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Yield per recruit and spawning biomass per recruit analyses for Splendid Alfonsino (*Beryx splendens*) in the North Pacific

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1 INTRODUCTION

Splendid Alfonsino (*Beryx splendens*) is captured by bottom trawl and bottom gillnet fisheries conducted by Japan, Korea and Russia in the Emperor Seamounts of the North Pacific Ocean and managed by the North Pacific Fisheries Commission (NPFC). As for today, there are no estimates of biomass and/or fishing mortality that could guide fisheries management for the sustainability of this species. Splendid Alfonsino is a priority species for the NPFC and has exhibited a decrease in mean size (Sawada et al., 2018). The Small Science Committee on Bottom Fish and Marine Ecosystems of the NPFC has committed to initiating a sustainable and precautionary approach to manage its bottom fish fisheries including the fishery for Splendid Alfonsino as part of its five-year work-plan (2020-2025). As part of this work-plan, Yield per recruit (YPR) and Spawning Biomass per Recruit (SBPR) analyses have been suggested as a first approximation on the use of data limited methods for stock assessment to assist the SWG NPA-SA to conduct a pre-assessment of the Splendid Alfonsino.

Yield per recruit (YPR) analyses are used to estimate the expected lifetime catch (yield) of an average recruit (an individual fish entering the fishable stock) under different fishing pressures and management strategies through changes in selectivity (Beverton and Holt, 1957). This analysis helps determine the optimal fishing mortality rate that maximizes the yield per recruit, balancing the benefits of harvesting against the need for sustainable fish populations.

YPR analysis helps balance the trade-off between growth and mortality. If fish are harvested too early, they may not reach their optimal size, resulting in lower yield. Conversely, if harvest is delayed too long, natural mortality may reduce the number of fish available for capture. This analysis identifies the optimal age or size at which to harvest fish to maximize yield. Different management scenarios, such as changes in gear selectivity, minimum size limits, and closed seasons, can be evaluated using YPR analysis. This allows managers to simulate the effects of various regulations and choose the most effective strategy for sustainable yield.

The objective of this study is to evaluate the application of YPR and SBPR analyses for Splendid Alfonsino in the North Pacific Ocean and the sensitivity of the results to different life-history and selectivity assumptions.

2 METHODS

To conduct YPR and SBPR analyses, several key inputs are required:

2.1 Growth Parameters

Growth estimates are essential in YPR analysis because they determine the expected size of fish at different ages, which directly influences the productivity of fish stocks. Without reliable growth estimates, there's a risk of overestimating or underestimating stock productivity, potentially leading to unsustainable fishing practices and depletion of fish populations. In the YPR and SBPR analyses, we used the growth parameters estimates from the 'optim' function in *R* (R Core Team 2023) using length and age composition data from both fishing gears, gillnets and trawl estimated in Amoroso et al. (2024). We also ran two sensitivity analyses using the 'optim' estimates from only using data from gillnets, and the estimates from only using data from trawlers (Table 2.1).

Table 2.1: Estimated growth parameters from Amoroso et al. (2024) used in the base models and sensitivity runs for growth. L∞ represents the asymptotic maximum length, k is the growth coefficient, and t_0 is the hypothetical age at zero length.

Parameter	Value	Run
L∞	556.62	Base
k	0.08	Base
t_0	-4.77	Base
L∞	483.57	Sensitivity lower *L*∞
k	0.08	Sensitivity lower *L*∞
t_0	-8.48	Sensitivity lower *L*∞
L∞	672.44	Sensitivity higher *L*∞
k	0.05	Sensitivity higher *L*∞
t_0	-5.93	Sensitivity higher *L*∞

2.2 Maturity Parameters

Maturity estimates are crucial in SBPR analysis because they determine the age and size at which fish become reproductively active, which directly affects the reproductive potential and sustainability of fish populations. Without reliable maturity data, there is a risk of overfishing young fish before they can spawn. For the SBPR base case analysis, we selected the maturity parameters estimated with the gonadosomatic index using all data before August (pre-spawning in Table 2.2) presented in Amoroso et al. (2024). We also ran two sensitivity analyses using the estimates from Korea (the lowest estimates of size at maturity), and the estimates from Japan (the highest estimates of size at maturity) (Amoroso et al., 2024, Table 2.2).

Table 2.2: Estimated maturity parameters from Amoroso et al. (2024) used in the base models and sensitivity runs for maturity. L_{50} and L_{95} are the sizes at which 50% and 95% of the fish are mature respectively.

