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## REVISITING TARGET REFERENCE POINTS FOR TROPICAL TUNAS IN THE EPO

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**SUMMARY**

Target and limit reference points are an important part of contemporary fisheries management. Although the Antigua Convention provides little guidance on reference points, it commits the IATTC to applying the precautionary approach in accordance with the United Nations Fish Stocks Agreement (UNFSA), which offers some guidance on the definition and use of reference points. Unfortunately, it could be argued that this guidance is somewhat contradictory. For tropical tuna in the EPO, IATTC Resolution C-16-02 formalized a harvest control rule with interim target and limit reference points, with target reference points corresponding to Maximum Sustainable Yield (MSY). The reference points have been used for yellowfin and bigeye tuna. This resolution was amended by IATTC Resolution C-23-06 to include the use of interim *proxy* target reference points due to the difficulty in defining MSY-based target reference points for skipjack tuna. The reference points are explicitly included in the operational harvest control rule, both as the applied fishing mortality rate and as probability-based trigger points and rebuilding targets.

MSY based reference points are conditional on the size of the fish caught and therefore can change as the proportion of catch varies among the different fleets that catch different fish sizes. This is a particular concern for bigeye tuna in which small fish are caught in the floating-object purse-seine fishery and large fish are caught in the longline fishery. The increase in catch from the purse-seine fishery during the mid-1990s greatly reduced the MSY available from the stock. In addition, the target biomass reference point is estimated at a stock size that is highly depleted, particularly when recruitment is assumed to be weakly related to the adult stock size, and this has been exaggerated ($B_{\mathrm{MSY}}$ corresponds to 17% of the unfished level in some stock assessment scenarios) in the most recent assessment due to changes in the assumptions about age-specific natural mortality, assumed now to have higher natural mortality for immature fish than in previous assessments (SAC-15-02). This estimated highly depleted stock level at MSY has raised concerns about the definition of the target reference point. A more global approach to defining MSY, which is designed to support a range of proportioning of catch among the fleets, supports a less depleted biomass (30%). This is consistent with the 0.3 *proxy* previous proposed by the staff and could be used as an interim target reference point until discussions under a comprehensive Management Strategy Evaluation process determine target reference points based on a variety of objectives.

**INTRODUCTION**

Target and limit reference points are an important part of contemporary fisheries management and are an integral component of most, if not all, ecolabeling and consumer-based certification programs. The Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fishing, recommends that Regional

Fisheries Management Organizations (RFMOs) should adopt, on the basis of the best scientific information available, stock-specific target and limit reference points, and corresponding management actions. Reference points are used as both performance measures and as part of harvest control rules. For example, the status of stocks as determined by management agencies, certification bodies, or other organizations (e.g. FAO and NGOs) are often determined by target reference points or related quantities. The definition of target and other reference points should take into consideration their intended use.

Maximum Sustainable Yield (MSY) is commonly used to define target reference points. MSY is defined as the maximum yield that can be sustained from the stock on a long-term basis and is typically calculated using equilibrium conditions. MSY is a function of the stock's biology (growth, natural mortality, and the stock-recruitment relationship) and size/age of the fish caught (availability and/or selectivity). In particular, MSY is conditional on the age-specific fishing mortality used for its calculation and is typically taken as recent levels. When different fishing methods that catch very different sized fish act on the same stock, as is the case for many tuna stocks, MSY based reference points become complicated to interpret. In addition, objectives other than maximum yield, such as socio-economic objectives, might become important to consider.

The IATTC's Antigua Convention has little direct guidance on the definition and use of reference points, stating only that populations should be maintained or restored at levels of abundance which can produce the maximum sustainable yield. However, the convention commits the IATTC to applying the precautionary approach, in accordance with the United Nations Fish Stocks Agreement (UNFSA), which provides some guidance on the definition and use of reference points. Through adoption of resolutions, target reference points have been defined by the IATTC as those corresponding to MSY. When adopted, the Commission noted these reference points as interim, although these reference points have become well established for yellowfin and bigeye in the EPO.

Here we revisit target reference points for tropical tunas in the EPO and address 1) how they are defined in the IATTC convention, 2) how they are used by the IATTC, and 3) the important issue of the sizes of fish caught. Then we discuss the definition of target reference points in the context of bigeye tuna in the EPO.

**How target reference points are defined in the IATTC convention**

Much of this interpretation of how reference points are defined in the IATTC convention comes directly from an earlier SAC report that discussed reference points in the context of managing tuna stocks in the EPO (Maunder, 2013).

