated with these objects. In particular for the TAO buoys located in the eastern Pacific Ocean, there exists an incredibly rich time series (1995-2010) of sightings of TAO buoys (the buoy was visited, but not set), and catch information from sets. It might also be possible on some TAO buoys to utilize current monitoring data which may provide presence/absence information on tunas at the buoys.

Recommendation 9: Analyses of TAO data. A study should be conducted with the aims to (A) Compile data sets for individual TAO buoys comprising sets and sightings that did not result in sets plus oceanographic information collected by the TAO buoys; (B) develop population dynamics model to attempt to estimate local abundance through time which may be related to the more broader regional stock size; and, (C) Provide proof of concept for the development of monitoring of moored FADs to develop indices of abundance.

As alternatives to efforts to further standardize PS effort, development of use of FOBs and other platforms (e.g. anchored oceanographic buoys) for ocean observations to obtain "fishery independent" means for monitoring floating object associated species stock components (e.g. skipjack, yellowfin and bigeye plus many others) should be further advanced. Use of FOBs and other platforms as ocean observatories for indexing tuna abundance will require access to detailed GPS and echo-sounder data and scientists should work with industry in pursuit of this research.

Recommendation 10: Develop the quantitative basis for the potential use of floating objects to monitor relative abundance or density. This research would support the development of models based on the behavior of tunas to obtain indices of abundance. Data needed are residence times on- and off-floating objects, densities of floating objects and abundances of tunas at floating objects from echosounder buoys. A pilot project is proposed utilizing an existing dataset from IATTC. Subsequently, this could be extended to other regions by conducting additional archival and acoustic tagging. In addition, technological improvements in echosounders and other sensors onboard buoys should be supported.

Development of models based on the behavior of tunas is a component useful for developing indices of abundance from FAD echo-sounder and trajectory data. Quantifying fish associative behavior at FOBs can provide the opportunity of using FOBs as fishery-independent indices of the abundance of tuna and other associated species.

For this purpose, it is important to pursue the development of behavioral models (e.g. stochastic differential equations) based on field data: residence times of fish on- and off-FOBs, abundance of fish at FOBs, densities of FOBs. These data can be obtained through the use of electronic tags, echosounder buoys attached to FOBs, catch and observers data. The model will depend on the nature of the social behavior of each species (nonsocial or social, with different categories of social behavior).

Recommendation 11. Collection of new field data on the behavior of fish and abundance at FOBs. In parallel to the pilot study in Recommendation 9, new projects should start collecting new field data (it is key to collect concomitant data on each area: associated biomass, individual residence times on- and off-FOBs, densities of FOBs) in various areas and different species, including dedicated experiments to assess and quantify the sociality of the studied species. Additionally, the technology (echosounder buoys) should be improved to increase the quality of data from these devices (abundance by species/sizes).

Recommendation 12: Carry out power and economic analysis to detect changes in population size with new methods. FAD-based eco-sounders and acoustic tagging combined with FAD acoustic sensors may provide either relative trends in abundance or estimates of population size. The design of these experiments can be informed by the construction of operating models that describe the large-scale spatial dynamics of the stock, small scale aggregation of fish on FADs and the exploitation dynamics of fisheries. Key inputs include the cost of deploying the technologies and the desired power of statistical tests to detect a desired change in abundance. Outputs could include the number of acoustic tags to be released, the spatial allocation of releases and the location of sensor FADs.

4.5 Other statistical analyses

A number of relatively new statistical methods have become available that may assist in standardizing CPUE estimates or estimating technological change in econometric models. Generalized additive models, zero-inflated models, mixed-effects models, regression trees, and random forest models may improve scientists' ability to deal with repeated measures, nonlinearities, zero-inflation, and high-order interactions. Some of these methods can also be used for interpolation algorithms; in fact, some the random forest statistical packages contain built-in interpolation algorithms (of unknown reliability). The Workshop undertook preliminary analyses for yellowfin and bigeye tuna in the EPO (Appendix 3). Regression tree analysis identified factors such as species abundance, vessel capacity, net length, presence of aircraft, net depth, and the year the vessel was built as being important.

Recommendation 13: Investigate the use of regression trees and associated methods. The application of these methods should be explored to determine what affect the choice of method may have on our estimates of CPUE or technological change and if and how these apparent difference affect our estimates of abundance from stock assessment models.

An operating model may be described that encompasses a range of population, fishery and observation dynamics. Given that the simulated 'true' biomass is known, the performance of a range of candidate standardization methods may be compared. It may be possible to evaluate the relative importance of assumptions (e.g. marginal areas effects versus time x area interactions) and mode of analysis (e.g. regression trees versus generalized linear modeling). Performance of standardization methods may be evaluated in a simple way by direct comparison with the known abundance trend. Alternatively, the results of stock assessment methods that make use of the derived index may be compared to the simulated true reference points (e.g. estimated F_{MSY} versus simulated F_{MSY}). This may be extended to illustrate the long run performance of a standardization method in terms of management objectives such as probability of overfishing and yield.

Recommendation 14: Implement simulation models for testing the performance of different CPUE standardization methods. The aim of this work would be to test how different methods perform in terms of supporting management decisions.

Recommendation 15: Evaluate alternative uses of effort to develop an index of abundance. Indices of abundance might be developed using purely effort-based or biology-based information, essentially ignoring the amount caught. For example, rather than CPUE, perhaps search time/search area/number of FOBs checked may track abundance. Similarly, rather than the abundance of fish at a FOB, the relative rate of accrual of fish at a random set of FOBs tracks abundance, given some estimate of FOB density. The performance of any of these approaches is currently unknown, but future research might wish to explore such possibilities.

Recommendation 16: Further development of spatial population dynamic models to impute cells with missing CPUE. Spatial population models can be used to model spatially specific CPUE data and impute spatial/temporal cells with missing CPUE data. These models use the population dynamics to predict the abundance in spatial/temporal cells with missing CPUE data. Spatial expansion of the fishery often means that low abundance cells at the edge of the spatial range have the least data and parameters for these cells may be poorly estimated. Using mean parameter estimates would overestimate the productivity of these cells. A more appropriate approach is to model the spatial correlation in model parameters. Other developments should also be investigated such as the movement of individuals among cells. Initial modeling might require simplified models to reduce computational demands.

5. CONCLUSIONS AND ADJOURNMENT

The analysis of purse seine CPUE data for the purpose of obtaining relative indices of abundance remains a difficult issue. Participants felt, however, that good progress was made during the workshop in terms of describing historical changes in technology, in data that should be collected, and on further analyses to be carried out. It is hoped that, collectively, these will provide a framework to improve the understanding of purse seine data in order to make it more useful in tuna stock assessments.

Participants thanked M. Maunder for his excellent chairmanship during the Workshop and ISSF for convening it. The Workshop was adjourned on July 19 and the report was adopted by correspondence.

Appendix 1. Agenda

Description of tuna purse seine fisheries and their data
  Fonteneau: Introduction and historical changes
Behavior of tuna with respect to purse seine fishing
  Schaefer: Introduction
Current use of Purse seine CPUE in tuna RFMOs (10 minute max presentations)
  IOTC - Sharma
  ICCAT - Pallares
  WCPFC/SPC - Harley
  IATTC - Maunder
Behavior of fishing vessels
  Langley: VMS (30 Min)
  Maunder: Code groups
  Gaertner and Pallares: Efficiency of the tuna purse seiners and effective efforts
  Bez: Use of VMS data to get indices of abundance.
Measures of effort and covariates
  Maunder: Introduction
Traditional approaches to derive indices of abundance from CPUE data
  Cooper: Introduction
  Morón and Soto: Estimates of Catchability and fishing efficiency and it's effect on purse seine CPUE estimates
FADS
  Dagorn and Cappello:
    How do tuna distribute among floating objects
    Potential use of FADs to provide fishery-independent indices of abundance
  Chassot: The analysis of buoy trajectories for the French PS fleet to identify spatio-temporal variations in FAD deployment, FAD densities and trajectories, FAD lifespan, etc
Mechanistic models
  Maunder: Introduction
  Chassot: The analysis of CPUE for free-swimming schools with a focus on its different components
Oceanography
  Maunder: Intro
Spatial temporal variation
  Carruthers: Introduction and spatial aspects of CPUE analysis
  Fonteneau: peculiarities and importance of tuna Concentrations and their increasingly intensive exploitation by PS
Alternative methods
  Maunder: Introduction
  Maunder: Dolphin sets as a random sample of non-target species
  Maunder: Known abundance species ratios
What data should be collected to develop indices of abundance from purse-seine catch and effort data?
  Maunder: Introduction
Breakout groups
Recommendations

Appendix 2. References and background reading material

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IATTC observer database manual

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Appendix 3: Analysis of eastern Pacific Ocean tuna catch and effort data

By Mark Maunder

Catch per unit effort (CPUE) data for the eastern Pacific Ocean (EPO) purse seine fleet were analyzed by a subgroup of the meeting participants to illustrate the types of data available and issues related to analyzing the data. First, characteristics of the fishing effort were investigated for trends over time. Next, residuals of the IATTC stock assessment fit to the purse seine CPUE based indices of abundance were investigated for trends over time and compared with trends in the characteristics of fishing effort. Finally, regression trees were applied to the data to investigate what characteristics influence the CPUE. CPUE in the Tree analysis was defined as catch per day fished and each data point was a trip. The characteristics explored were vessel capacity, purse seine net length, purse seine net depth, vessel speed, the year the vessel was built, the use of aircraft, the use of sonar and annual biomass of yellowfin or bigeye tuna from the stock assessments. Other characters examined included the use of bird radar, age of the vessel, and dolphin mortality limits (DML). The tree analysis was carried out for CPUE of yellowfin and of bigeye tuna.

There are three main purse seine set types in the eastern Pacific Ocean: 1) sets on tunas associated with dolphins, 2) sets on tunas associated with floating objects, and 3) sets on unassociated schools. Vessels often specialize in either dolphin associated sets or floating object associated set. Both types of vessels also make sets on unassociated schools. The main set type for a vessel may differ among years. These two sets types are very different and should be analyzed separately. Vessels that make dolphin sets are required to have DMLs and this can be used to identify vessels that mainly fish on tuna associated with dolphins. Unfortunately, the requirement to have a DML only started in 1992. Therefore, the proportion of sets of each type made by a vessel in each year (Figure A3.1) were investigated to determine rules to define vessels that mainly set on tuna associated with dolphins (proportion of dolphin sets greater than 0.3) and vessels that set mainly on floating objects (proportion of dolphin sets less than 0.05).

Information on vessel and gear characteristics recorded by observers is thought to be more accurate than that from logbooks since they make new records for each trip. Therefore, observer data was used for the main analysis. However, the regression tree analysis was also repeated using logbook information for trips with no observer data. In addition, tree analyses with and without the variable year are conducted. Because of changes through time in a number of the other factors, year is confounded with these other factors. In the tree analysis with year, year is included as a categorical variable.