Model	L_{50}	L_{95}	**Run**
Gonadosomatic all pre-spawning	302.66	386.57	Base
Histological Jap all data	397.20	640.01	Sensitivity highest Mat
Histological Kor all data	263.20	327.06	Sensitivity lowest Mat

2.3 Length-Weight Relationship

Length-weight relationships in YPR and SBPR analyses provide a way to estimate the biomass of individual fish based on their length which directly impacts yield predictions. The function used is the one presented in Amoroso et al. (2024):

$$W = 3.24e^{-}05L^{2.932}$$

where W is the weight, L is the length, a is a constant (intercept), and b is the exponent (slope).

2.4 Natural Mortality

Accurate estimates of natural mortality (*M*) are essential for predicting how many fish will survive to reach harvestable sizes. For Splendid Alfonsino a previous estimation based on an empirical function by (Then et al., 2015) exists. We used this value of 0.162 years^{-1} as a base *M* parameter. In addition, using the base and the two selected set of parameters for the sensitivity runs of growth parameters, (t_{max}) of 13 years (Amoroso et al., 2024) and age at maturity (a_{mat}) of 6 years (Amoroso et al., 2024) we used 12 empirical estimators available at the barefoot ecologist Natural mortality tool (available here http://barefootecologist.com.au/shiny_m.html) to have a distribution of possible *M* values. From the resulting distribution we ran sensitivities analyses using the 25% and 75% quantiles (see the results section).

2.5 Selectivity

The term selectivity used in this document refers to the combined effect of 1) gear selectivity and its probability of catching a fish of a specific age or size; and 2) fish availability that considers the overlap between the fishing effort and the distribution of fish.

To estimate the selectivity ogive from the available data we used the Length-Based Spawning Potential Ratio (LBSPR) model (Hordyk et al., 2015). This method is commonly used to assess the status of fish stocks in data-limited fisheries. The model only relies on the size structure of the fish population and the life history parameters of the species to estimate the spawning potential ratio (SPR), which is a measure of the reproductive capacity of the population relative to an unfished state. One of the key components of the LBSPR model is estimating the selectivity of the fishery, which refers to the probability that fish of different lengths are captured by the fishing gear, which is crucial for understanding the impact of fishing on different sizes of fish within the population.

The LBSPR model makes several assumptions: 1) the population is in equilibrium (constant recruitment and mortality over time); 2) length data is representative of the population; 3) life history parameters (growth, natural mortality, the weight-at-length relationship and maturity) are accurately estimated; and 4) the selectivity of the fishing gear is logistic.

The LBSPR model uses maximum likelihood estimations (MLE) to fit the selectivity curve to the observed length frequency data. The goal is to find the parameters LS_{50} and LS_{95} that maximize the likelihood of observing the given length frequency data under the model. This involves iterating over different values of L_{50} and L_{95} to find the best fit. The likelihood function incorporates the difference between the observed and predicted length frequencies.

For the trawl fishery we have not found an approach to estimate a dome-shaped selectivity based on the observed length of the catch. Therefore, we decided to use a double logistic selectivity curve fixing their parameters to mimic the length distribution observed in the trawl catch (see the results section). We used this dome-shaped selectivity, as well as the selectivity estimated by LBSPR for both gears combined and for the gillnet fishery in the YPR and SBPR analyses.

2.5.1 Estimation of SPR for Splendid Alfonsino

We also estimated using LBSPR the SPR, which is the ratio of the SBPR in a fished population to the SBPR in an unfished population:

$$SPR = \frac{SBPR_{fished}}{SBPR_{unfished}}$$

The SBPR is calculated by integrating the product of the survivorship, maturity, and weight-at-length functions:

$$SBPR = \int_{L_{min}}^{L_{max}} S\,(L) \cdot m(L) \cdot w(L)\, dL$$

where $S(L)$ is the survivorship at length L. $m(L)$ is the maturity at length L. $w(L)$ is the weight at length L.

Survivorship ($S(L)$) is given by the exponential decay function:

$$S(L) = e^{-Z \cdot t(L)}$$

2.6 Length Composition Data

The length composition data available for the LBSPR analysis covers the period from 2013 to 2023 for the Japanese fleet. Individual lengths were recorded as fork lengths for both gillnet and trawl fishing operations. The length distribution of Splendid Alfonsino by gear is shown in Figure 2.1. The individuals caught by trawlers are smaller than the ones caught by the gillnet fishery suggesting that the trawl fishery has a dome-shaped selectivity, where large animals, present in the population, are not being caught by this gear (Figure 2.1).

