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Consideration of target reference points for WCPO stocks with an emphasis on skipjack tuna

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Executive Summary

This paper is one of a suite of three pieces of work contracted to inform the WCPFC Management Objectives Workshop, planned to be held prior to WCPFC9. This paper focuses on target reference points, and the other two papers focus on limit reference points and harvest control rules. The presentation of this work to SC8 will provide the feedback necessary to undertake further analysis (as necessary) and refine the material that will be presented to the participants of the WCPFC Management Objectives Workshop.

This paper:

- discusses biological, socio-economic and empirical target reference points, their strengths and weaknesses, and decisions needed to operationalise them;
- raises issues to be recognised when considering candidate target reference points, including concepts of risk and trade-offs;
- provides a simple evaluation of the performance of five alternative target reference points for the WCPO skipjack tuna stock through stochastic projections;
- provides a preliminary evaluation of the utility of empirical indicators for this stock.

Tables and figures are presented examining the performance of alternative targets relative to:

- the risk involved with each target reference point, evaluated relative to candidate limit reference points: $20\%SB_0$, $20\%SB_{CurrentF=0}$ and SB_{MSY};
- catch levels within the tropical purse seine fishery over the projection period;
- the stock biomass vulnerable to the FAD associated purse seine fishery.

The paper <u>does not aim to identify which target reference point is 'best' for WCPO skipjack</u>. Target reference points should be defined by managers based on their desired goals for the fishery. In turn, the performance measures to be used when evaluating their performance should be linked to the manager's aims for the fishery, and allow decisions on the 'acceptable' trade-offs between these and other consequences arising from a target reference point.

OFP, SPC will be guided by the discussions at SC8 on future work in this area for presentation to the planned WCPFC Management Objectives Workshop. In particular, feedback is sought on:

- the planned goals of fishery managers, to help identify new candidate target reference points for evaluation and presentation;
- performance measures of interest to managers for evaluation, to allow a fuller analysis of the trade-offs inherent in alternative target reference points, and the timeframe for which they should be calculated;
- definition of the limit reference points to be used within evaluations;
- alternative empirical indicator reference points for examination.

Introduction

The selection of target reference points and corresponding limit reference points frames desirable exploitation levels for the stock in question. However, they represent one piece of the overall fishery management strategy. Along with harvest control rules and management considerations of acceptable risk, these components work together to achieve the overall goals for the fishery (see also Norris, 2009; SC5-ME-WP-01). As a result, the current paper forms only part of the discussions fishery managers need to undertake, and should be considered alongside Harley et al. (2012; SC8-MI-WP-01) and Berger et al. (2012; SC8-MI-WP-03) (Figure 1). This paper does not aim to provide a comprehensive review of target reference points; the wider literature referenced within (e.g. Sainsbury, 2008) should be referred to.

The FAO Code of Conduct for Responsible Fisheries (FAO 1995; section 7.5.3) notes that "[Regional fisheries management organizations] should, on the basis of the best scientific evidence available, *inter alia*, determine: a) stock specific target reference points, and, at the same time, the action to be taken if they are exceeded; and b) stock specific limit reference points, and, at the same time, the action to be taken if they are exceeded; when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded" (see also Harley et al., 2012; SC8-MI-WP-01)."

The UN Fish Stocks Agreement (Annex II; United Nations Conference on straddling fish stocks and highly migratory fish stocks, Anon. 1995) also notes "target reference points are intended to meet management objectives [intended state of the managed system]... Fishery management strategies shall ensure that target reference points are not exceeded on average [it is expected that the actual state of the fishery will fluctuate around the target(s)]."

Many countries and regional organizations provide overarching objectives for the management of fisheries in their waters. The WCPFC Convention text is no exception: "the long-term conservation and sustainable use of highly migratory fish stocks", while "ensuring conservation and promoting the objective of optimum utilization of highly migratory fish stocks throughout their range" and " avoid adverse impacts on the marine environment, preserve biodiversity, maintain the integrity of marine ecosystems". In turn, the Convention principles include the need to "maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors". Fisheries are therefore managed to achieve a combination of biological, economic, social (and political) objectives.

Target reference points therefore attempt to make desired biological, (ecosystem) and socio-economic objectives of management operational, in a measurable way. They are generally translated into the states of fish stocks and fisheries (biomass, fishing mortality) required to achieve them, allowing them to be related to the results of scientific stock assessment. However, the example overarching management statements above provide no indication of the levels of these targets, nor where the priorities of fisheries management lie within them.

It is therefore the role of fishery managers and relevant stakeholders to identify the desirable fishery and stock conditions that define target reference points as well as the tradeoffs and risks associated with them. Those candidate reference points can be tested by scientists.

To provide a background to discussions on target reference points for the WCPO skipjack fishery, this paper reviews biological, socio-economic and empirical target reference points considered and used around the world, detailing their strengths and weaknesses, and the management decisions that are needed to make them operational. Based on this summary, we select a number of candidate reference points for the skipjack tuna stock in the WCPO, calculate the corresponding values based on the 2011 stock assessment, and provide a simple evaluation of their performance through the use of stochastic projections. The paper represents progress towards the ultimate review by the WCPFC Management Objectives Workshop scheduled for later in 2012.

Biological (fishery) target reference points

Desired management targets in terms of stock conservation, sustainability and for overall yields are generally translated into the states of fish stocks and fisheries (biomass, fishing mortality) required to achieve them.

MSY-related levels

'Maximum sustainable yield' (MSY) is an 'equilibrium' concept, and represents the point at which increased fishing effort results in no further increase in catch levels. The concept of MSY and its technical equivalents (e.g. the value of MSY, Bmsy, Fmsy) was historically viewed as a reasonable target level. However, given the uncertainties in assessing stock status and natural stock variability, practical experience and scientific analysis has shown that treating F_{MSY} as a target often results in depletion of fish stocks, and that recovery from over-depletion is difficult (Caddy and Agnew, 2004). The use of MSY as a target is also often sub-optimal economically.

A similar overall catch can be taken for lower total effort where biomass is greater than B_{MSY}. The greatest economic benefit generally occurs in this state too (unless unusual circumstances occur), while the fish caught within the fishery will also tend to be larger and the ecological impact lower. As a consequence of these observations, the Precautionary Approach states that 'the fishing mortality rate which generates MSY (F_{MSY}, and consequently the biomass at MSY (B_{MSY}) that would result at equilibrium) should be regarded as a minimum standard for limit reference points. Therefore, targets equating to biomass levels greater than MSY, and fishing mortality levels less than F_{MSY}, have become common.

Related to this, Optimum Yield (OY) is a harvest concept defined in the US Magnuson-Stevens Fishery Conservation and Management Act. It represents "(a) the amount of fish which will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems; (b) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor; and (c) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery."

Spawning potential ratio

Spawning potential ratio (SPR) is based on the goal that sufficient fish should survive to reproduce in order to maintain the fish population. SPR is the ratio between the number of spawners (or eggs) produced over a recruit's lifetime (given fishing mortality, F and other population dynamics) divided by the number of spawners produced without fishing; as such, it measures the proportional reduction in total potential productivity attributable to fishing. %SPR values are often used as proxies for MSY-related goals. This metric is felt to have advantages in the common situation where knowledge of the stock-recruitment relationship is poor.

Making biological reference points operational

The management yield targets represented by optimum yield (or MSY) need to be translated into their equivalent stock biomass, fishing mortality or other metrics of relevance from routine stock status evaluation. This is commonly done using outputs from the same analytical stock assessment models that are used to identify stock limit reference points.

An example of the use of MSY-related values as a target is the Australian Commonwealth Harvest Strategy Policy (DAFF, 2007). The policy aims to maintain biomass at an average of $1.2B_{MSY}$ or higher (an MEY target proxy; see later), while avoiding the limits of both $0.5B_{MSY}$ and F_{MSY} with high probability.

Target reference points can be set relative to unexploited levels (B_0[2]). Given variability in the stock and environment, and for a given acceptable level of risk, a target $\%B_0$ can be selected so that biomass will be above the limit biomass level with high probability. For example, given the accuracy of most stock monitoring, the biomass target might be set at $40\%B_0$ or above to avoid an (MSY-based) limit of $30\%B_0$.

%SPR is often made operational by presenting in terms of the level of fishing mortality that achieves the selected SPR (F%SPR), for a given fishery selectivity. Calculations have suggested that $F_{50\%}$ (the fishing mortality that gives a 50% reduction in the spawning potential ratio) would provide high sustainable yields and maintain biomass above $25\%B_0$ for most stocks (an MSY proxy), while $F_{40\%}$ could be a reasonable target for stocks with a reproductive longevity greater than 5 yrs (Sainsbury, 2008).

Fishing mortality levels defined by the Optimum Yield (OY) can be used as target reference points, and in the US are commonly related to %SPR. The OY is required to be risk averse so that greater uncertainty corresponds to greater caution in setting harvest rates and catch levels. For example, F_{oy} can be set at a maximum of $F_{40\%}$ (SPR), and is scaled down dependent on uncertainty in knowledge and species biology. A similar approach is taken in the US west coast groundfish fishery, where F_{oy} targets range between $F_{40\%}$ to $F_{50\%}$.

Socio-Economic target reference points

Many fishery management statements specifically indicate desired (socio-) economic situations, for example, "maximising economic returns" (e.g. Australian Fisheries Management Act, 1991).

[2] the average biomass that would be present in the absence of fishing (unexploited biomass). In the WCPFC stock assessments, B_0 is also calculated using estimated model parameters, but assuming that fishing mortality was zero (the dynamic biomass in the absence of fishing; $B_{tF=0}$). This incorporates recruitment variability, acknowledging the possibility for reduced recruitment in exploited populations through stock-recruitment effects.