Article VII 1I of the IATTC's Antigua Convention states that "[The Commission shall perform the following functions…] to maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield". Resolution C-16-02 interpreted this to mean that the target reference points are those corresponding to MSY.

The Antigua Convention also commits the IATTC to applying the precautionary approach, in accordance with the United Nations Fish Stocks Agreement (UNFSA):

> "The members of the Commission, directly and through the Commission, shall apply the precautionary approach, as described in the relevant provisions of the Code of Conduct and/or the 1995 UN Fish Stocks Agreement, for the conservation, management and sustainable use of fish stocks covered by this Convention." (Article IV of the Antigua Convention).

The UNFSA states that reference points:

> "Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives." (Annex II of the United Nations

Fish Stocks Agreement (UNFSA 1995))

and:

> "Such reference points shall be used to trigger pre-agreed conservation and management action." (Annex II UNFSA 1995)

The UNFSA further defines how reference points should be used in decision rules:

> "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average." (Annex II UNFSA 1995)

The UNFSA provides minimum standards for some reference points:

> "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points." (Annex II UNFSA 1995)

and decision rules:

> "For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield" (Annex II UNFSA 1995)

Both the UNFSA and the Antigua Convention explicitly state that the amount of uncertainty should be taken into consideration when taking management action, and therefore it should be part of the decision rule:

> "In particular, the members of the Commission shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures." (Article IV of the Antigua Convention)

Therefore, interpretation of the IATTC reference points should be in a probabilistic context.

There is no clear definition of target reference points in the Antigua Convention. The only explicit guide is to maintain the populations at levels of abundance which can produce the maximum sustainable yield. This implies that the target should be $B_{MSY}$ or higher. In contrast, the UNFSA states that $F_{MSY}$ should be regarded as a minimum standard for limit reference points. This could imply that $B_{MSY}$ should also be a limit since $B_{MSY}$ corresponds to $F_{MSY}$. However, even under $F_{MSY}$, $B$ could fluctuate around $B_{MSY}$ due to variation in recruitment, if $B_{MSY}$ is defined on an equilibrium (or average) basis. Alternatively, $B_{MSY}$ is often defined dynamically, which explicitly takes recruitment variation into consideration. In addition, the UNFSA also states that the risk of exceeding limit reference points should be very low, which, in contrast, would likely make using $B_{MSY}$ as a limit reference point result in unreasonably conservative targets, particularly given the uncertainty in assessing a stocks status and the natural variability of stocks and fisheries.

Neither the Antigua Convention nor the UNFSA provide details of the definition of reference points. For example, they do not define what age-specific fishing mortalities should be used to calculate MSY quantities or if the biomass reference points should be dynamic (i.e. take temporal variation of recruitment into consideration) or equilibrium. Therefore, it appears that the IATTC has broad scope for defining target reference points as long as the target biomass reference point is $B_{MSY}$ or higher and $F$ at or below $F_{MSY}$. The latter takes the position that the UNFSA statements about $F_{MSY}$ is a "minimum standard for limit reference points" and "risk of exceeding limit reference points is very low" are incompatible, while also noting that $F_{MSY}$ corresponds to $B_{MSY}$, which is often used as a target.

## How target reference points are used by the IATTC

Reference points can be used for multiple purposes including to determine the status of the fishery, as performance measures, and as components of harvest control rules (HCR). The IATTC has used reference points for all of these purposes both formally, as adopted by resolutions, and informally through operational usage. For example, Resolution C-16-02, which defines the harvest control rule using reference points, limits fishing mortality to levels that do not exceed $F_{MSY}$ and when the limit reference points have been exceeded (probabilistically) fishing mortality should be reduced to $F_{MSY}$ and $B_{MSY}$ is a rebuilding target. The IATTC has used reference points for multiple purposes as outlined in Table 1.

Table 1. Use of reference points by the IATTC.