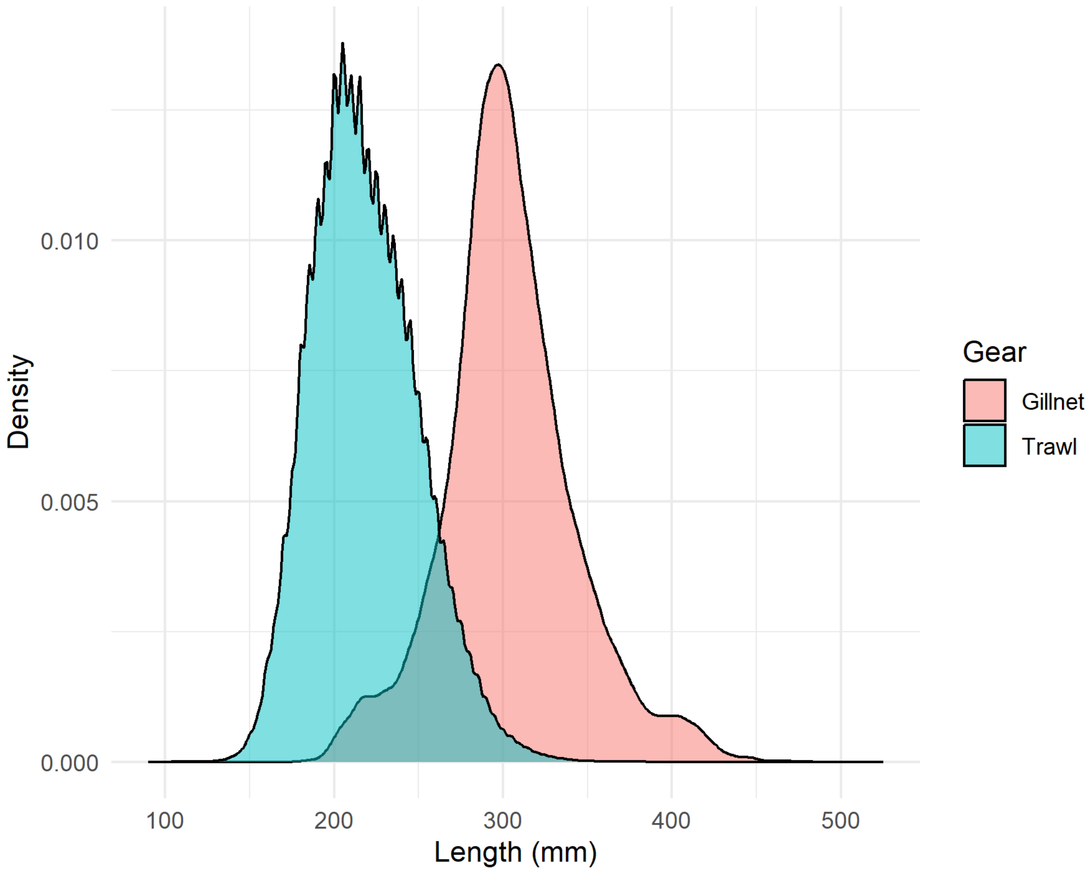

Figure 2.1: Length distribution of Splendid Alfonsino by fishing gear from the Japanese fleet.

3 RESULTS AND DISCUSSION

3.1 Natural Mortality estimates

Figure 3.1 shows the distribution of M values calculated using different empirical estimators as explained in the methodology. The two sensitivities runs for M in the YPR and SBPR analyses were using the 25% quantile of 0.11 years^{-1} and the 75% quantile of 0.22 years^{-1} (Figure 3.1).