To achieve these goals, a commonly referred to economic reference target is MEY, which represents the level of effort that maximises profits - i.e. the difference between total revenue and total costs (the vertical dashed line in Figure 2). This can refer to the fishery specifically, or be expanded into the maximum economic benefits to society as a whole.

As noted by Ditchmont et al. (2010) MEY, like MSY, is an equilibrium concept, but fisheries and their markets are seldom in that state. Making the MEY concept operational requires models that take the dynamics of stocks, costs and prices into account. Compared to complex biological models, which are fed by considerable long-term data collection programmes, economic data are harder to obtain, particularly across vessel types in international regional fisheries such as those of the WCPFC. They need regular updating due to uncontrolled factors (e.g. the price of fuel as a global commodity) and are difficult to predict when analysing potential future performance.

As noted by Norris (2009; SC5-ME-WP-01), determining MEY becomes further complicated in WCPO tuna fisheries, due to the alternative aims of different fishery stakeholders. While vessel owners may wish to achieve maximum financial returns, an individual country may be focused on obtaining the highest possible access fees from licenced vessels, and wider income from value-added components such as employment and onshore infrastructure development (social objectives).

Calculating MEY in a multispecies fishery is complex, and the optimal fishing mortality for a target species may drive others to unsustainable levels. Multi-fleet fisheries add further complexity in both data requirements and the resulting calculations, since they are likely to have different cost structures and target various overlapping species groups.

The Australian Fisheries Harvest Policy targets, as noted earlier, translate MEY targets into operational biological targets through proxies such as $B_{MEY} = 1.2\ B_{MSY} = 48\%\ B_0$. However, these have generally been estimated from single species theoretical models. Their validity in multi-species fisheries is not yet clear, but are unlikely to be correct for most species.

There are few specific social target reference points in fisheries. Social considerations are frequently combined with desirable economic levels. For example, the calculation of MEY or related values may include the benefits of the entire fisheries sector, including catching, processing, market and distribution, which will include issues of employment. Indeed, many of the choices of economic and biological reference points include an implicit, rather than explicit, consideration of social issues such as the sustainability of subsistence fishing, employment within the fishery sector, or national food security (see FAO, 1999, for additional social criteria).

Socio-economic considerations also feature in harvest control rules (see paper MI-WP-03), where the annual allowable rate of change in the level of fishing mortality may be reduced, or the length of time a fishery is allowed to take to rebuild from an over-exploited state under pre-defined recovery plans extended due to social considerations, For example, in the US the rebuilding time for a stock can be adjusted upwards to a maximum of 10 years for ‘socio-economic’ reasons, allowing employment to be maintained under situations where a shorter rebuilding time might require closure of the fishery (see also Berger et al., 2012; SC8-MI-WP-03).

Empirical reference points

'Classical' reference points for quantities of direct interest (biomass, fishing mortality) are generally stock assessment 'model-based' estimates. Empirical reference points, in contrast, relate to directly measurable quantities such as catch, catch rate, or size composition of the catch. While the use of empirical reference points is not widespread (although see Maunder and Deriso, 2007, for eastern Pacific skipjack, and NRLMG, 2010 for New Zealand rock lobster) they have the advantage of being easily understood and communicated, are often simpler and cheaper to apply, and may indicate changes in the fishery faster than the results of a stock assessment model. On the other hand, empirical indicators may integrate a number of population processes and be difficult to interpret, e.g. a stable CPUE could occur as stock biomass declines and fishing power or catchability increases.However, where stock assessments are not performed frequently, empirical indicators may monitor stock health in the interim, triggering both management action and new analytical stock assessments to improve knowledge of stock status when necessary.

With empirical indicators, specific variable levels are selected to act as limits, targets or desirable ranges to remain within, in order to judge fishery status and hence the need for management action. For example, where CPUE levels are above agreed catch rate limits, the stock is assumed to be exploited sustainably. If CPUE falls below that limit catch rate, action is taken to reduce the fishery impact. Levels can also link to economics; for example setting management rules to ensure that catch rates do not fall below current levels should maintain similar levels of profitability in fisheries.

A primary concern is to ensure that selected indicator levels provide a reliable indication of the management quantities of key interest - e.g. stock biomass and fishing pressure. In the example of CPUE above, it assumes there is a direct link between catch rate and stock size, that changes in the ability of vessels to catch fish (and hence change the relative relationship between stock size and CPUE) is taken into account, and that (for example) environmental influences will not unduly bias the relationship.

As an example, Punt et al. (2001) tested empirical reference points for a broadbill swordfish fishery off eastern Australia. The examination included trigger reference points based on catch rates, and percentiles of the fish length and fish weight distribution in the catch. The results indicated that management based on these empirical reference points had potentially high rates of failure. Action could be triggered when it was not needed, or not triggered when it was required. Therefore the selection of the trigger points becomes critical; as noted by Sainsbury (2008) a risk-averse selection increases the protection of the stock, but at low exploitation rates and low yields from the fishery. These empirical reference points were extended to use catch rate and catch size distribution, combined with a detailed set of management decisions which separated the different causes of change in the indicator and hence appropriate management action (Davies et al., 2007; see also Campbell et al., 2007 SC3-ME-WP-4). The framework of reference points and management action was tested using simulation approaches (see below) and found to meet the Australian Commonwealth Harvest Strategy Policy.

Target setting: considerations

Along with decisions on the desired target and limits for the fishery/stock, there are a number of additional concepts that fisheries managers should consider.

Uncertainty and Risk

Even for the best-studied fish stocks and fisheries, uncertainty in biological, environmental, and fishery components, along with our ability to collect data on and hence accurately estimate key values of interest within those components, can be high. Readers should refer to Harley et al. (2012; SC8-MI-WP-01) for evaluations of limit reference points and associated risk in WCPO stocks.

The precautionary approach states that 'fishery management strategies shall ensure that the risk of exceeding limit reference points is very low'. The acceptable numerical level of risk of a fishery breaching the limit reference point when aiming for the target level is a management decision (see also Harley et al., 2012; SC8-MI-WP-01). The level of risk should be influenced by the level of knowledge available within the fishery. Under the precautionary approach, in fisheries with limited information and hence uncertain stock status, targets should be conservative (i.e. not close to the limit reference points) until knowledge improves. Operational targets may therefore require adjustment to be consistent with agreed constraints (limits) and risks (i.e. targets are not so close to limits that the chance that limits are exceeded are greater than the agreed level of risk).

It should be noted that a target reference point that is close to a limit reference point may give good management outcomes if there is accurate monitoring of the stock combined with quick and effective management responses as the target is exceeded or the limit is approached. But the same target reference point is likely to lead to poor management outcomes if the monitoring and management response is poorly directed, ineffective or slow. Therefore the performance of the reference point framework and acceptable levels of risk must be considered within the structure of the fishery management system as a whole.

Trade offs

The definition of targets requires a consideration of the trade-offs between management objectives (e.g. stock sustainability, maximising economic factors, ensuring social benefits) and multispecies-multifleet fisheries. As noted above, maximising economic benefits from a target species may allow fishing at levels that reduce bycatch species to low levels. In this example, the status of bycatch species have been traded off in favour of optimising benefits from the target species. To allow testing of the performance of potential reference points and management regimes, quantifying the acceptable trade-offs between different goals is therefore important.

Updating reference points

The value of reference points may need updating, based on changes in the fishery, the biology of the stock, or the ecosystem. For example, long-term persistent changes in ecosystems or ‘regime shifts’ (e.g. Scheffer et al. 2001) may lead to changes in the reproductive capacity of species, and hence their resilience to fishing. In a similar way, the value of reference points may be affected by changes in fishery structure and/or their selectivity.

Review Summary

From the discussion above, some general concepts fall out:

- Limit reference points represent undesirable stock situations (where stock reproductive status is reduced) to be avoided;
- Target reference points represent a desirable state of the stock to be achieved on average;
- Target reference points should be separated from limit reference points with an appropriate buffer;
- Targets are set so that, if they are achieved on average, there is a low chance that reasonable expectations of natural variability, in combination with the fishery, will result in the limit being approached or exceeded;
- Rules used to set targets should explicitly be risk averse, so that greater uncertainty regarding the status or reproductive capacity of a stock corresponds to greater caution ('safety margins') in setting targets;
- It is the role of fishery managers to define the candidate fishery management systems (targets, levels of risk, harvest control rules). It is the role of scientists in the process to evaluate the fishery system in this way to identify whether the targets are likely to be achieved.

Evaluating potential skipjack target reference points in the WCPO

We selected a limited range of potential target reference points for skipjack tuna in the WCPO for evaluation using stochastic population projections, based upon the above discussion. The aim of this section is to provide examples of the issues involved in selecting and evaluating target reference points in relation to limit reference points and the overall consequences for the fishery. It is not designed to provide definitive advice on the 'best' target reference points for the skipjack stock; this requires greater discussion on manager's desired outcomes from the fishery, as planned for the WCPFC Management Objectives Workshop in late 2012.

The performance of target reference points, corresponding limit reference points, and the harvest control rules selected to achieve the fishery performance defined by those reference points, requires the use of Management Strategy Evaluation (MSE) simulation approaches that incorporate a range of the uncertainties within the fishery system into that evaluation. The current approach captures only a component of future uncertainty due to variability in the potential future population recruitments of the skipjack stock, and therefore the performance of targets relative to limits described below is likely to be optimistic.