| Use | Component | Details | Source |
|---|---|---|---|
| Stock status | Ftarget | $F_{MSY}$, interim target reference point | 87th meeting of the IATTC |
| | Flimit | $F_{B/B0=0.077}$, which corresponds to the biomass where recruitment = 0.5R0 assuming steepness h = 0.75 | 87th meeting of the IATTC; Maunder and Deriso, 2014 |
| | Btarget | $B_{MSY}$, interim target reference point calculated as a dynamic quantity (i.e. takes the time series of recruitment into consideration) | 87th meeting of the IATTC |
| | Blimit | $B/B_0$=0.077, which corresponds to recruitment = 0.5R0 assuming steepness h = 0.75. Calculated as an equilibrium quantity. | 87th meeting of the IATTC, Maunder and Deriso, 2014 |
| | F and B proxies | $B_{MSY}/B_0$ based on the assessment and the assumption of a conservative value for the steepness (h = 0.75) of the Beverton-Holt stock-recruitment relationship or $B_{MSY}/B_0$ = 0.3, whichever is highest; This extended Resolution C-16-02 by allowing for proxy reference points for $B_{MSY}$ and $F_{MSY}$ when they cannot be reliably estimated (or otherwise specified) from parameters estimated within the assessment model. The IATTC staff proposed proxy limit and target reference points that can be used for tuna, billfish and other highly productive fishes, and specifically skipjack tuna, in the EPO. | Resolution C-23-06; Maunder, 2024; Maunder et al., 2024 |
| | | | |
| HCR | F | An operational HCR limiting fishing mortality ($F$) to levels that do not exceed the level corresponding to MSY. For example, the days of closure are set based on the stock | e.g. Resolution C-10-01 |

| | | | |
|---|---|---|---|
| | | assessment $F_{\text{multiplier}}$ ($F_{\text{MSY}}/F_{\text{cur}}$) adjusted by changes in fishing capacity. | |
| | | Attempt to prevent the fishing mortality rate ($F$) from exceeding the best estimate of the rate corresponding to the maximum sustainable yield ($F_{\text{MSY}}$) for the species that requires the strictest management. | Resolution C-16-02 |
| HCR trigger point | F | If the probability that $F$ will exceed the limit reference point ($F_{\text{LIMIT}}$) is greater than 10% | Resolution C-16-02 |
| | B | If the probability that the spawning biomass (S) is below the limit reference point ($S_{\text{LIMIT}}$) is greater than 10% | Resolution C-16-02 |
| | | | |
| Rebuilding target | F | Have a probability of at least 50% of reducing $F$ to the target level ($F_{\text{MSY}}$) or less, and a probability of less than 10% that $F$ will exceed $F_{\text{LIMIT}}$. | Resolution C-16-02 |
| | B | Have a probability of at least 50% of restoring $S$ to the target level (dynamic $S_{\text{MSY}}$) or greater, and a probability of less than 10% that $S$ will descend to below $S_{\text{LIMIT}}$ in a period of two generations of the stock or five years, whichever is greater | Resolution C-16-02 |
| | | | |
| Performance metric | | Performance metrics have not yet been formally adopted, although some have been proposed as part of the MSE process (see SAC-15-07). | |

**How the sizes/ages of fish caught influence the target reference points**

The calculation of MSY is conditional on the age specific fishing mortality, which is a function of the selectivity of each fishery and the allocation of effort among fisheries (it can also be related to the areas fished if the age of fish differs among areas). This age-specific fishing mortality is scaled to maximize the catch under equilibrium conditions. In general, catching larger fish produces higher MSY at a higher $B_{\text{MSY}}/B_0$, since most fisheries catch a range of sizes, but this can vary based on multiple factors. This phenomenon can be partly seen for the EPO bigeye tuna fishery where the MSY was high before the 1990s when the longline fishery that catches large fish was taking the majority of bigeye but dropped after the 1990s as the floating-object purse-seine fishery, which catches small bigeye, expanded (Figure 1). However, the $B_{\text{MSY}}/B_0$ did not follow this pattern (Figure 1) because the longline fishery catches fish before they mature and before the female natural mortality increases (Figure 2). Typically, the recent age-specific fishing mortality is used in calculating MSY under the assumption that the size of fish caught is not going to change (e.g. the IATTC staff uses the most recent three years for tropical tunas in the EPO).

Theoretically, global MSY (the highest possible MSY obtainable under any possible age-specific fishing mortality) can be calculated and generally occurs by fishing all the fish at a particular age (Maunder, 2002). However, catching all fish at particular age is not practical or logistically possible in most fisheries. An alternative approach is to calculate the maximum MSY that can be obtained using knife-edged selectivity (e.g., Getz, 1980; Reed, 1980) or fishing mortality by fishing method (e.g., Maunder, 2002).