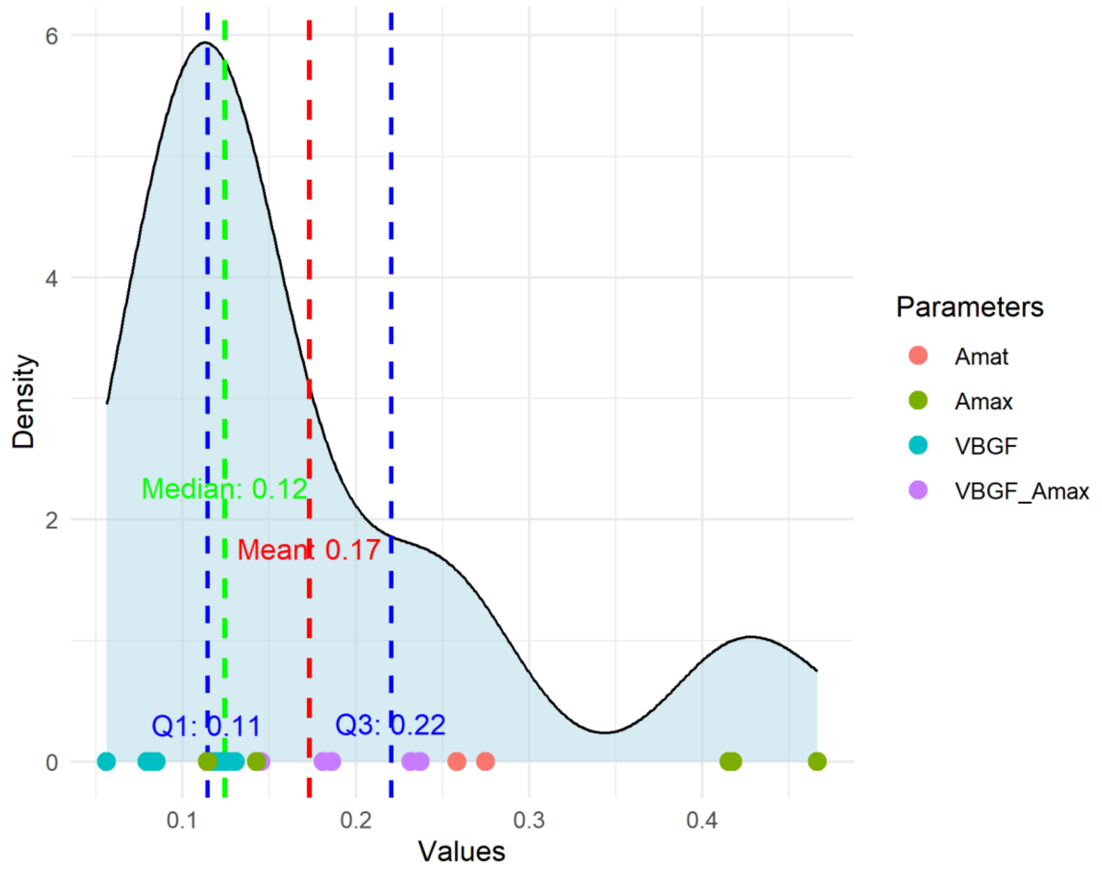

Figure 3.1: Distribution of Natural mortality (M) empirical estimators for Splendid Alfonsino

3.2 Selectivity

Based on the observed length distribution of the catch, the LBSPR model was used to estimate the selectivity of the fishing gear needed to be used in the YPR and SBPR analyses. Two approaches were used: 1) we used the length distribution coming from the gillnet fishery that we know has a logistic selectivity; and 2) the length distribution of all gears combined (trawl and gillnets), that are representative of what is being observed in the catch of Splendid Alfonsino. This last approach might underrepresented large fish, since the gillnet fishery has a much lower catch than the trawl fishery (Amoroso et al., 2024). In both cases, we calculated a combined selectivity for the period 2019 to 2023, after the mesh size regulation was implemented (NPFC, 2020).

The estimated selectivity curve for both gears combined for the period 2019-2023 showed that Splendid Alfonsino is starting to be selected before they reach maturity. The estimated LS_{50} is 191.5 mm compared to LM_{50} of 302.66 mm. In the gillnet fishery is different, fish are being selected after they reach maturity with an estimated LS_{50} of 300.3 mm. Figure 3.2 shows the two estimated logistic selectivity and the fixed dome-shaped selectivity for the trawl fishery to be used in the YPR analyses.