Projection approach

The 2011 reference case stock assessment model for WCPO skipjack tuna was used as the basis for the projections (see Hoyle et al., 2011; SC7-SA-WP-04). The population was projected from 2011 onwards for 30 years within 200 stochastic simulations, drawing future recruitments from the recruitment estimates across the 1972-2010 assessment period.

Future stock status was examined for a range of candidate target reference point levels. Multipliers on 2010 fishery conditions (scalars on equivalent catch or effort[3], dependent upon the fishery) were calculated so that the population, on average, achieved the candidate target level by the end of the 30 year projection period; i.e. the same multiplier was used for all fleets after 2010[4]. Six alternative scenarios for candidate target reference points were examined (Table 1):

- 48%SB_0 and 48%$SB_{CurrentF=0}$ (potential MEY proxies);
- 1.2SB_{msy} (another potential MEY proxy);
- SPR50%; and
- current (2010) spawning biomass.

These were compared to a 'status quo' situation, where fishery impacts were maintained at 2010 levels.

The 'performance' of the fishery under the target reference points was examined in three ways:

- The risk involved with each target reference point. The proportion of the years in the 200 simulations in which the stock fell below three candidate limit reference point levels (20%SB_0, 20%$SB_{CurrentF=0}$ and SB_{MSY}) was evaluated;
- To illustrate the potential trade-offs involved in selecting a target reference point, the potential fishery/economic implications were examined. The catch within the tropical purse seine fishery over the projection period was the example performance measure used.
- The implications for the stock biomass vulnerable to particular gears (a proxy for trends in catch per unit effort). The FAD associated purse seine fishery in region 2 (western equatorial region) was used to illustrate the potential change under each scenario.

Projection results

The multipliers relative to 2010 conditions of fishery catch or effort required to achieve each reference point are presented in Table 1. Long-term 2010 conditions (status quo; multiplier = 1) are approximate to those required to achieve an $F_{SPR\_50\%}$ (multiplier = 1.02). To maintain the population spawning biomass at estimated 2010 levels, a multiplier of 0.79 was applied, implying a reduction in fishing impacts relative to 2010 levels. To achieve all other targets examined, an increase in fishing impacts compared to 2010 levels was implied. In particular, the 1.2SB_{MSY} target theoretically required a considerable increase from 2010 fishing impacts to be achieved, when applied uniformly across all fisheries. As noted above, however, the significant impacts on stock biomass from current levels required to achieve that target, by applying a single multiplier across all fleets used in this evaluation led to considerable instability in the MFCL projection. This reduction in spawning biomass may also have biological consequences, which are discussed below.

[3] The multiplier acted on 2010 effort for the majority of fleets. Multipliers on 2010 catch was used for fisheries in Indonesian and Philippines archipelagic waters. For a further example, see Hampton et al. (2012; WCPFC-SC8 -2012/MI-WP-01)
[4] The exception was the 1.2SB_{MSY} target, where applying a consistent multiplier across all fisheries led to a failure of the MFCL projection. A lower multiplier was required for the Region 2 purse seine free school fishery to allow these indicative projections to run. See Table 1.

Achieving and maintaining the stock at each of the five candidate target reference points kept the projected skipjack spawning stock biomass above both candidate limit reference points with very high probability, under the levels of uncertainty examined within this simulation (Table 2, Figure 3). Only where $1.2SB_{MSY}$ was used as a target reference point did the projected population fall below the SB_{MSY} limit. By the end of the projection period (2040), the population was below this candidate limit in 12% of simulations[5] (Table 2), due to simulated recruitment variability alone.

The mean catch levels in the projected period were examined for the tropical purse seine fishery (regions 2 and 3 of the stock assessment model, FAD and free school 'fisheries' combined) under each target reference point (Figure 4). Average annual future catch in this fishery was projected to be higher than 2010 levels where the $1.2SB_{MSY}$ and either $48\%SB_0$ targets were used. A target of $F_{50\%SPR}$ equated to similar future catches to the status quo scenario, as would be expected from its corresponding multiplier (Table 1), both being lower than 2010 levels. Given the reduction in fishing impacts required to achieve the SB_{2010} target, significantly lower average annual future catches were projected.

The use of different target reference points has potential implications for future fishery catch rates. This can be approximated by examining the vulnerable biomass available to particular fisheries, relative to the levels estimated in the simulated absence of fishing. As an example, the vulnerable biomass available to the 'associated set' tropical purse seine fishery in region 2 of the assessment model (western equatorial region) in 2040 was examined relative to that present in that year in the absence of fishing (Figure 5). All targets implied a depletion of over 50% from estimated equivalent unexploited levels. As expected, there was a negative correlation between the estimated catches resulting from the use of alternative targets (Figure 4), and the corresponding catch rates. For example, a target of $1.2SB_{MSY}$ implied greater decreases (to 24%) in vulnerable biomass (and hence CPUE) than all other targets. Status quo resulted in a median reduction to 43% of equivalent un-fished conditions. The lowest reduction in potential CPUE resulted from a target of SB_{2010} (49% of un-fished levels), the scenario that resulted in the lowest future catch.

Initial examination of empirical indicators for the WCPO skipjack stock

For empirical indicators, such as those based upon catch rates, to have utility as the basis for a reference point, they need to reflect the status of the stock in question. We examined a range of candidate empirical indicators for skipjack in the WCPO relative to the status of the stock (annual SB/SB_{MSY}) and fishery impact (F/F_{MSY}) indicated by the 2011 reference case stock assessment (Hoyle et al., 2011; SC7-SA-WP-04). The indicators examined across the period 1979 to 2010 were based upon the activities of the tropical purse seine fishery:

- the number of sets;
- the number of days fished (defined as a set made or spent searching);
- the number of sets with no catch of SKJ;
- the proportion of sets with a successful (non-zero) SKJ catch;
- the number of fishing days with no catch of SKJ;
- the proportion of days with a successful (non-zero) SKJ catch;

[5] As an alternative metric, across all projected years across the 200 simulations, this limit was breached in 641 of 6000 simulated years (11%). Note that this number includes those initial projection years where the fishery was well above and moving towards the target.

- the annual catch of SKJ (from raw logsheet data);
- the number of sets per day fished;
- the average skipjack catch per set, and per day fished;
- the mean size of fish above a particular size 'fully recruited' to the fishery in the FAD or free school purse seine fishery (1993-2010 only).

A priori relationships between trends in these indicators and skipjack stock status can be assumed (Table 3). The resulting trends are presented in Figures 6a to 6l. In the left hand panels, the pattern of each indicator over time is overlaid by the F/F_{MSY} and SB/SB_{MSY} time series. In the right hand panels, the indicator and stock status ratios are scaled so that the largest value of the indicator seen and the largest impact on the stock seen within the assessment period (i.e. maximum F/F_{MSY} or SB_{MSY}/SB, where the larger the value of the ratio, the greater the impact on the stock) are both equal to 1. The red line in the latter plots represents a lowess smoother fit through the data; the anticipated relationship between the indicator and stock status ratio is indicated by the dotted straight line (see Table 3).

Of the indicators examined, the number of sets, the number of fishing days and number of sets with zero skipjack catch[6], the logsheet annual skipjack catch, and to a lesser extent fishing days in a year, showed a relationship with the F/F_{MSY} in that year. This was clearest in more recent years where the change in annual F/F_{MSY} is higher.

The number of sets or fishing days in a year are direct measures of fishing effort. While related to fishing mortality, the relationship may not be linear: catchability in the assessment is not constant for purse seines, and issues such as effort creep need to be considered. In turn, sets and days do not take into account any targeting or use of FADs, nor do they currently incorporate any scaling for the potential impact of individual vessel size on the stock, a measure that has been shown to be important through the PNA's purse seine Vessel Days Scheme.

The catch of skipjack in a year, and the number of sets or days with zero skipjack catch, will be affected by the degree of targeting and FAD use within the fishery as well as the state of the stock. Management actions such as the FAD closure periods of recent years may bias any relationship between stock size and an indicator. Examining free school fisheries during particular periods of the year may prove useful.

In contrast to F/F_{MSY}, no clear linear relationship was found between the indicators selected and the corresponding scaled SB_{MSY}/SB ratio. In part this may result from the fact that the signal of fishery impacts in the spawning biomass may take a number of years to be manifest. While some of the indicators examined appear to capture fishery impact, signals for underlying stock size relative to MSY are less clear over the range of values in the indicators examined within this analysis.

Nominal catch rates (catch per set, or catch per day) generally increased over time within the fishery. They therefore show a trend opposite to that expected; catch rate increases as fishery impact is assessed to have increased. This may reflect improvements in fishery targeting and operations, and hence in further work is needed to standardise CPUE to remove such artifacts. There remains much discussion on suitable CPUE measures for purse seine fisheries that can reasonably reflect stock status.

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[6] but not the proportion of sets or days with non-zero skipjack catch

Scaled mean size of skipjack in the catch shows a lack of contrast compared to the fishery impact measure. This may result from the shortened time series that was available, or may indicate that inter-annual variability due to recruitment variation and other factors may mask any information in this indicator. Other measures of size (e.g. upper 95^{th} percentile) may provide a stronger signal of fishery impacts and stock status. However, interpreting the signal given by size trends can be difficult. A decline in mean size, for example, could indicate higher fishing mortality, or an increase in recent recruitment levels. Both positive and negative processes for stock health can therefore produce similar indicator signals.

Discussion

The simple evaluation performed above indicates the trade-offs that need to be considered by managers when selecting target reference points.