**Target reference points for bigeye tuna in the EPO**

$B_{MSY}$ and $F_{MSY}$ are used as target reference points for bigeye tuna in the EPO and are part of the harvest control rule. The age-specific fishing mortality used to calculate the MSY quantities is the average of the most recent three years. During this period, most of the bigeye catch is of small individuals in the floating-object purse-seine fishery. In combination with no relationship, or a weak relationship, between recruitment and the adult stock (i.e. high steepness of the Beverton-Holt stock-recruitment relationship), this age-specific fishing mortality corresponds to a $B_{MSY}$ occurring at a highly depleted stock for some model assumptions (e.g. 0.17). This level is even lower than the previous assessment due to a change in the assumption about natural mortality that was increased for immature individuals. However, historically (before the 1990s), when most of the bigeye was caught in the longline fishery, MSY was much higher (Figure 1). In contrast, the corresponding $B_{MSY}/B_0$ actually reduced (Figure 1). This is because even the longline fishery catches bigeye before they mature and before the female natural mortality increases (Figure 2). If bigeye were only caught by the longline fishery, the MSY would be about twice as high as under the current catch allocation and occur at a lower $B_{MSY}/B_0$ (Table 2). However, the longline effort may have to increase by an unrealistic amount.

MSY was calculated using a range of knife-edge selectivity options to determine the optimal knife- edge selectivity and the corresponding $B_{MSY}/B_0$ (Figures 3 and 4, Table 2). The highest knife-edge MSY occurred when bigeye were fully selected at ages 15-20 quarters depending on steepness of the stock-recruitment relationship and was about two and a half times the current MSY and occurred at $B_{MSY}/B_0$ of 0.25-0.44 (Table 2). This MSY was only moderately higher than the MSY obtainable by the longline fisheries and occurred at a higher $B_{MSY}/B_0$. The probabilities of the different steepness hypotheses used in the risk analysis are 0.46, 0.32, 0.22 for $h$ values of 1, 0.9, and 0.8, respectively. Weighting the $B_{MSY}/B_0$ for each hypothesis by these probabilities gives a $B_{MSY}/B_0$ of 0.3.

**DISCUSSION**

Target and limit reference points are an important part of contemporary fisheries management. Although the Antigua Convention provides little guidance on reference points, it commits the IATTC to applying the precautionary approach in accordance with the United Nations Fish Stocks Agreement (UNFSA), which offers some guidance on the definition and use of reference points. Target reference points corresponding to MSY have been used for yellowfin and bigeye tuna in the EPO. MSY based reference points are conditional on the size of the fish caught. This is a particular concern for bigeye tuna in which small fish are caught in the floating-object purse-seine fishery and large fish are caught in the longline fishery. The target biomass reference point, under some scenarios, occurs at a stock size that is highly depleted. This highly depleted stock level has raised concerns about the definition of the target reference point. Therefore, target reference points for tropical tuna in the EPO should be revisited.

A target reference point that is more global, in the respect that it can support MSY from different fishing methods or different combinations of fishing methods might be more generally consistent with the Antigua Convention's objective to maintain populations at levels of abundance which can produce the maximum sustainable yield. This type of approach would accommodate unforeseen changes in the allocation of catch among methods or the desire to improve overall yields or achieve socio-economic objectives. Global MSY, which is the absolute highest MSY that can be achieved, is impractical and therefore not a useful metric. Maunder (2002) suggested using two thirds of global MSY based on considerations about the practicality of fishing for yellowfin tuna in the EPO. However, this does not define the associated biomass and fishing mortality reference points. It is simply a gage to determine how efficient in terms of catch is the current allocation among gears.

Maunder et al. (2024) proposed proxy target and limited reference points for tuna, billfish, and other highly productive fishes in the EPO. Maunder (2024) used the same approach to propose reference points for skipjack tuna. The proxies are calculated based on a conservative assumption about the steepness of the Beverton-Holt stock-recruitment relationship ($h$ = 0.75). An additional precaution is applied to the biomass target limiting it to a minimum of $B_{MSY}/B_0$ = 0.3, mainly to avoid low target biomass reference points due to the current selectivity patterns. They suggest that these interim reference points would be used until more information about the tradeoffs related to the age-specific fisheries selectivities is available. However, the value $B_{MSY}/B_0$ = 0.3 was not based on explicit considerations of the age of fish caught. Other more arbitrary proxy reference points such as the value advocated by the Marine Stewardship Council (MSC) for stocks that do not have explicitly calculated reference points, SPR[1] = 0.4, could also be used. SPR is equivalent to $S/S_0$ when steepness = 1. However, these reference points do not take into consideration the characteristics of many species caught in the EPO tuna fisheries.