Net depth, net length, the presence of an aircraft, and the use of bird radar, show the most changes over time for vessels that make sets mainly on tuna associated with dolphins (Figure A3.2). The year that the vessels were built does not change much over time so the average age of vessels generally increases by one year each year (Figure A3.2a). The use of bird radar was adopted by most of the fleet over a few years and the information was not recorded for many vessels in the initial period of the adoption (Figure A3.2b).

Net length has not changed as much for vessels making sets mostly on tuna associated with floating objects (Figure A3.3a) compared to those setting mostly on tuna associated with dolphins (Figure A3.2a). However, the net depth for some vessels is deeper and the vessels slower (Figure A3.3a). Aircraft are seldom used on vessels making sets mainly on floating objects; however, their use of sonar has increased steadily over time (Figure A3.3b).

The residuals of the yellowfin tuna IATTC stock assessment fit to the floating object CPUE based indices of abundance generally changed from positive (observed CPUE larger than predicted) to negative over time (Figure A3.4). The change in residuals appears to have occurred in the early 1990s when the floating object fishery started to expand. The only pattern seen in the unassociated fisheries are the positive residuals in the southern area around 1990 (Figure A3.5). The residuals of the dolphin associated fisheries CPUE changed from negative to positive over time (Figure A3.6). The residuals of the bigeye tuna IATTC stock assessment fit to the floating object CPUE show some similarities among the areas with a general change from positive residuals around 2000, to negative residuals around 2005, and back to positive residuals around 2010. However, this trend is not seen in all areas. It is difficult to correlate changes in residuals with changes in the characteristics of the fisheries since the changes in characteristics are often monotonic trends over time (e.g. net length) or abrupt changes (e.g. bird radar).

The regression tree analysis found that yellowfin tuna biomass explained the most variation in yellowfin tuna catch per day fished by vessels that make sets mainly on tuna associated with dolphins (Figure A3.8). Vessel capacity, net length, and the presence of aircraft were also chosen as important factors. Yellowfin tuna biomass also explained the most variation in yellowfin tuna catch per day fished by vessels that make sets mainly on tuna associated with floating objects (Figure A3.9). Vessel capacity was not selected, but net depth was. The regression tree analysis found that vessel capacity explained the most variation in bigeye tuna catch per day fished by vessels that make sets mainly on tuna associated with floating objects (Figure A3.10). The year the vessel was built and bigeye tuna biomass were also selected as important factors. Some tree branches had few observations indicating that there may be uncertainty in whether some of the chosen factors are important. When the logbook data was used for vessels without observer data in the analysis of yellowfin catch per day fished for vessels mainly making sets on tuna associated with dolphins, the same factors were chosen, but the tree had a different shape (Figure A3.11). When year was added as a categorical variable yellowfin biomass and net length was replaced by year as the important factors (Figure A3.12). Several variables selected in the tree analyses are at least partially confounded with spatial factors. An example is vessel capacity; larger vessels tend to be able to fish further offshore. However, in these analyses, it was not possible to try to separate gear effects from spatial effects, for example, by building trees with spatial variables, because the data were aggregated to the trip level.

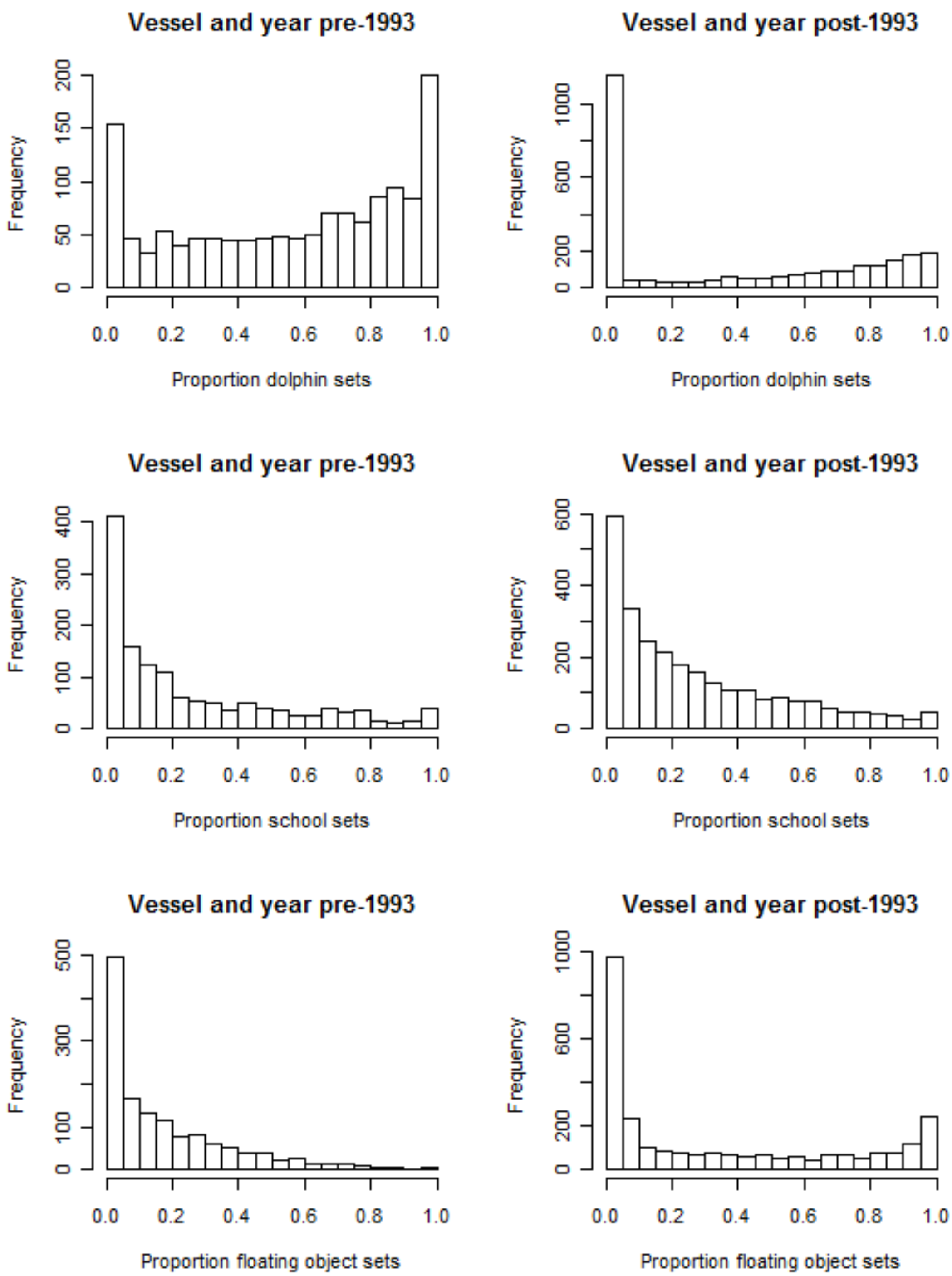

Figure A3.1. Frequency of vessel-year combinations with given proportion of sets of a particular set type in the eastern Pacific Ocean for the time periods pre and post 1993 when the floating object fishery expanded.

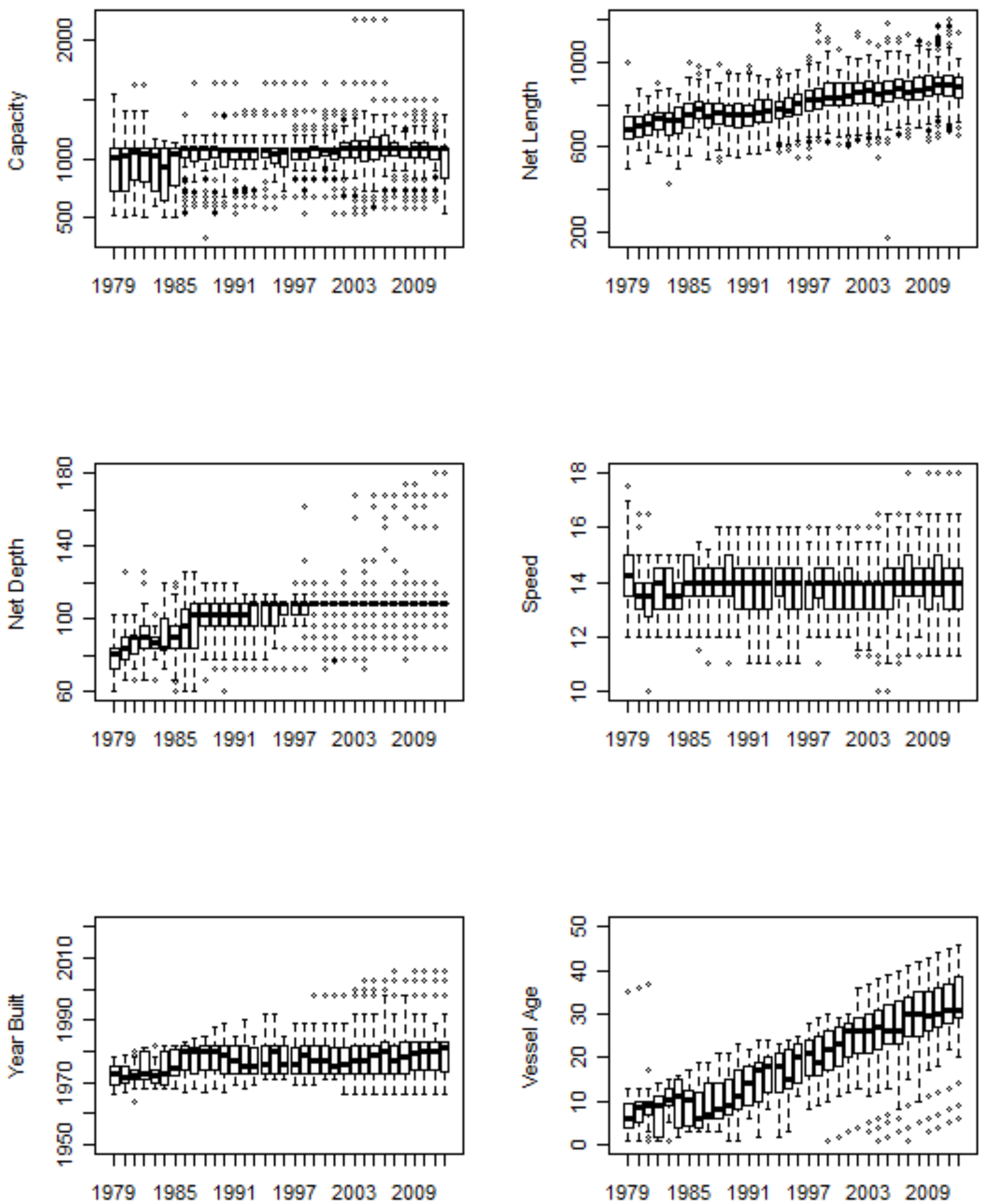

Figure A3.2a. Vessel and gear characteristics for eastern Pacific Ocean vessels making mainly dolphin sets (proportion dolphin sets greater than 0.3).