All candidate target reference points met the criterion of biological risk relative to the limit candidate $20\%SB_0$, maintaining the population above that level in all simulations. Only the candidate target reference point of $1.2SB_{MSY}$ resulted in the population falling below the SB_{MSY} limit in 2040 in 12% of runs. Dependent on the manager's acceptable level of risk and selected limit reference point, the latter performance may be unacceptable. Indeed, the uncertainties examined within these projections are limited, and the risk of falling below the limits is likely higher for all candidate targets.

The range of target reference points examined had very different potential consequences for both future catches and future fishing effort levels. The candidate target $1.2SB_{MSY}$ requires greater fishing impacts to achieve it and results in future average catches ~5% higher than 2010 levels. This may imply for example increased potential employment in the processing sector, and potential licence revenue (noting that fishing impacts does not necessarily equate directly to boats on the water). However, it conversely implies potentially significantly lower catch rates and hence industry profitability, compared to other targets. The opposite is seen in the case of a target such as SB_{2010}, with around 10% lower future catches but around 5% higher vulnerable biomass than the status quo. Other targets (e.g. $48\%SB_0$ or $48\%SB_{currentF=0}$) may imply lower increases in fishery impact, some increases in future catches, but some negative implications for catch rates.

It should also be noted that high fishery multipliers, like those required to achieve $1.2SB_{MSY}$, have biological implications. The resulting higher fishing mortalities will reduce the stock size, and likely result in the capture of smaller fish. This may have consequences for fishery revenue in the absence of market adjustments, and potential changes in the spatial distribution of the stock, with corresponding potential implications for domestic and distant water fishing operations.

The empirical indicators examined showed varying power to provide a (linear or non-linear) signal of fishery impact (F/F_{MSY}) and no clear power to signal instantaneous stock status (SB/SB_{MSY}). Refinements to the indicators, as discussed above, might improve their performance. Other indicators are also of interest, including skipjack catch rates in other fisheries (e.g. pole and line, noting the lack of spatial overlap with the majority of the skipjack fishery) and information from tagging. Furthermore, economic indicators could be developed from some of the metrics examined, where financial data are available. A minimum CPUE, developed on a financial basis, could provide a useful indicator and trigger for management action. This measure would either need to be standardised, to take into account both operational and environmental variability, or the risk of falling below that trigger CPUE due to chance needs to be carefully considered.

The comparatively short life history of skipjack may imply a greater power for indicators to signal stock status and fishery impact (although the evidence of the former is currently limited). For other tuna species, with longer life histories, that power may be reduced. Where a relationship is identified between an indicator and stock status, it must be ascertained whether it holds both in a declining (fishing down) phase, and in an increasing (recovery) phase. An incorrect assumption that the relationship holds could lead to poor future performance.

This paper provides a background to candidate target reference points, their selection, and some of the issues to consider. It does not identify which target reference point is 'best' for WCPO skipjack. As noted throughout, target reference points should be defined by managers based on their desired goals for the fishery, not purely on the likely ability of a selected target to avoid breaching selected limit levels with high probability. This is demonstrated by the presented evaluation of alternative target reference points through three performance measures (spawning biomass, future catch, future vulnerable biomass). Ultimately the measures to be examined when evaluating the performance of target reference points should be linked to the manager's aims for the fishery - be they biological, economic and/or social. In turn, as demonstrated, managers need to consider the 'acceptable' trade-offs between these and other factors when selecting a target reference point.

Next steps

OFP, SPC will be guided by the discussions at SC8 on future work in this area for presentation to the planned WCPFC Management Objectives Workshop. In particular, feedback is sought on:

- the planned goals of fishery managers to help identify new candidate target reference points for evaluation and presentation;
- performance measures of interest to managers for evaluation, to allow a fuller analysis of the trade-offs involved in the choice between different target reference points, and the timeframe for which they should be calculated (short-, medium- or long-term, or in specific years of the simulation). In turn, discounting approaches could be used to 'down-weight' future catches compared to near-future catches;
- definition of the limit reference points to be used within the evaluations;
- alternative empirical indicators for examination.

Potential areas of further work by OFP, SPC in this area could:

- more fully capture uncertainties within the fishery system in the projections performed. Refer to the fuller discussion on this subject in Harley et al. (2012; SC8-MI-WP-01);
- incorporate the estimated skipjack stock recruitment relationship to better capture the impact of declines in stock size on future recruitment;
- consider the use of fishery-specific scalars, noting the issues in a blanket multiplier across all fisheries that arose in the $1.2SB_{MSY}$ target projections. This may be defined by how managers in different fishery components (PNA, non-PNA) plan to manage those relative components.

- consider multispecies issues. The effort increases involved in achieving a 1.2SB_{MSY} target for the skipjack stock could have significant impacts on bycatch species. This would require greater consideration of the future multipliers for fisheries in projections from the relevant species stock assessments. Given that the different species' stock assessments have different fleet structures, an approach to making the multipliers consistent across those different fleets would be required.

This work will link closely with the activities examining harvest control rules.

As noted above, ultimately the process would benefit from the full evaluation of the performance of selected target and limit reference points - combined with any harvest control rule - for their robustness to uncertainties within the fishery system through MSE simulation.

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Table 1. Candidate reference levels evaluated, based on the 2011 SKJ 'reference case' stock assessment (Hoyle et al., 2011).

Reference level	Limit or target	Multiplier on 2010 fishery conditions	Estimated F/F_{MSY_2040}
$20\%SB_0$	Limit	-	-
SB_{MSY}	Limit	-	-
Status quo	-	1.00	0.52
$1.2SB_{MSY}$	Target	3.01*	0.96
$48\%SB_0$	Target	1.16	0.58
$48\%SB_{CurrentF=0}$	Target	1.28	0.62
$SB_{(2010)}$	Target	0.79	0.44
$F_{SPR50\%}$	Target	1.02	0.53

* separate multiplier for the purse seine free school fishery in geographic region 2 of the assessment model = 1.45. See main text for details.

Table 2. Probability of falling below the candidate limit reference points (proportion of simulations where the population is projected to be below the limit in the year 2040) when the relevant target is achieved on average in 2040.

	$1.2SB_{MSY}$	$48\%SB_0$	$48\%SB_{CurrentF=0}$	SB_{2010}	F_{SPR_50}
$20\%SB_0$	0.0	0.0	0.0	0.0	0.0
$20\%SB_{CurrentF=0}$	0.0	0.0	0.0	0.0	0.0
SB_{MSY}	0.12	0.0	0.0	0.0	0.0

Table 3. Anticipated relationship between an increasing indicator value and corresponding impact on the skipjack stock.

Indicator	**Expected stock impact with increasing indicator value**
Number of sets/year	Negative
Number of days fished/year	Negative
No. sets with no SKJ catch	Negative
Proportion of sets with successful catch of SKJ	Positive
No. days with no SKJ catch	Negative
Proportion of days with successful catch of SKJ	Positive
Annual total catch of SKJ	Negative
No. sets per day fished	Uncertain
Avg skipjack catch/set	Positive
Avg skipjack catch/day	Positive
Mean size of fish in catch	Positive

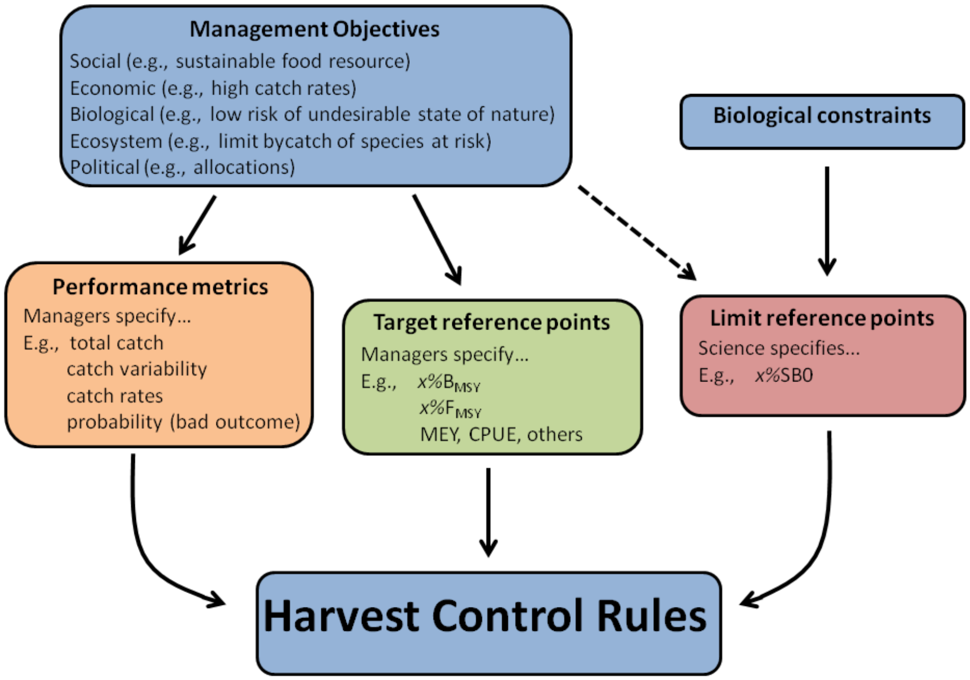


Figure 1. Conceptual model of how management objectives and biological constraints inform the development (reference points) and guide the selection (performance metrics) of harvest control rules. Abbreviations: B: biomass, SB: spawning biomass, F: fishing mortality, MSY: maximum sustainable yield, MEY: maximum economic yield, CPUE: catch-per-unit-effort.