In contrast, our analysis for bigeye tuna explicitly evaluates the size of fish caught by looking at a range of knife-edged selectivities. Knife-edged selectivity may approximate a somewhat practical fishing approach. For bigeye tuna, our analyses suggests that MSY based on knife-edged selectivity is maximized when all the bigeye aged 15-20 and older are fully vulnerable to the fishery, depending on the steepness of the stock-recruitment relationship. This occurs at a $B_{MSY}/B_0$ of 0.3, when weighted by the probabilities of steepness used in the risk analysis, and covers the $B_{MSY}/B_0$ of the longline fishery. This is similar to the 0.3 proxy already recommended (Maunder et al., 2024). Therefore, $B_{MSY}$ = 0.3 could be used as a target reference point that accommodates variation of the allocation of catch among fishing methods.

An alternative reason to define a target is to avoid breaching the limit reference point which might result in drastic management action. It also suggests that target reference points (TRPs) should be defined based on the assessment uncertainty, so that, as the assessment uncertainty reduces, the TRP should get closer to the limit reference point (LRP). Determining such a reference point would require extensive simulation analysis. The target, which may be more appropriately defined as a trigger point in an HCR, would then be conditional on the limit reference point (or trigger point) and the action that would be taken.

It should be noted that fishing at levels above $F_{MSY}$ or stocks at levels below $B_{MSY}$ are not necessarily unsustainable. By definition, they are at levels that do not support MSY conditional on the age-specific fishing mortality. There have been many stocks that have a long sustainable history exceeding these levels. In mixed stock fisheries it is often difficult, if not impossible, to manage fisheries to obtain reasonable yields while also satisfying targets for all species. Therefore, flexibility might be needed when defining targets in multispecies fisheries such as the tropical tuna fishery in the EPO. There also may be inconsistencies among the IATTC's Antigua Convention, objectives, practicalities, and what is sustainable.

Target reference points should take a number of factors into consideration including socio-economic factors. For example, Sun et al. (2019) found that fishing for bigeye tuna in the EPO by only longline would increase the value of the fishery by over half a billion $US even if the longline fishing effort was not increased. A comprehensive evaluation of the objectives of the fishery and evaluating different harvest control rules to achieve these objectives using Management Strategy Evaluation (MSE) is the most

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[1] SPR spawning potential ratio defined as spawning stock biomass (S) /recruits (R) over spawning stock biomass in an unfished condition (dynamic S0)/recruits in an unfished condition (dynamic R0).

appropriate approach to define the target reference points and is currently underway at the IATTC (SAC-15-07).

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**TABLE 2.** Estimated MSY and corresponding $B_{MSY}/B_0$ for an OBJ fishery, a longline fishery, and the highest MSY from a knife edge selectivity.

| Scenario | | Age | MSY | BMSY/B0 |
|---|---|---|---|---|
| h = 1.0 | Current | | 87779 | 0.17 |
| | OBJ | | 64898 | 0.09 |
| | Longline | | 198733 | 0.11 |
| | Knife edge selectivity | 15 | 224090 | 0.25 |
| h = 0.9 | Current | | 84598 | 0.23 |
| | OBJ | | 55407 | 0.19 |
| | Longline | | 170769 | 0.20 |
| | Knife edge selectivity | 17 | 208332 | 0.31 |
| h = 0.8 | Current | | 82775 | 0.27 |
| | OBJ | | 54235 | 0.24 |
| | Longline | | 150445 | 0.25 |
| | Knife edge selectivity | 19 | 195303 | 0.39 |
| h = 0.75 | Current | | 110516 | 0.28 |
| | OBJ | | 53901 | 0.26 |
| | Longline | | 140976 | 0.27 |
| | Knife edge selectivity | 20 | 187512 | 0.44 |