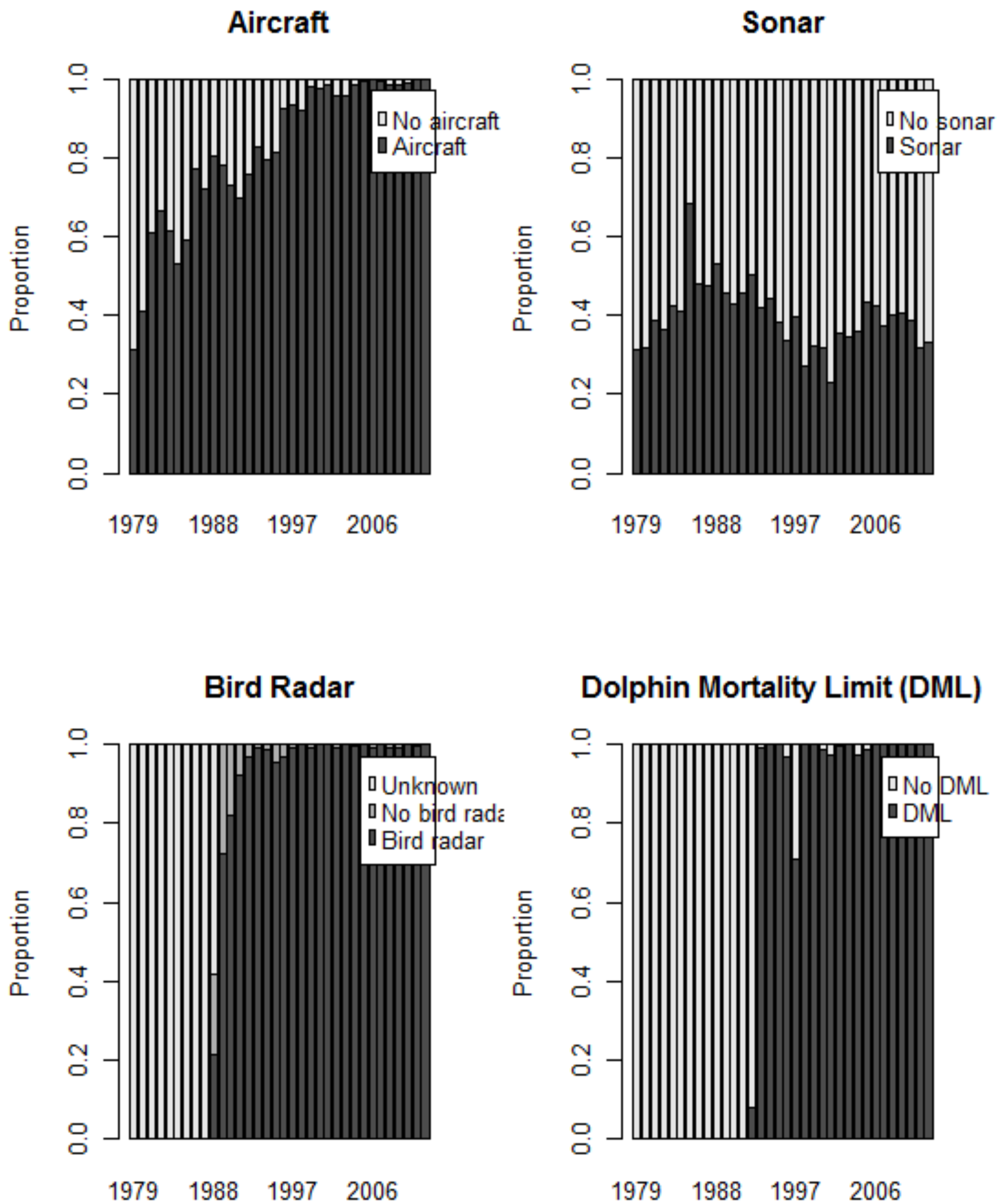

Figure A3.2b. Vessel and gear characteristics for eastern Pacific Ocean vessels vessels making mainly dolphin sets (proportion dolphin sets greater than 0.3)

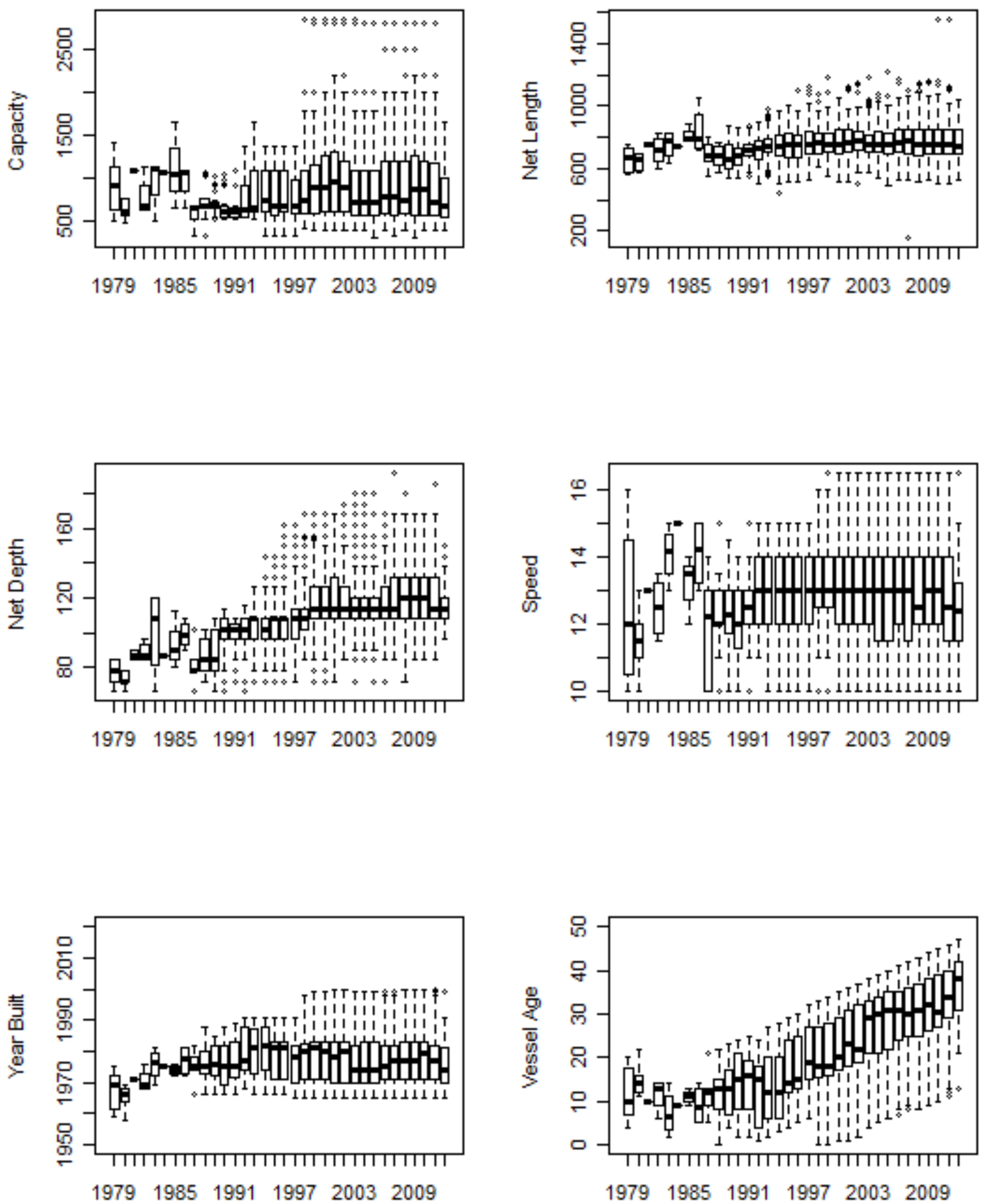

Figure A3.3a. Vessel and gear characteristics for eastern Pacific Ocean vessels making mainly floating object and school sets (proportion dolphin sets less than 0.05)

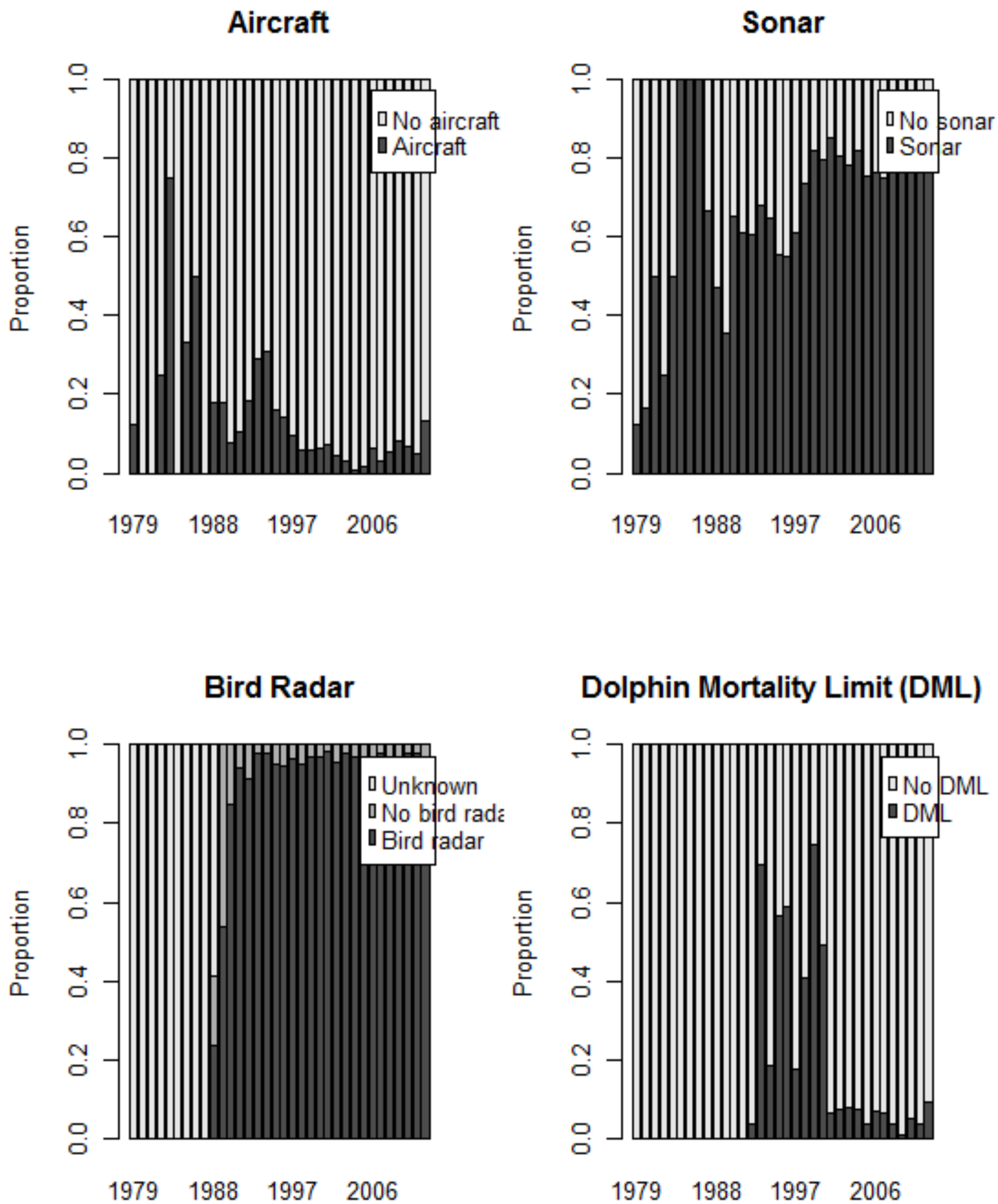

Figure A3.3b. Vessel and gear characteristics for eastern Pacific Ocean vessels making mainly floating object and school sets (proportion dolphin sets less than 0.05)