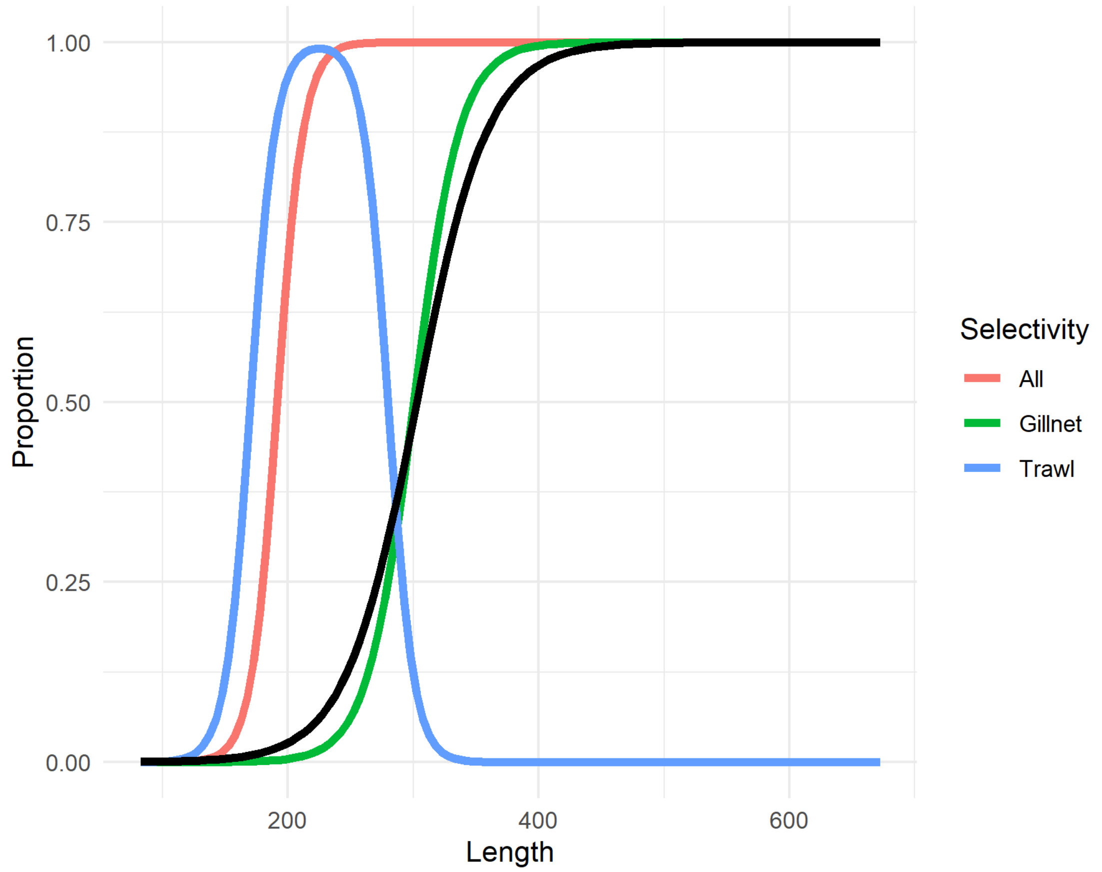

Figure 3.2: Selectivity estimated by LBSPR for both gears combined and for the gillnet fishery, and the fixed dome-shaped selectivity for the trawl fishery. The black solid line shows the maturity ogive used in the base models.

4 SPR Results

The fits to the length distribution of Splendid Alfonsino using LBSPR for both approaches (both gears combined and gillnets only) look very good (Figure 4.1 and Figure 4.2).

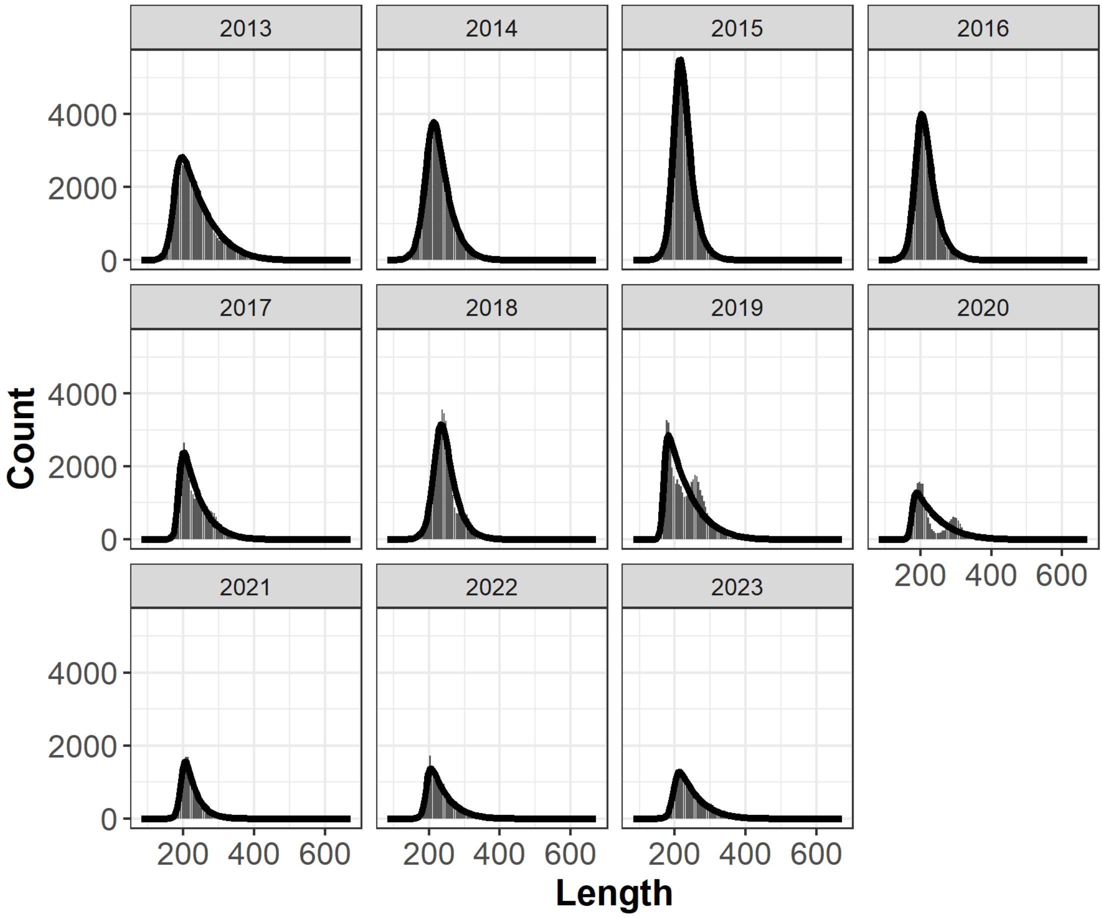

Figure 4.1: Fit to the combined length data from both gears using LBSPR model.