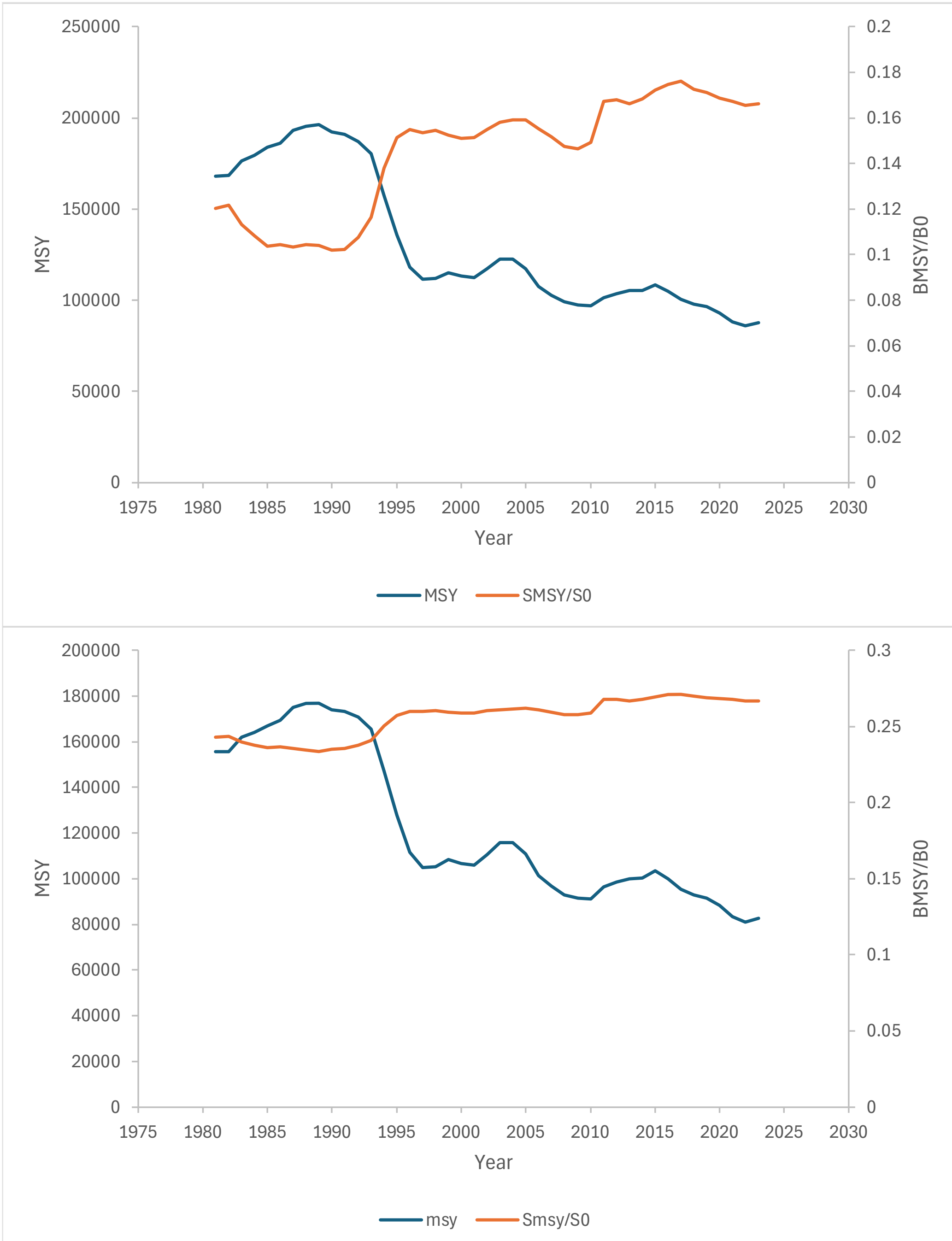


**FIGURE 1.** Estimates of MSY and $B_{MSY}/B_0$ based on the age-specific fishing mortality for each year of the bigeye assessment for steepness of the stock recruitment relationship h = 1.0 (top) and h = 0.75 (bottom).