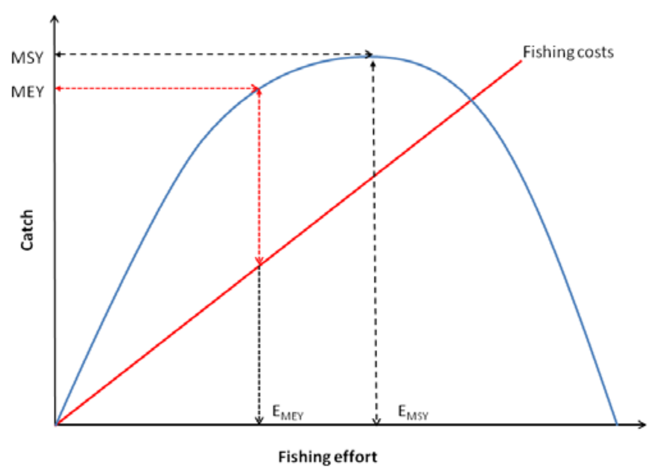


Figure 2. Hypothetical equilibrium effort/yield curve showing MSY and MEY fishing levels and corresponding equilibrium catch.

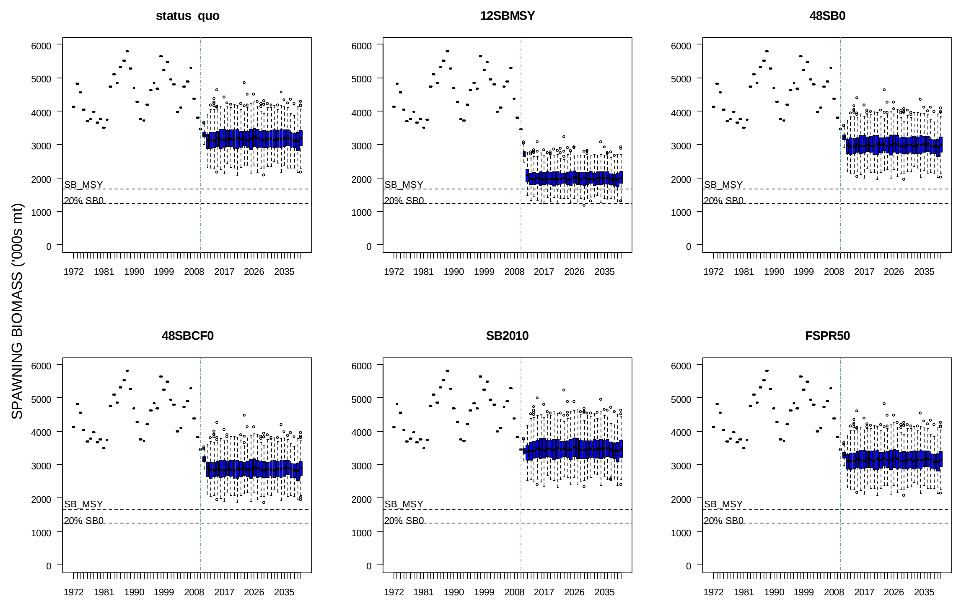


Figure 3. Box plots of annual spawning stock biomass of WCPO skipjack under the five examined candidate target reference points, relative to the two examined limit reference points (SB_{MSY} and $20\%SB_0$, dotted horizontal lines) based on stochastic projections drawing from recent average recruitment.

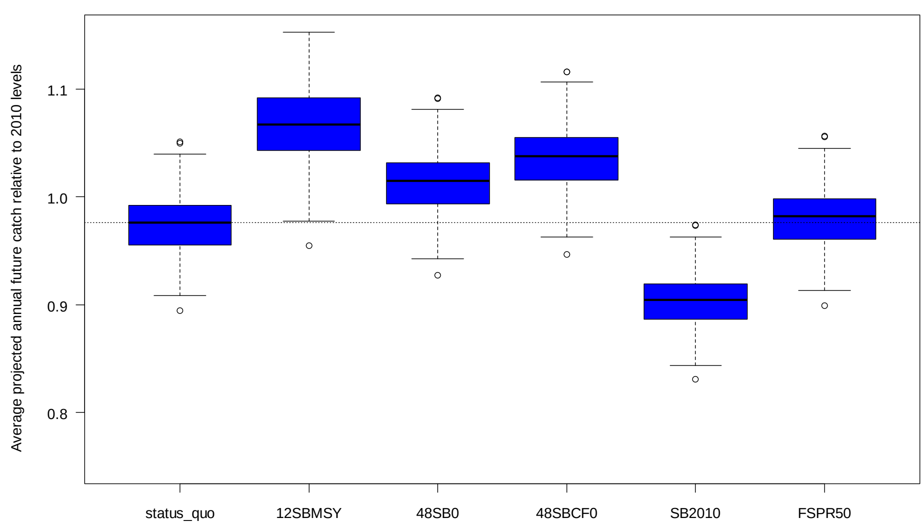


Figure 4. Box plot by candidate target reference point of average annual (2011-2040) projected catch from the WCPO skipjack stock within the tropical purse seine fishery (FAD and free school 'fisheries' combined), relative to the catch in 2010. Median represented by the horizontal line. Boxes represent the 25th, and 75th percentiles, whiskers show 5th and 95th percentiles. Horizontal dotted line represents the median catch under the status quo scenario.

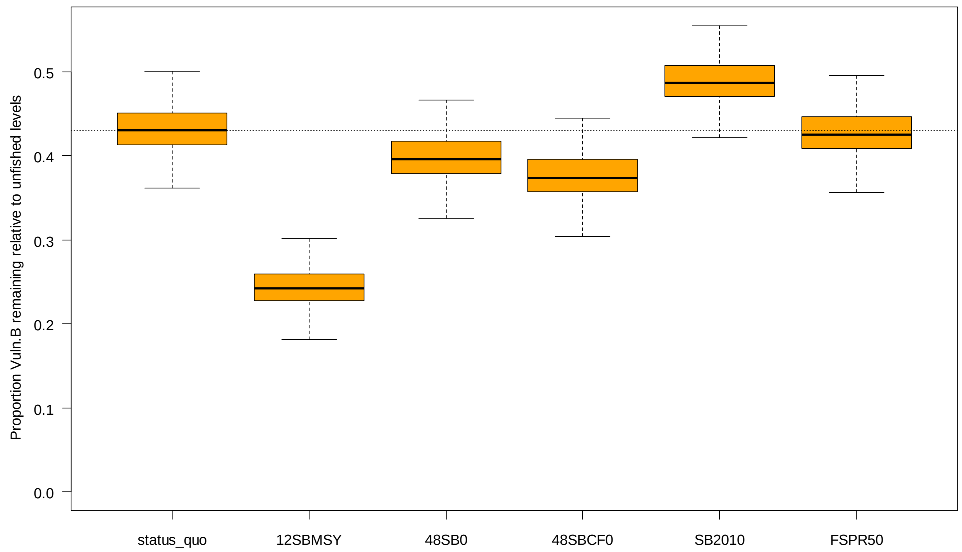


Figure 5. Box plot of the depletion of the vulnerable biomass in the Associated tropical purse seine fishery in region 2 in 2040, relative to calculated unfished levels in 2040, by candidate target reference point. Boxes represent the 25th, and 75th percentiles, whiskers show 5th and 95th percentiles. Horizontal dotted line represents the median remaining under the status quo scenario.

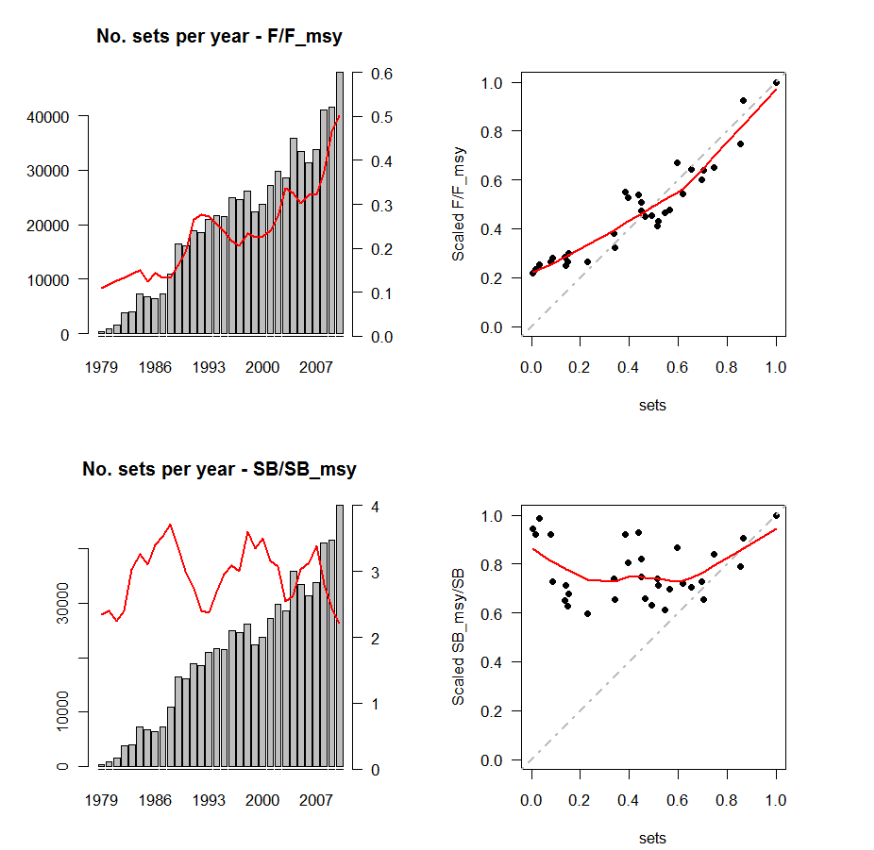


Figure 6a. Left panels: time series of purse seine sets per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled sets per year (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