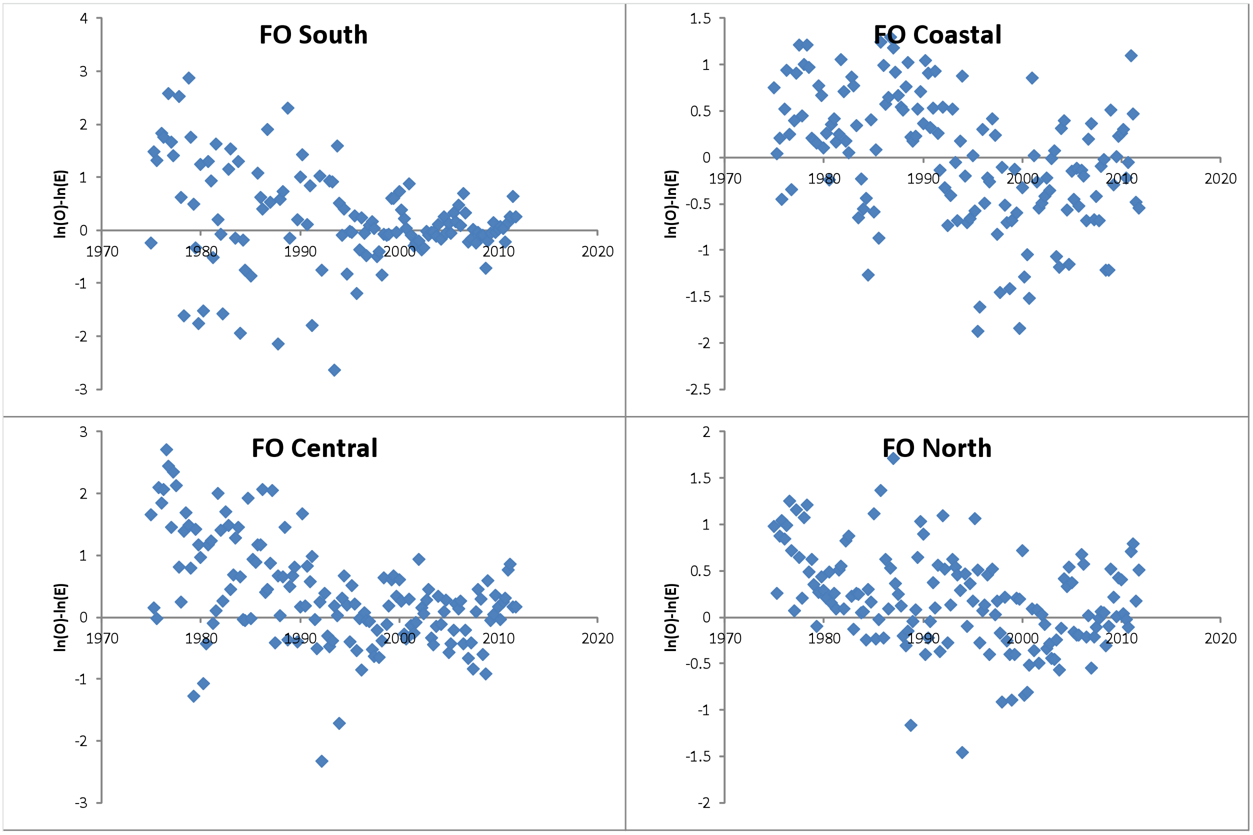

Figure A3.4. Quarterly residuals for the fit to the floating object CPUE in the IATTC EPO yellowfin tuna assessment.

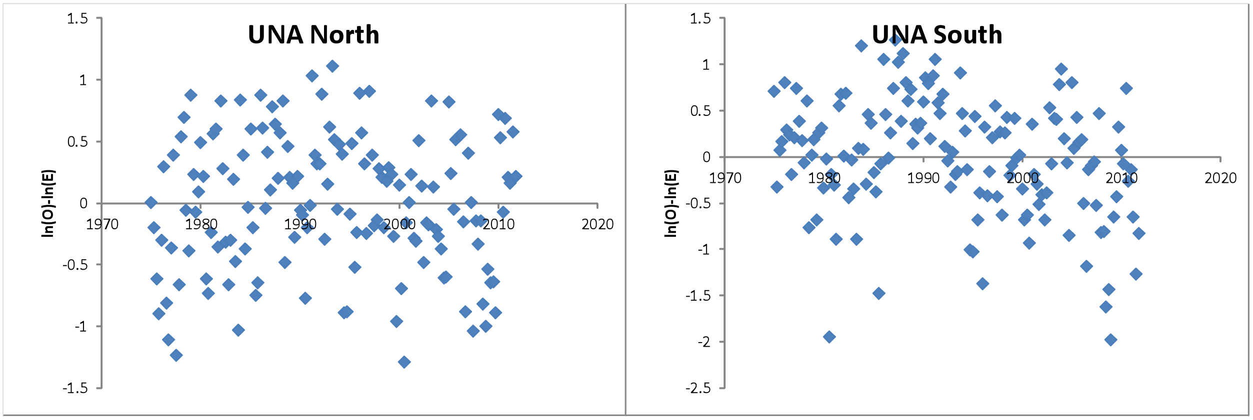

Figure A3.5. Quarterly residuals for the fit to the unassociated CPUE in the IATTC EPO yellowfin tuna assessment.

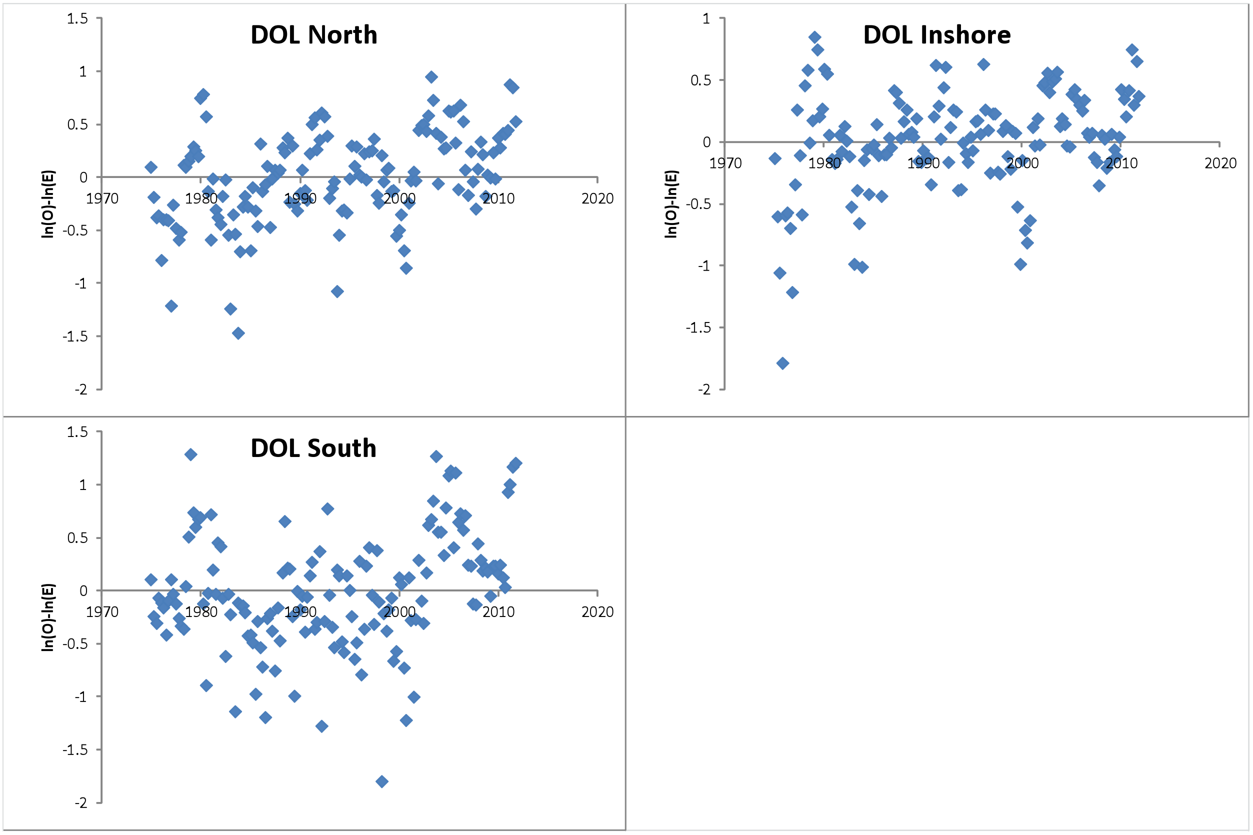

Figure A3.6. Quarterly residuals for the fit to the dolphin associated CPUE in the IATTC EPO yellowfin tuna assessment.