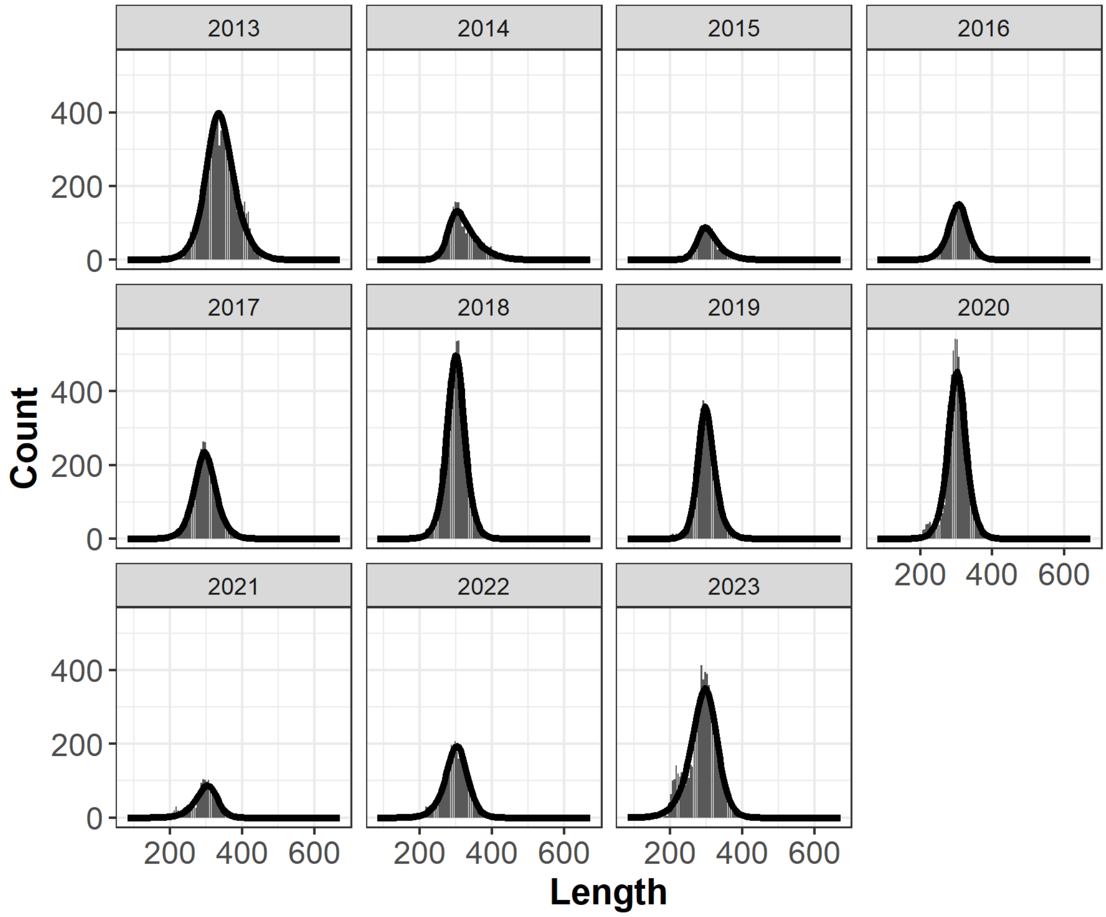

Figure 4.2: Fit to the gillnet fishery length data using LBSPR model.

The results from the LBSPR model using the length distribution of both gears combined resulted in high estimations of *F/M* and low *SPR* suggesting recruitment overfishing for Splendid Alfonsino in the North Pacific (Figure 4.3). Combining all length data, showed the most pessimistic scenario, *F/M* might be overestimated and *SPR* underestimated because of the large proportion of small individuals caught by the trawl gear compared to the low proportion of large individuals caught by the gillnet fishery (Figure 2.1). The most optimistic results are shown when using only the gillnet length composition data. However, this scenario also showed signs of recruitment overfishing for Splendid Alfonsino with *SPR* declining and below 20% of SPR in an unfished state (Figure 4.4).