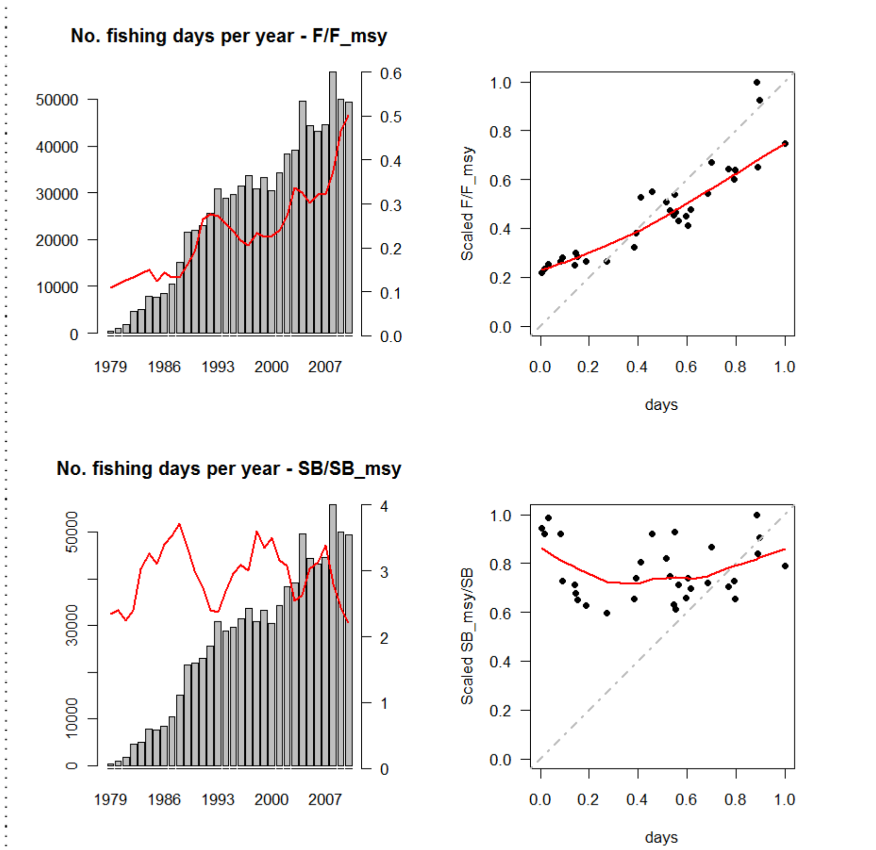


Figure 6b. Left panels: time series of purse seine days fished per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled days fished per year (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

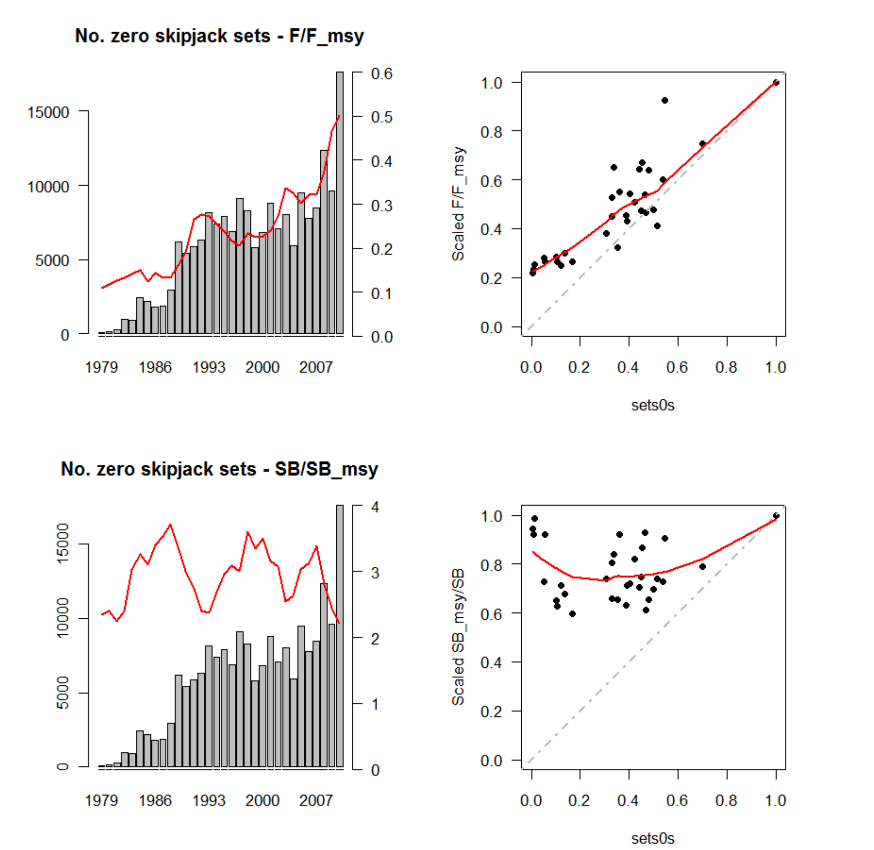


Figure 6c. Left panels: time series of number of sets with no skipjack catch per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled number of sets with no skipjack catch (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

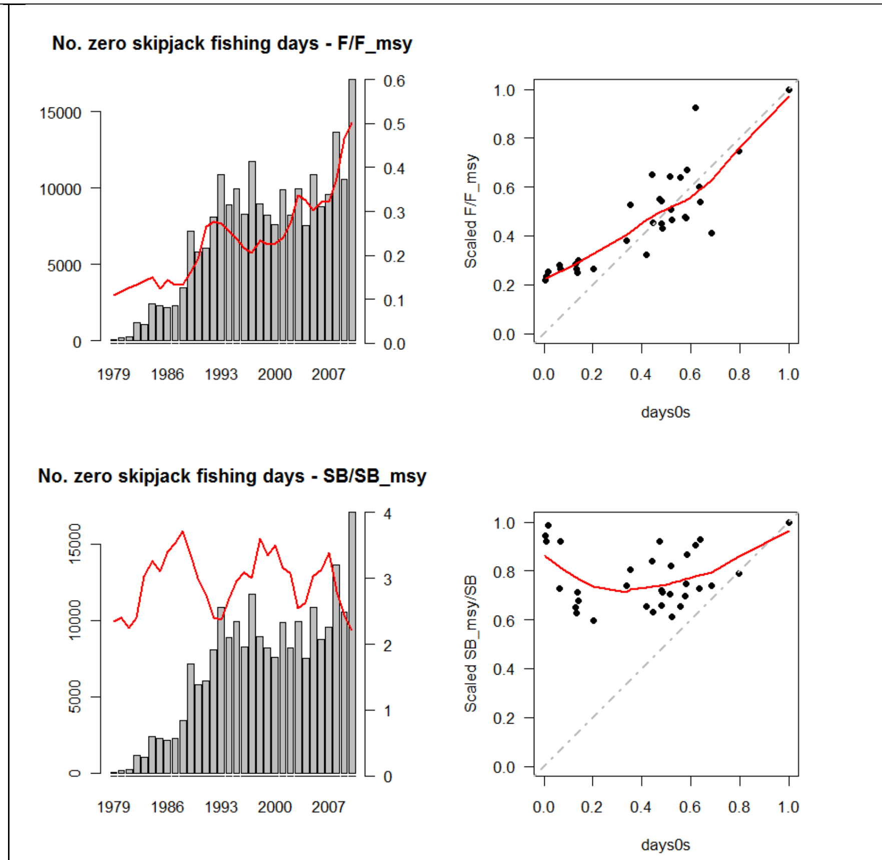


Figure 6d. Left panels: time series of number of fishing days with no skipjack catch per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled number of days with no skipjack catch (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

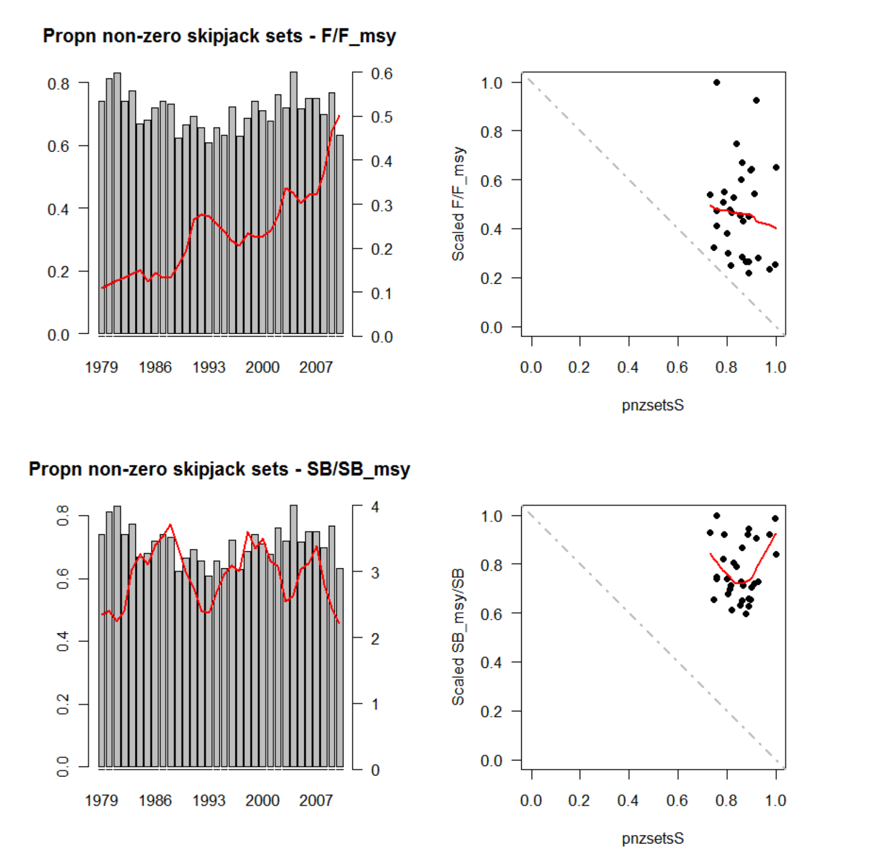


Figure 6e. Left panels: proportion of sets with successful skipjack catch per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled proportion of sets with successful skipjack catch (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