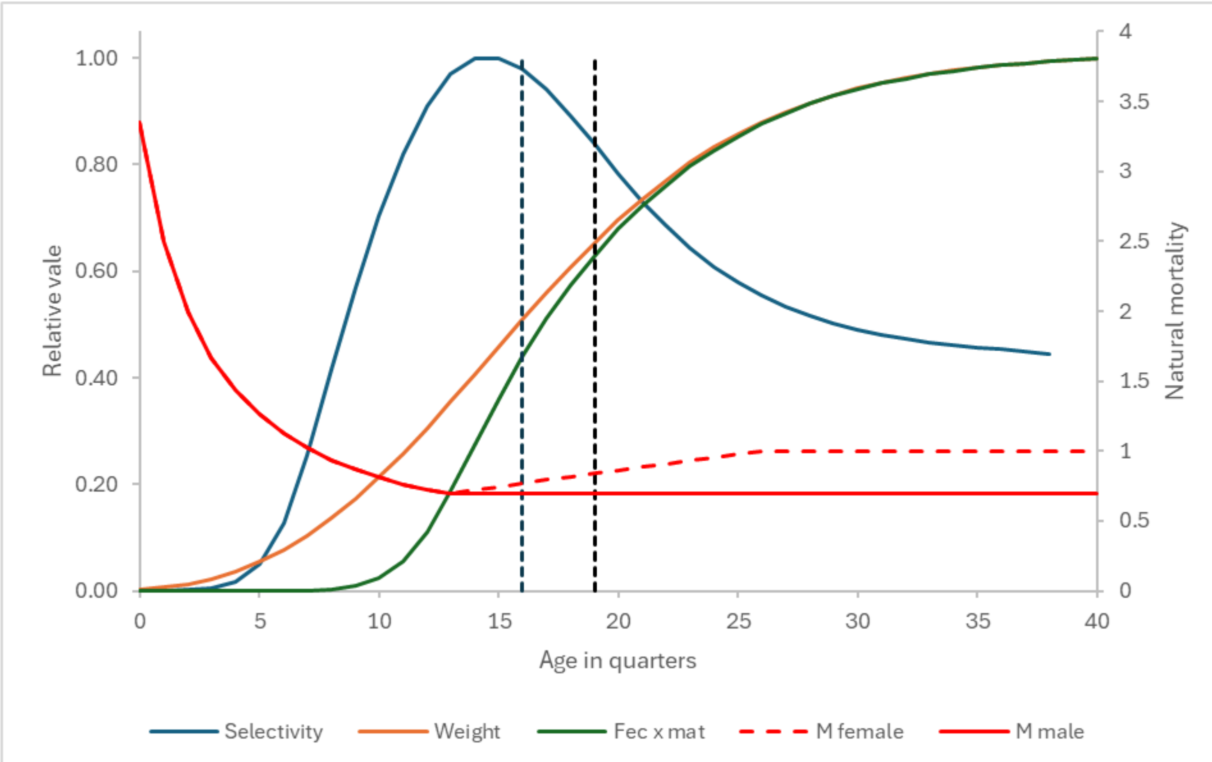


**FIGURE 2.** Comparison of longline selectivity with population processes. The vertical lines are the age of knife edged selectivity the maximize MSY under steepness of h = 1 (age 16 quarters) and h = 0.75 (age 19 quarters)

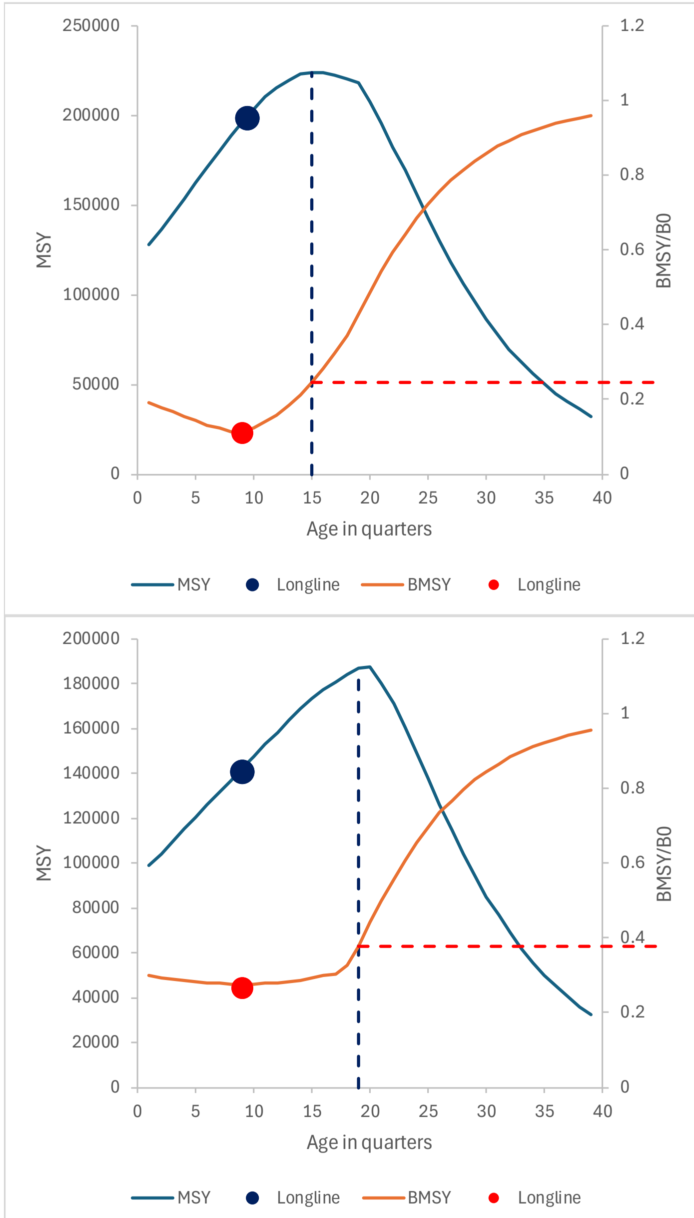


**FIGURE 3.** Estimates of MSY and corresponding $B_{MSY}/B_0$ under knife-edge selectivity at various ages of entry to the fishery for steepness of the stock recruitment relationship, h = 1.0 (top panel) and h = 0.75 (bottom panel). The points represent the values (not ages) related to the overall longline selectivity.