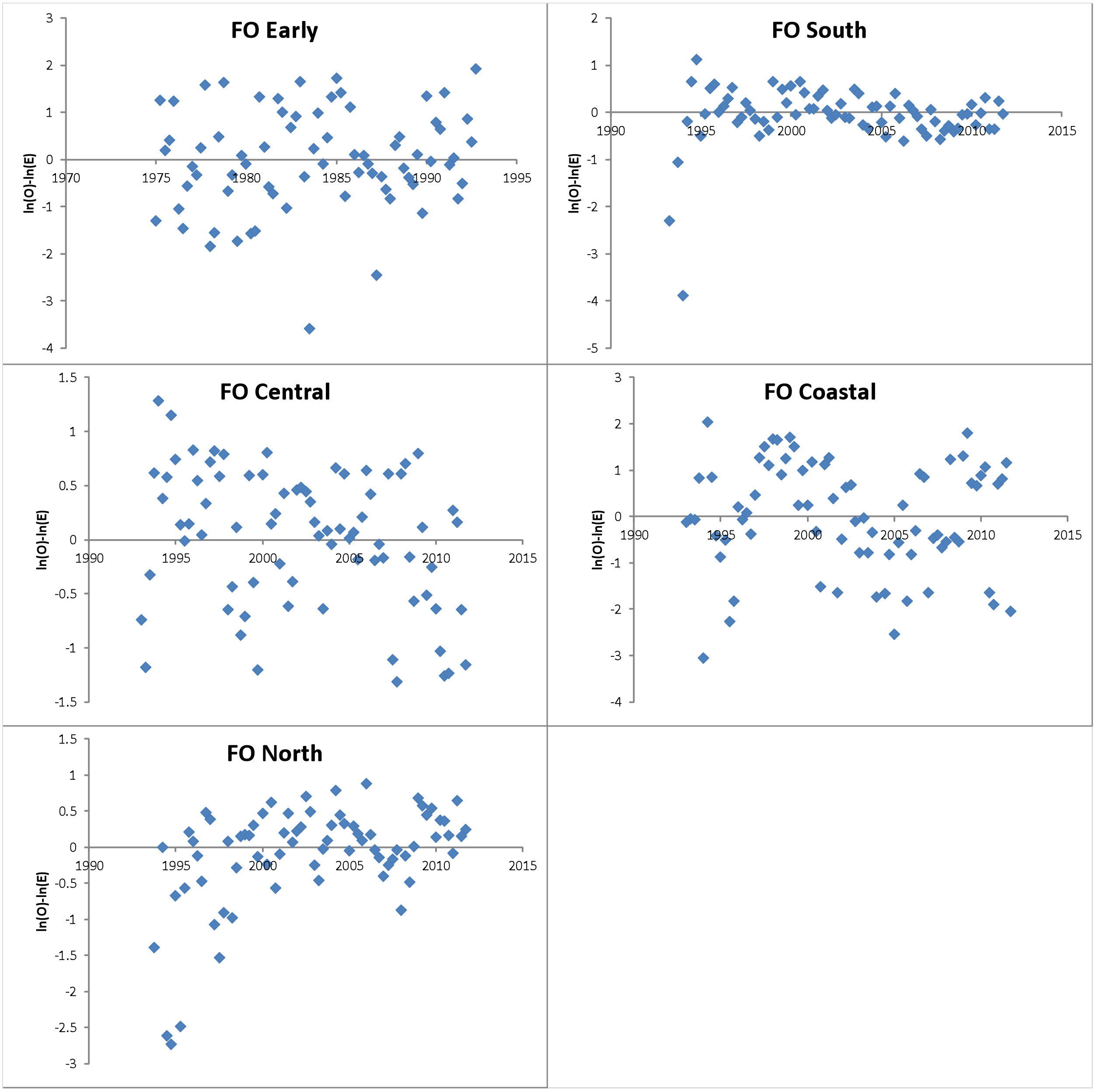

Figure A3.7. Quarterly residuals for the fit to the floating object CPUE in the IATTC EPO bigeye tuna assessment.

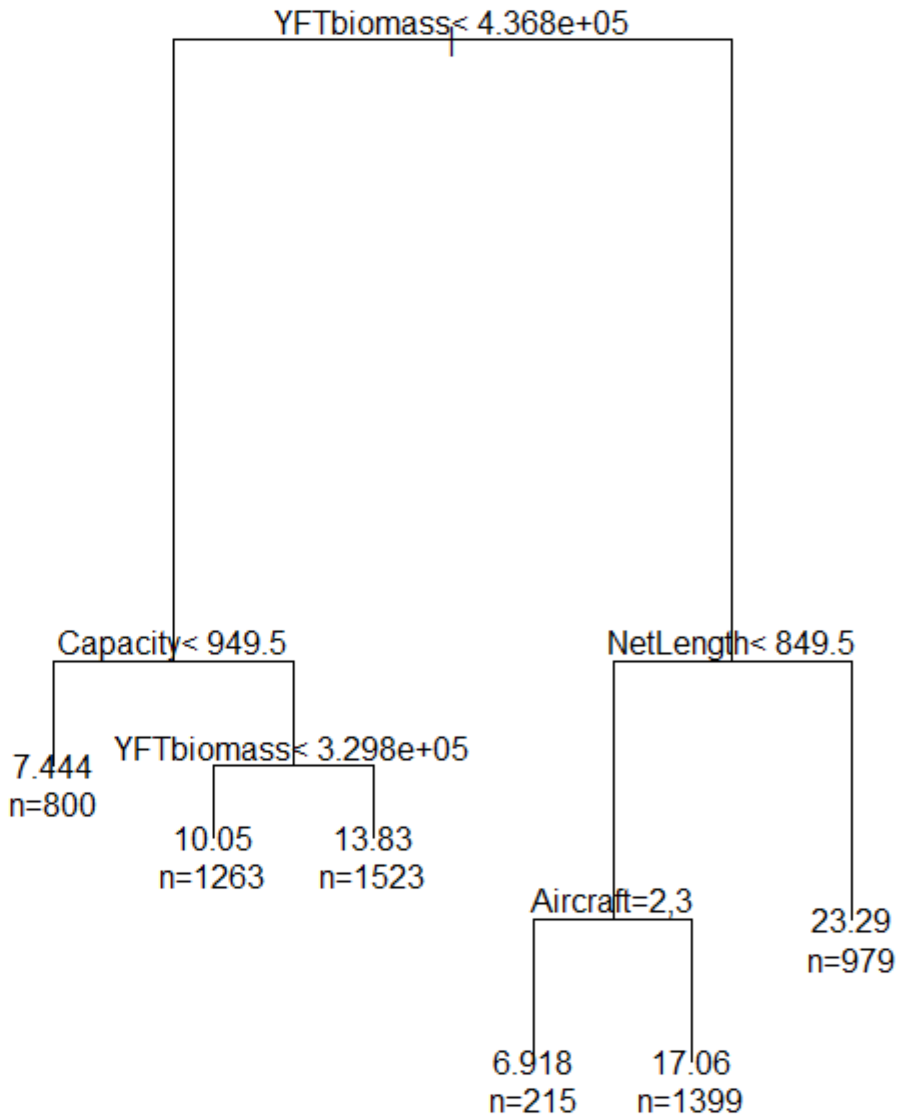

Figure A3.8. Regression tree for eastern Pacific Ocean yellowfin tuna catch per day fished using observer data for vessels making mainly dolphin sets (proportion dolphin sets greater than 0.3).

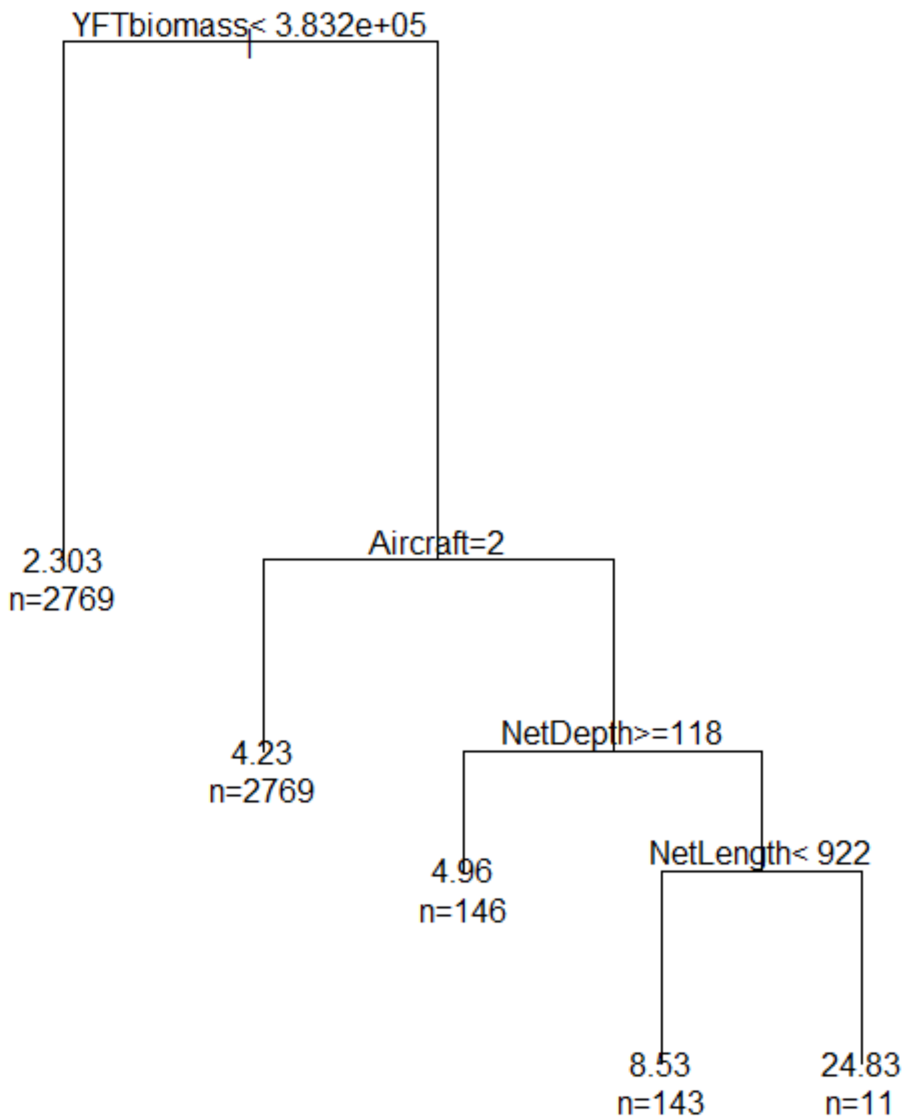

Figure A3.9. Regression tree for eastern Pacific Ocean yellowfin tuna catch per day fished using observer data for vessels making mainly floating object and school sets (proportion dolphin sets less than 0.05).