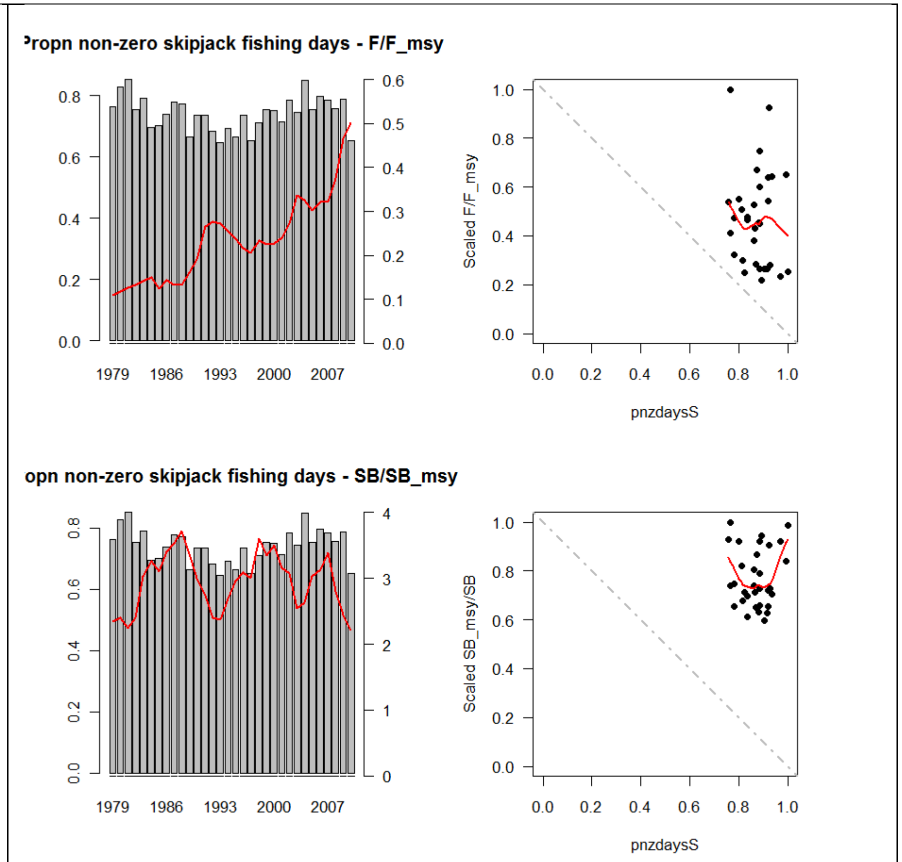
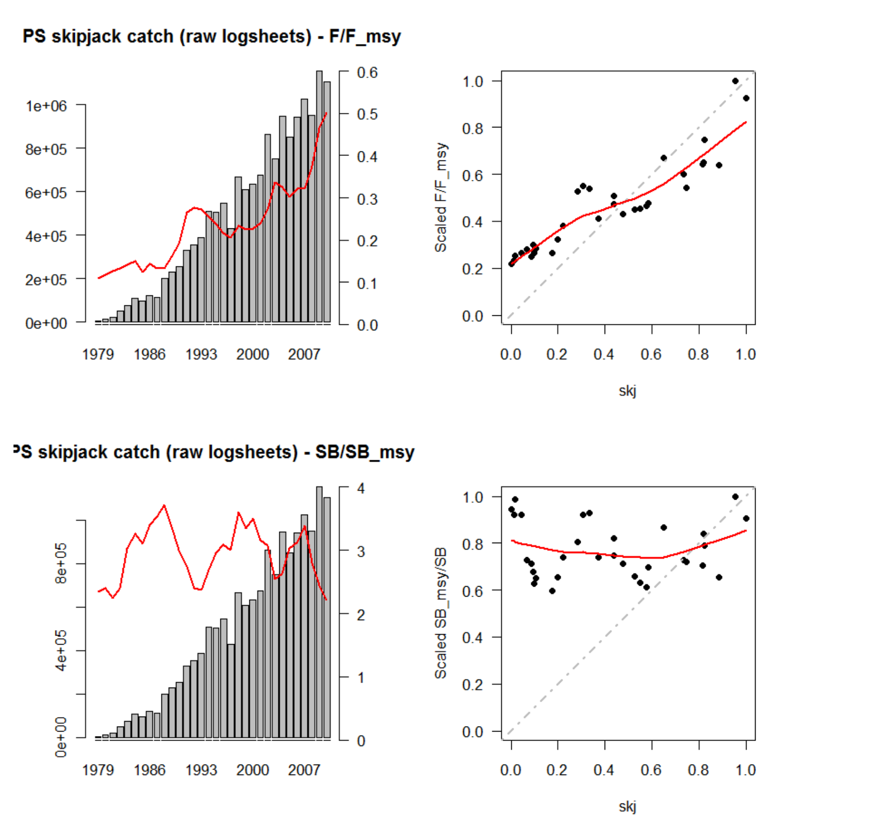


Figure 6f. Left panels: proportion of fishing days with successful skipjack catch per year, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled proportion of fishing days with successful skipjack catch (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.



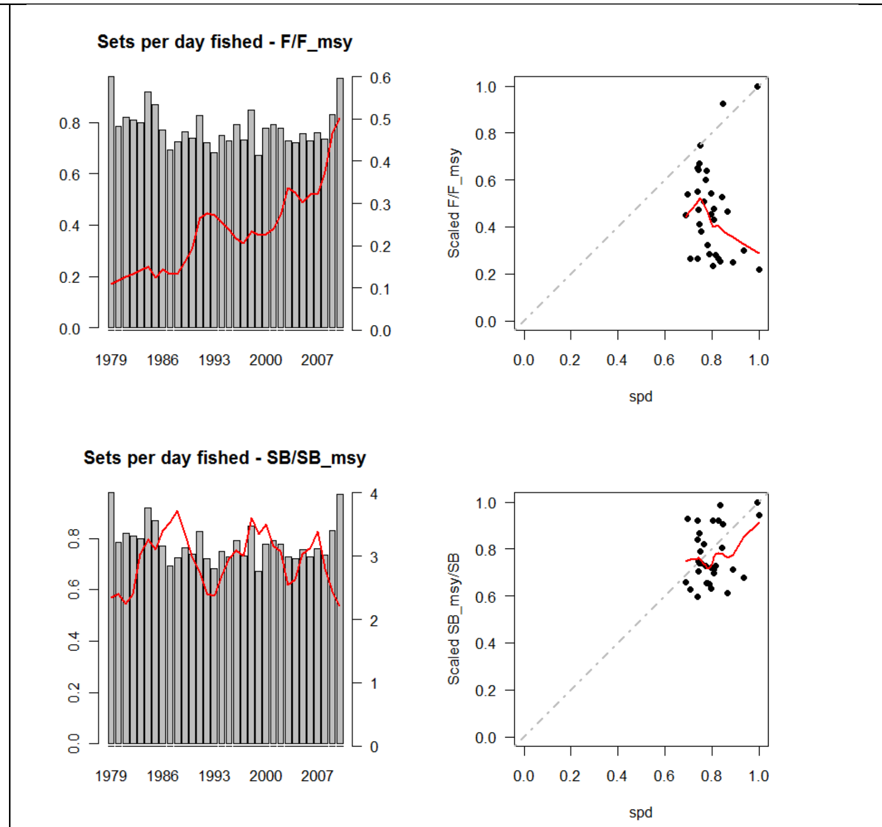


Figure 6g. Left panels: annual raw logsheet skipjack catch, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled annual raw logsheet skipjack catch (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

Figure 6h. Left panels: average sets per day fished, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled average sets per day fished (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