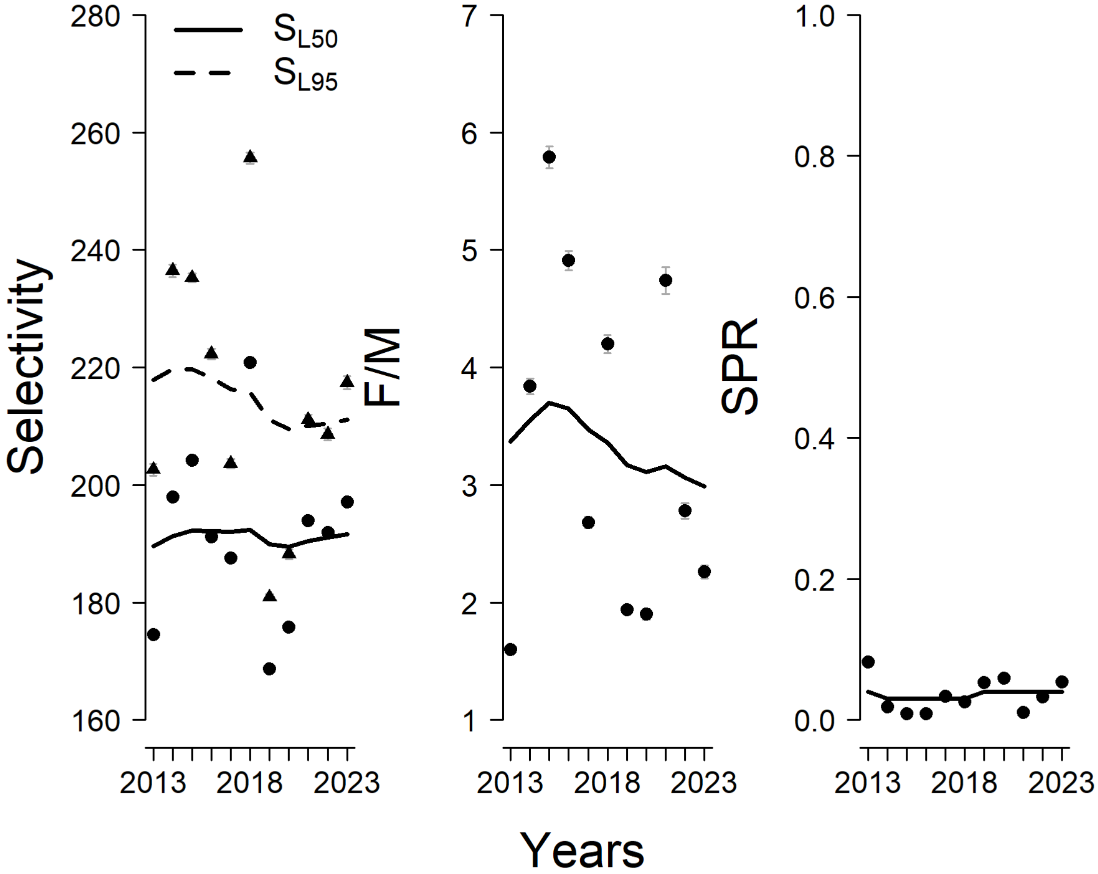

Figure 4.3: Estimated SL_{50}, SL_{95}, F/M and SPR using the LBSPR model for Splendid Alfonsino using the length distribution of both gears combined. SL_{50} and SL_{95} are the sizes at which 50% and 95% of the fish are selected by the fishing gear respectively