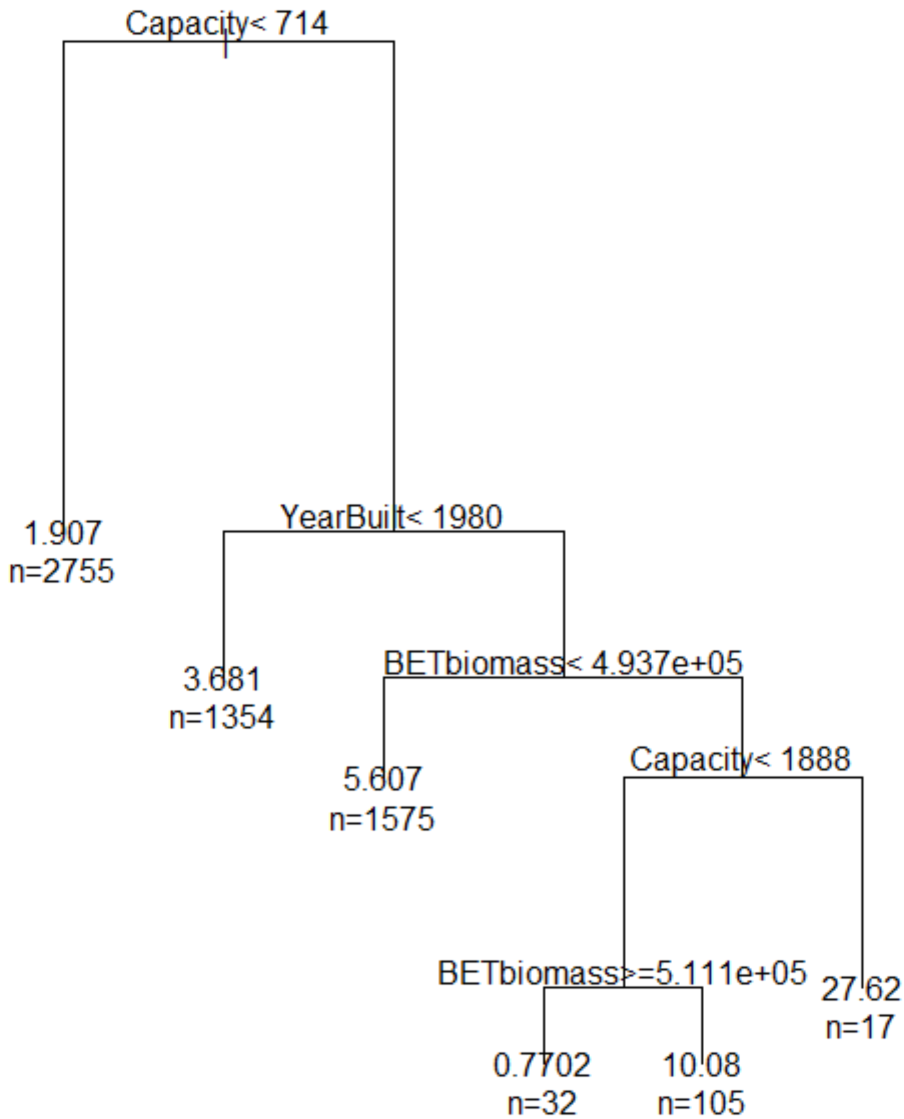

Figure A3.10. Regression tree for eastern Pacific Ocean bigeye tuna catch per day fished using observer data for vessels making mainly floating object and school sets (proportion dolphin sets less than 0.05).

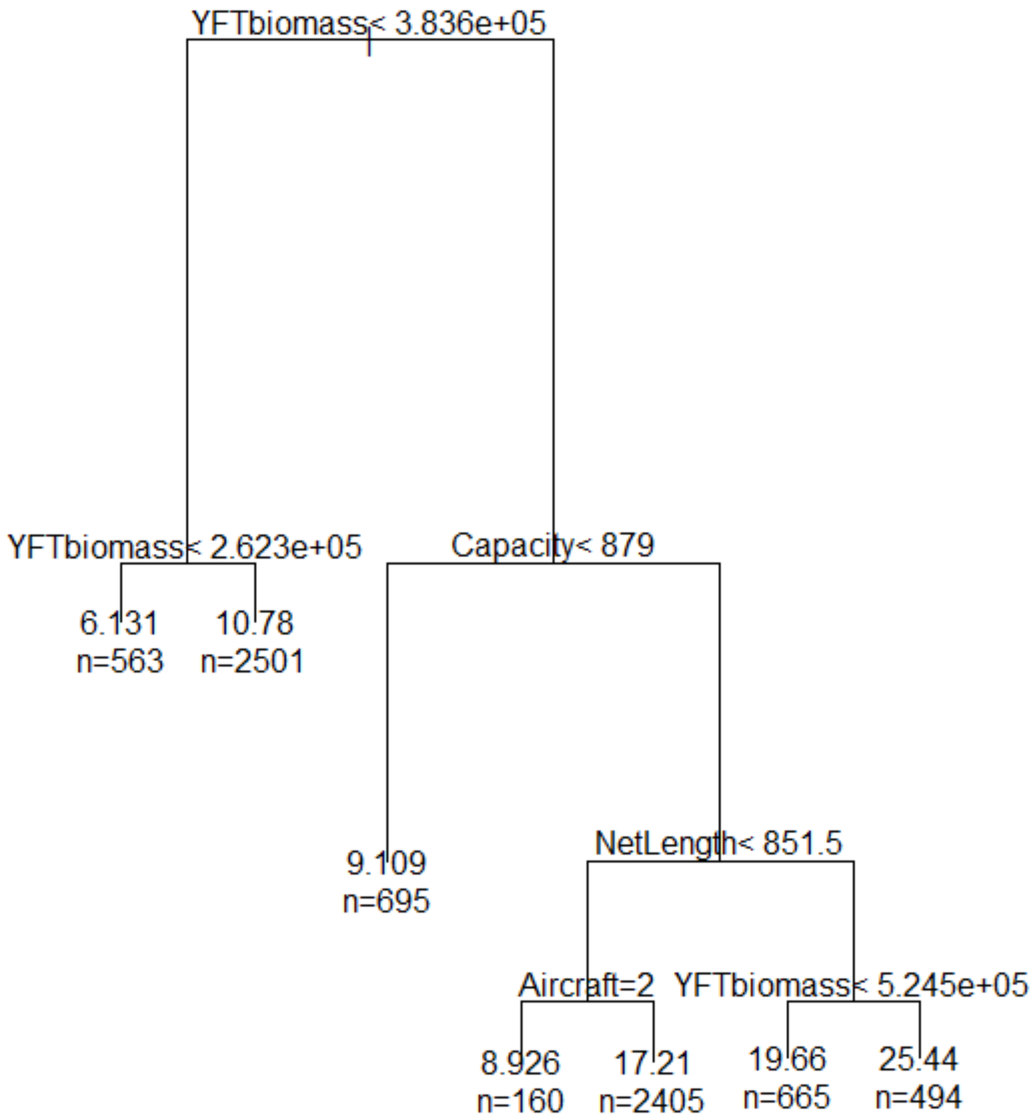

Figure A3.11. Regression tree for eastern Pacific Ocean yellowfin tuna catch per day fished using observer and logbook data for vessels making mainly dolphin sets (proportion dolphin sets greater than 0.3).

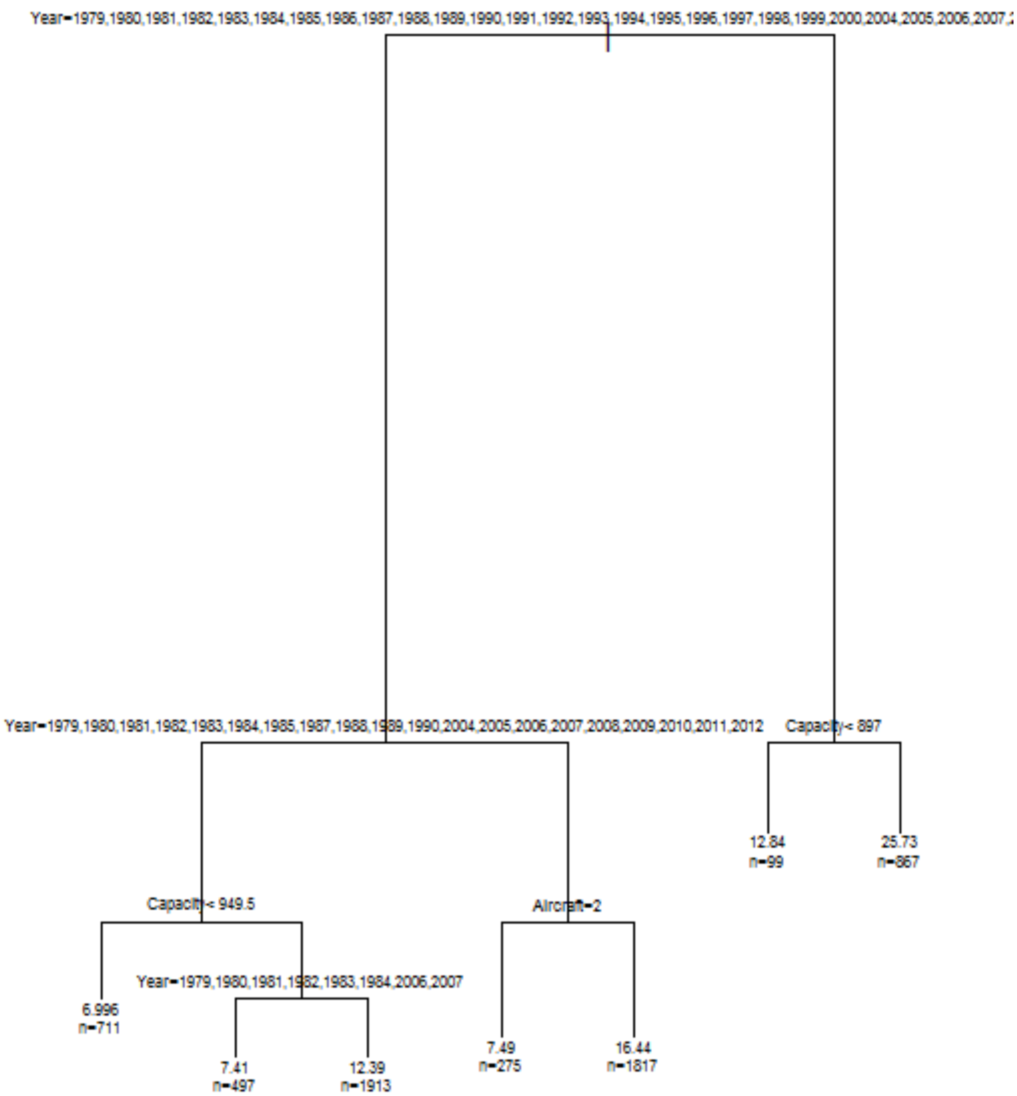

Figure A3.12. Regression tree for eastern Pacific Ocean yellowfin tuna catch per day fished using observer data for vessels making mainly dolphin sets (proportion dolphin sets greater than 0.3). The analysis also includes the categorical variable year.

Appendix 4: Spatial analysis of French purse seine catch-per-unit-effort data for Indian Ocean yellowfin tuna

By Tom Carruthers and Emmanuel Chassot

Abstract

The dynamics of populations and fisheries determine the type of CPUE standardization model that may be logically applied. Since tagging data indicate that yellowfin tuna mix rapidly in the Indian Ocean, the modelling of time x area interactions may not be important for the reliable determination of a population-wide abundance index. In this application, the similarity in the indices derived from model with marginal area effects and no area effects implies that there have not been important systematic changes in the distribution of fishing. However when fitted, time x area interaction models reveal important spatial inconsistencies that call into question the validity of particular data points and the assumption of an aggregated population.