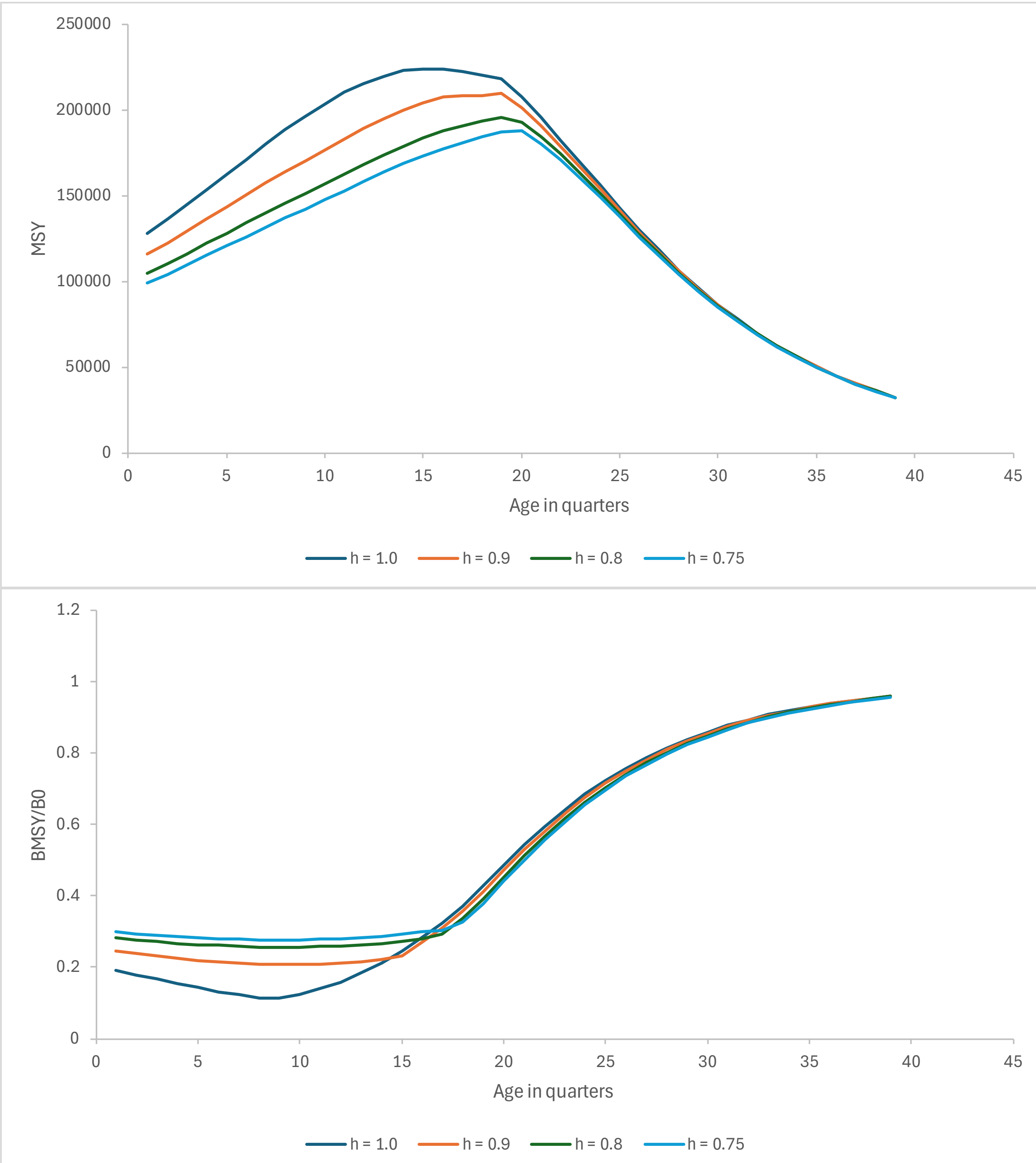


**FIGURE 4.** Estimates of MSY (top panel) and corresponding $B_{MSY}/B_0$ (bottom panel) under knife-edge selectivity at various ages of entry to the fishery for different steepness (h) of the stock recruitment relationship.