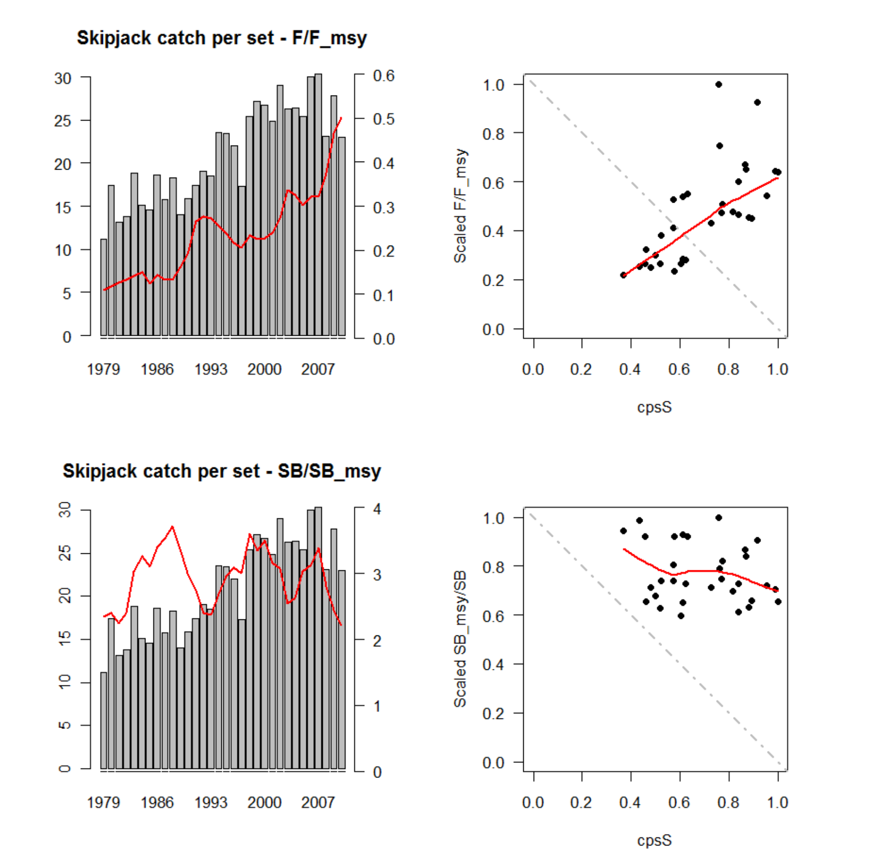


Figure 6i. Left panels: average skipjack catch per set, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled average skipjack catch per set (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

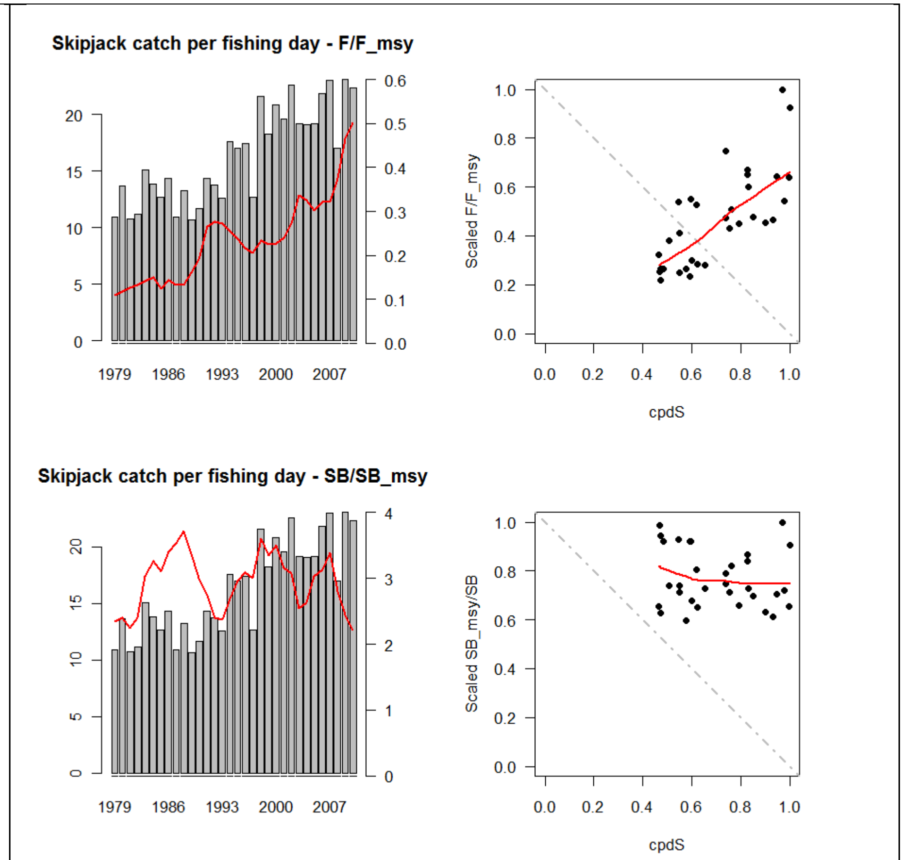


Figure 6j. Left panels: average skipjack catch per fishing day, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled average skipjack catch per fishing day (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

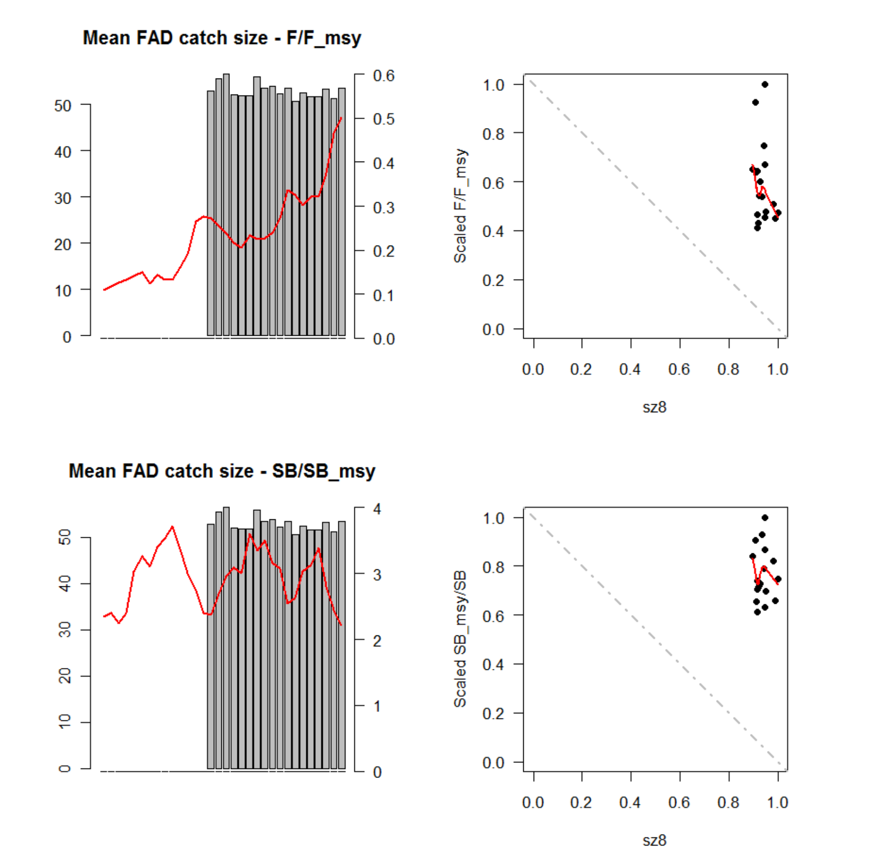


Figure 6k. Left panels: average size of skipjack caught in FAD-associated sets, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled average size of skipjack caught in FAD-associated sets (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.

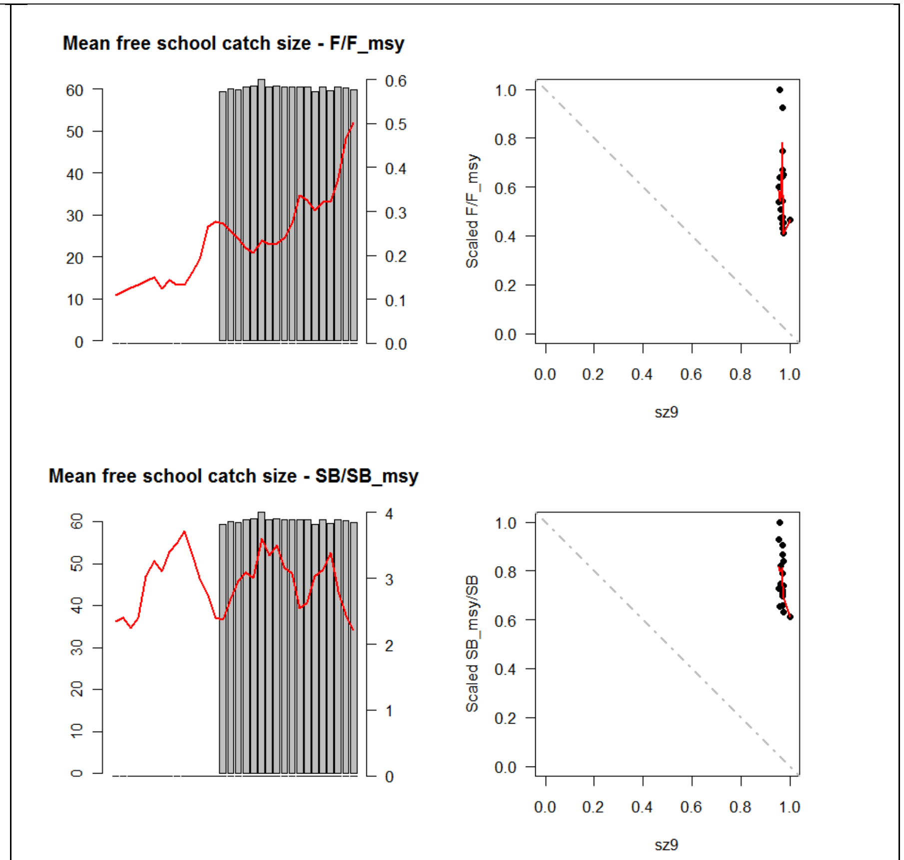


Figure 6l. Left panels: average size of skipjack caught in free school sets, relative to assessed F/F_{MSY} and SB/SB_{MSY}.
Right panels: scaled average size of skipjack caught in free school sets (1=max. in the time series) vs scaled F/F_{MSY} (top) and SB_{MSY}/SB (bottom) where 1=max. stock impact assessed.