Introduction

Exploited populations may exhibit limited exchange of individuals among areas. If regional abundance trends are different due to regional depletion for example, it may be necessary to account for time x area interactions when standardizing catch rates. In such cases, systematic changes in the spatial distribution of fishing over time can introduce bias. Where the distribution of fishing overlaps more with the stock over time, genuine declines in abundance may be masked (hyperstability). On the other hand, spatial avoidance of species over time can exaggerate genuine declines in abundance (hyperdepletion). To correct for this problem, missing time x area observations may be imputed therefore accounting for the systematic pattern in fishing.

Two methods of imputation have been applied previously: ad-hoc rules and prediction by spatial population dynamics model. We apply an ad-hoc rule (Carruthers et al. 2011a) that is a modified version of the approach described by Walters (2003). The method has previously been subjected to simulation evaluation and demonstrated to reduce bias from spatially expanding / contracting fisheries. When applied to the catch rate data of the Japanese longline fleet the method provided the same adjustment in relative abundance trend that were predicted given the simulation results and the observed pattern in fishing.

Imputation and spatial modeling may not be important for the standardization of Indian Ocean yellowfin tuna. Tagging studies indicate that yellowfin tuna are likely to exhibit relatively high mixing over the core area of the fishery. A large regional tuna tagging program carried out in the Indian Ocean (RTTP-IO) between 2005 and 2009 tagged over 50,000 yellowfin tuna of which 9,000 were recaptured with geo-location data. Figure A4.1 illustrates the pattern of movement of individuals tagged with conventional spaghetti tags. There is evidence of rapid movement away from tagging locations with mean recapture distance stabilizing at around 600-800 nautical miles after two months.

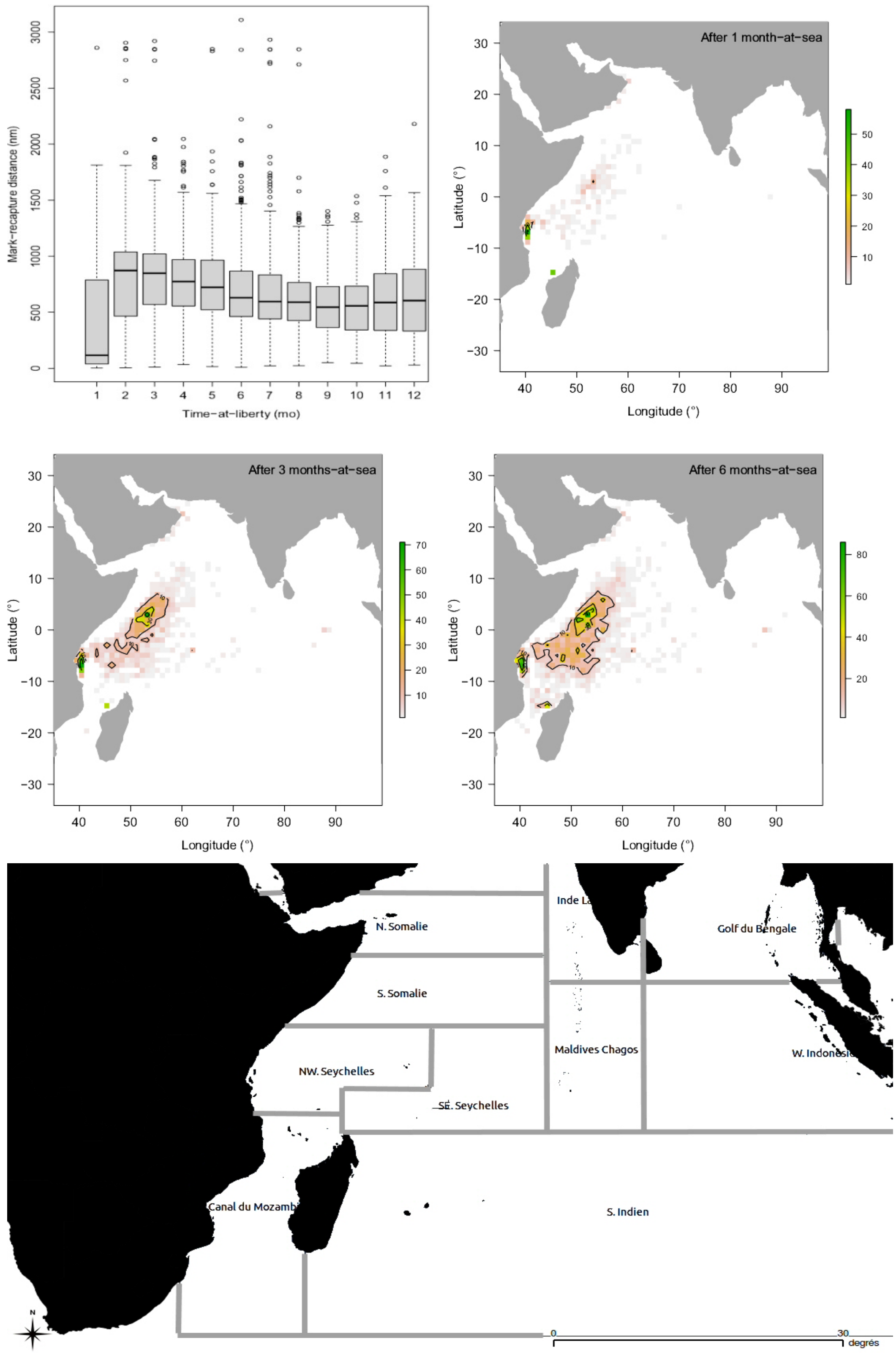

Figure A4.1. Mixing of conventional tags in the indian ocean (approximately 9,000 recaptures). The majority of tagged fish were juveniles with a mean fork-length around 60 cm. (top left) Recapture distance with increasing time-at-liberty. The apparent mark-recapture distance travelled (nm) in the first year-at-sea was computed as a function of time at liberty (months). Recapture distributions after (top right) one month-at-sea, (middle left) three months-at-sea and (middle right) six months-at-sea. (bottom) the area definitions for standardization.

The high level of stock mixing that can be observed would suggest that regional depletion is unlikely and that it is not necessary to model time x area interactions when standardizing catch-per-unit-effort data. We evaluate this hypothesis by undertaking CPUE standardization including (1) time x area interactions, (2) marginal time and area effects and (3) no consideration of area effects. The first scenario accounts for regional abundance trends and seeks to impute missing observations. The second scenario considers the stock well mixed and assumes that approximately the same fraction of the stock persists in each area regardless of changes in overall population size. The third scenario does not attempt to model any important regional effects in doing so this assumes that the overlap of the fishery on the stock remains relatively constant over time (that there are no regional abundance trends and the fishery does not exhibit any systematic changes in distribution relative to the stock).

Methods

French purse seine fishing activities have been monitored by the Institut de Recherche pour le Développement (IRD) in the Indian Ocean since 1981 through the collection of logbooks, well maps, and records of unloading and transshipment. Initially total catches declared in the logbooks were adjusted to the landings at the trip level. Subsequently species composition for the three principal market tunas has been calculated using size-species samples collected at unloading (Pallarés and Hallier 1997).

The number of fishing sets made on free-swimming schools per searching time may be used as a proxy of the number of tuna schools detected. Searching time *S*, was calculated by subtracting the time spent setting the gear from the fishing time. The time spent setting the gear was estimated by regressions linking duration and size of sets, from at-sea measurements made by scientific observers. Rather than fishing time, the searching time is an appropriate indicator of the actual effort deployed to scout the schools.

Three log-linear models were fitted that use search time and catch as a metric of density (Allen and Punsly 1984):

1) $$\log\left(\frac{C}{S}\right) = \mu + \beta_{t,a} + \gamma_v + \varepsilon$$ (time x area interactions)

2) $$\log\left(\frac{C}{S}\right) = \mu + \beta_t + \alpha_a + \gamma_v + \varepsilon$$ (marginal time and area effects)

3) $$\log\left(\frac{C}{S}\right) = \mu + \beta_t + \gamma_v + \varepsilon$$ (no area effects)

Where C is the catch of yellowfin tuna, S is the search time, μ is the overall mean catch rate, $\beta_{t,a}$ are the categorical time x area (t,a) effects, β_t are the categorical time effects, α_a are the categorical area effects and Υ_v are the categorical vessel (v) effects. The term ε represents the normal observation error model.

The linear models were fitted using the 'glm' function of the R stats package (R development core team 2012, R 2.11.1 64bit, Intel I7 2700 32GB). We account for unbalanced observations by weighting observations by the reciprocal of the number of observations in each strata (of Campbell 2004). This is easily implemented using the 'weights' argument of the 'glm' function. Indices were constructed by predicting CPUE using the fitted models for every level of each stratum (using the 'predict' function of R). The index was calculated as the sum of the CPUE predictions $\hat{i}$ over all strata in each year:

4) $$I_t = \sum_a \sum_v \hat{i}_{t,a,v}$$

In this comparative analysis we do not account for area size in the calculation of the index (standardized CPUE is assumed to be proportional to density). This could strongly affect results. In cases where the objective is to construct a time series of relative abundance (as opposed to comparing different area modelling assumptions) it is necessary to account for the size *A*, of each area *a*:

5) $$I_t = \sum_a \sum_v \hat{i}_{t,a,v} A_a$$

The calculation of A is not straightforward and is related to the size of the available habitat. Determining area sizes was considered beyond the scope of this preliminary investigation into spatial modelling assumptions.

In the case of linear model 1 that has time x area interaction effects, missing observations must be imputed. The imputation method applied here is similar to that of Walters (2003) (Figure A4.2). Where standardized CPUE data of a year–area strata are missing prior to fishing in that area, the average of the first three predictions for that area is imputed. Where standardized CPUE data are missing after fishing has occurred in an area, the last standardized CPUE datum for that area is imputed. Where data are missing between standardized predictions, values are interpolated with the mean of the nearest predictions before and after. As such, this ad-hoc method combines nearest-neighbour and mean imputation approaches.

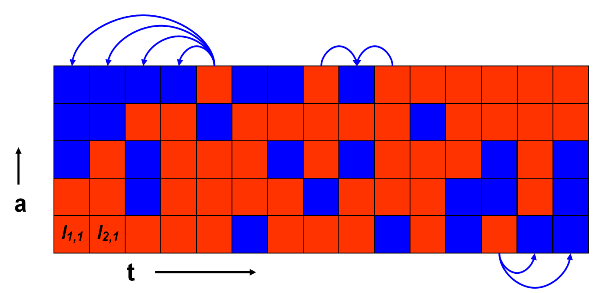

Figure A4.2. The imputation approach. *I* are the predicted abundance indicies of the GLM model with interactions. The population index for any year is then calculated as the average of all areas for a given year.

Results

The trend in inferred relative abundance of the total population is very similar among all three of the standardization models (Figure A4.3, Table A4.1). All indices remain relatively constant until 2002 and then experience a rapid (approximately three-fold) increase during 2004. After this spike, relative abundance indices decline to their pre spike level and remain relatively constant. For certain years, there is considerably more uncertainty in the index that includes time x area interactions. This is due to the greater uncertainty over each of the 119 (4 areas x 30 years – 1 intercept) estimated interaction effects. All indices have among their highest levels of uncertainty at the start and end of the time series.

When the area specific abundance is predicted, important inconsistencies among the models become apparent (Figure A4.4). The model with marginal time and area effects assumes that a constant fraction of biomass exists in each area over the time series. This model structure is constrained such that any spike in abundance must be spread over all areas in the same distribution as the rest of the time series. It follows that the 'Canal du Mozambique' region provides only a relatively small contribution to the pronounced spike in CPUE observed in 2004. The time x area interaction model can however model regional abundance trends. The predictions of this model attribute the majority of the 2004 spike to data from the 'Canal du Mozambique' area, a result strongly contrary to the marginal time and area effect model (predicted regional relative abundance in 2003 and 2005 were 2% and 4% of abundance in 2004, respectively).

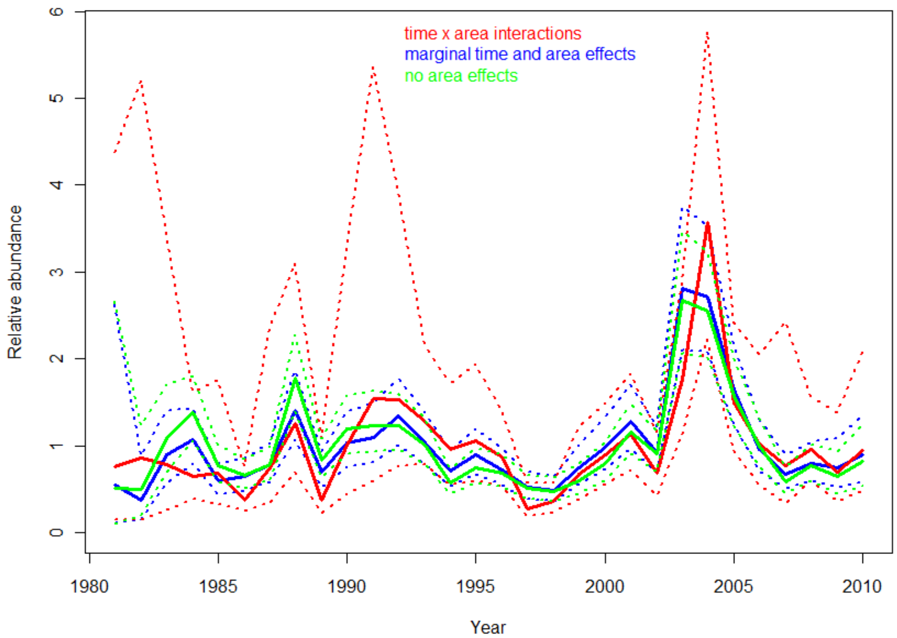

Figure A4.3. A comparative plot of the three indices. The solid lines represent the mean relative abundance. The dotted lines represent the 95% confidence interval. All indices are normalised to mean of 1.

Table A4.1. The mean values and CVs (standard deviation / mean) of the three relative abundance indices.

	Time x area interations		Marginal time and area effects		No area effects	
Year	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1981	0.753	2.457	0.548	1.932	0.510	2.150
1982	0.863	2.574	0.369	0.710	0.496	0.761
1983	0.781	1.741	0.899	0.289	1.087	0.287
1984	0.653	0.752	1.064	0.176	1.378	0.159
1985	0.679	0.805	0.591	0.174	0.769	0.158
1986	0.379	0.519	0.647	0.167	0.655	0.149
1987	0.742	1.114	0.778	0.163	0.779	0.142
1988	1.260	0.745	1.410	0.164	1.777	0.143
1989	0.367	0.993	0.696	0.172	0.831	0.155
1990	1.007	1.156	1.031	0.180	1.194	0.163
1991	1.547	1.258	1.100	0.181	1.227	0.165
1992	1.533	0.793	1.344	0.167	1.235	0.148
1993	1.287	0.344	1.036	0.169	1.013	0.154
1994	0.962	0.398	0.711	0.166	0.572	0.147
1995	1.055	0.429	0.892	0.170	0.746	0.152
1996	0.866	0.320	0.723	0.170	0.684	0.156
1997	0.275	0.553	0.519	0.175	0.504	0.158
1998	0.364	0.291	0.481	0.182	0.479	0.172
1999	0.675	0.414	0.748	0.180	0.597	0.165
2000	0.901	0.337	0.984	0.177	0.795	0.158
2001	1.138	0.312	1.287	0.164	1.157	0.143
2002	0.685	0.355	0.918	0.170	0.903	0.153
2003	1.767	0.321	2.808	0.173	2.671	0.152
2004	3.566	0.316	2.708	0.155	2.551	0.136
2005	1.492	0.316	1.644	0.159	1.569	0.142
2006	1.025	0.511	0.962	0.180	1.000	0.165
2007	0.774	1.085	0.671	0.170	0.585	0.151
2008	0.964	0.316	0.791	0.168	0.771	0.154
2009	0.693	0.510	0.748	0.226	0.650	0.221
2010	0.950	0.608	0.892	0.267	0.817	0.263

It should be noted that the high abundance in 2003 predicted by the marginal area effects model is not predicted by the model with time x area interactions. This is due to the tension between the marginal assumption and the strong impact of the 'Canal du Mozambique' area in 2004 (discussed further below).

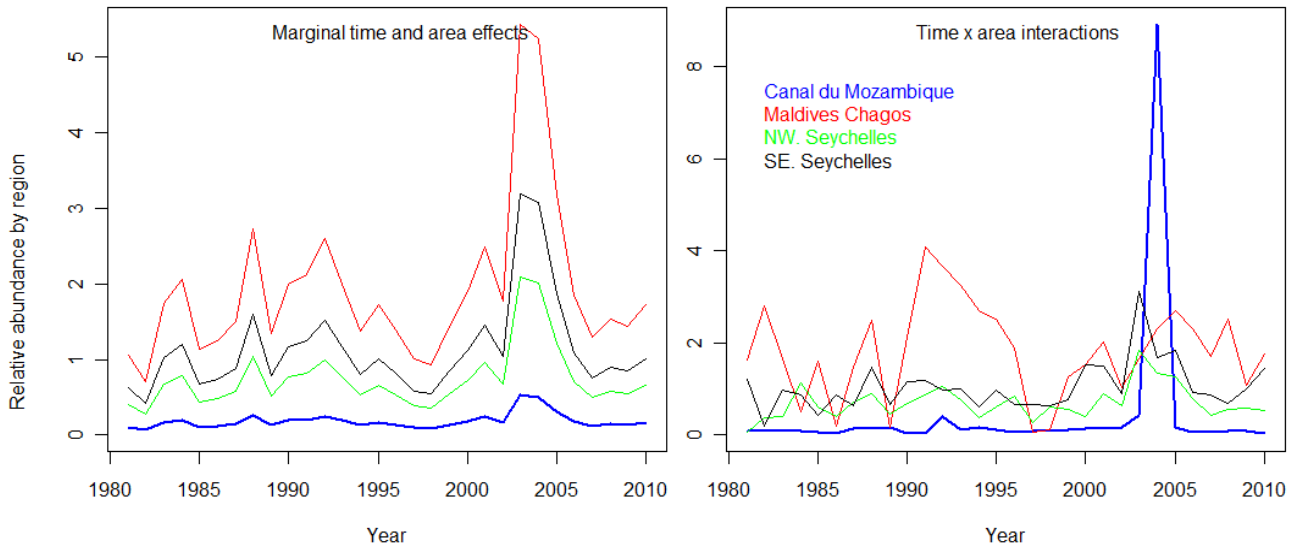

Figure A4.4. The predicted relative abundance indices by region. Plotted are the mean values. (left) The regional abundance predictions of the model with marginal time and area effects (model 2). (right) The regional abundance predictions of the model with time x area interaction effects (model 1). Note that the model with marginal time area effects assumes that a constant fraction of biomass exists in each area over the time series.

Discussion

Where total abundance trends are to be used in stock assessment, the lack of prevalent time x area interactions effects means that spatial CPUE standardization models provide similar results to models with marginal time and area effects. This is broadly consistent with the tagging observations that predict high levels of stock mixing. The similarity of total abundance trends between models with marginal area effects and no area effects indicates that systematic changes in the distribution of fishing over time are not important for Indian Ocean purse seine fisheries targeting yellowfin tuna. If for example, fishing had moved towards higher abundance areas, hyperstability would be evident in the indices with no area effects.

There is however evidence that spatial modelling of CPUE may be important for Indian Ocean purse seine fisheries. Spatial CPUE models provide more detailed information regarding regional abundance trends. The standardization model including time x area interactions indicates that the pronounced spike in CPUE observed in 2004 can be attributed to just one area, the Canal du Mozambique. Traditionally this area is has a relatively low density of yellowfin tuna and the spike in abundance predicted is of a magnitude that is not biologically feasible (approximately a 20 fold increase from 2003 and a 50 fold decline to 2005). Assuming that this regional data point is an anomaly, this is an example of where spatial population dynamics modelling (e.g. Punt et al. 2000; Carruthers et al. 2011b) might be desirable. Rather than constructing a spatially aggregated model that attempts to predict the population- wide index, a spatial population dynamics model would fail to predict such a data point and it would likely be ignored by the analysis.

The risk of making marginal area assumptions is also illustrated when looking at the predicted abundance for 2003 and 1992. In this case a relatively high prediction for the Canal du Mozambique area forces inflation in the predicted abundance of the remaining areas. Consequently the model with time x area interactions predicts an increase from 2003 to 2004 as opposed to a decrease that is inferred by the model that assumes marginal area effects.

Depending on the use of the relative abundance index it may not be necessary to undertake a spatial standardization of CPUE data. In the case of French purse seiners targeting Indian ocean yellowfin there is a high degree of stock mixing and a lack of strong systematic changes in the distribution of fishing. It follows that models that do not account for spatial effects provide similar predictions of overall population trends. However, when they are applied, spatial standardization models reveal regional detail that brings in to question the validity of data points for particular areas and the assumption of a spatially aggregated stock. The case study evaluated here draws attention to the 2004 data for the Canal du Mozambique region and the inference of high stock wide abundance in this year.

Recommendations

Undertake spatial standardization to separate fishing efficiency effects in order to investigate regional abundance trends.

Where possible use other data (e.g. tagging data) to determine the type of standardization model that is likely to be necessary (is it necessary to model time x area interactions and impute missing observations?).

If time x area interactions are likely (i.e strong regional changes in CPUE, tag recaptures indicate high stock viscosity) model time x area interaction effects and impute missing time x area predictions.

If interactions are unlikely but there is spatial heterogeneity in the distribution of the population (areas have different proportions of the population) and there are systematic changes in the distribution of fishing (movement towards or away from areas of higher abundance over time), model marginal area effects.

If the stock is well mixed and homogeneously distributed or is well mixed, spatially heterogeneous and there have been no important systematic changes in distribution of fishing over time, model CPUE without marginal area effects or time x area interaction effects.

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