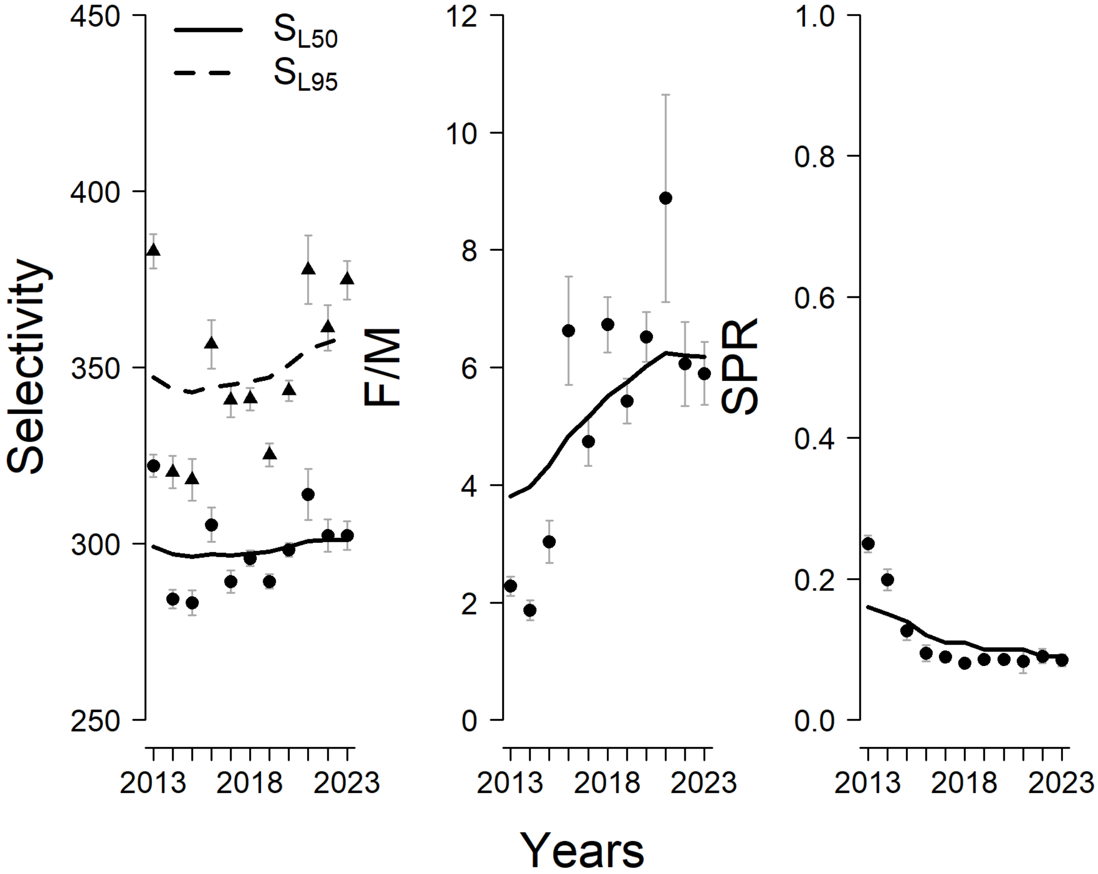

Figure 4.4: Estimated SL_{50}, SL_{95}, F/M and SPR using the LBSPR model for Splendid Alfonsino using the length distribution of the gillnet fishery. SL_{50} and SL_{95} are the sizes at which 50% and 95% of the fish are selected by the fishing gear respectively

5 YPR and SBPR results

The results from the base runs of the YPR and SBPR analyses are shown in Figure 5.1 under different selectivity scenarios. The first assumed a logistic shape of the selectivity curve estimated by LBSPR using length data coming from both gears combined (trawls and gillnets; "All" in Figure 5.1). The second, with a logistic selectivity also estimated by LBSPR, used the length composition coming from only the gillnet fishery ("Gillnet" in Figure 5.1). The third one, assumed a dome-shaped selectivity, consistent with the observed length distribution of the catch of the trawl fishery ("Trawl" in Figure 5.1, see section 3.2). The YPR curves for the three selectivity assumptions are quite different. The one using the logistic selectivity estimated by LBSPR with all length-composition data reached a peak at a fishing mortality smaller than the other two, (F_{max}=0.26 years^{-1}, (YPR_{max}=261.2 gr.) and it declines as fishing mortality increased. The individuals are being selected too early before they reach their maximum growth potential and therefore their maximum potential yield. For the gillnet fishery with the estimated logistic selectivity using LBSPR, the fishing mortality where the yield is maximized is higher (F_{max}=0.7years^{-1}) than for the one using all data. This gear selects individuals after they reach their maximum potential growth and therefore the maximum YPR is higher (YPR_{max}=300.4 gr.). For the trawl fishery, with a dome-shaped selectivity, the F_{max} is higher (1.07 years^{-1}), but the YPR_{max} (212.3 gr.) is lower than in the other two scenarios. the individuals are being selected too small (before they reach their maximum growth potential) and the big ones are not being selected (Figure 5.1).

The SBPR also showed different curves shapes for each selectivity scenario. The scenario using a logistic selectivity estimated with all length composition data in LBSPR and the scenario using the dome-shaped selectivity for the trawl fishery reach a minimum of zero at high fishing mortality rates. Lower Fs for the scenario with all gears compared to the scenario of the trawlers because in the first scenario we are fishing them all before they are mature, and in the second we are letting some big ones to spawn. However, at high fishing mortality rates, even in this scenario we are catching them all before they spawn. The scenario for the selectivity of the gillnet fishery showed that even fishing a high mortality rates we are expecting some spawning biomass to be in the water. With these scenarios we calculated the F_{40} which is the fishing mortality rate that leaves 40% of the spawning biomass in an unfished state in the water. Results are summarized in Table 5.1.

The trends in total biomass per recruit (BPR) look very similar to the SBPR but it does not reach zero at very high fishing mortalities rates because there are always some immature fish that are not being selected by any fishing gear.

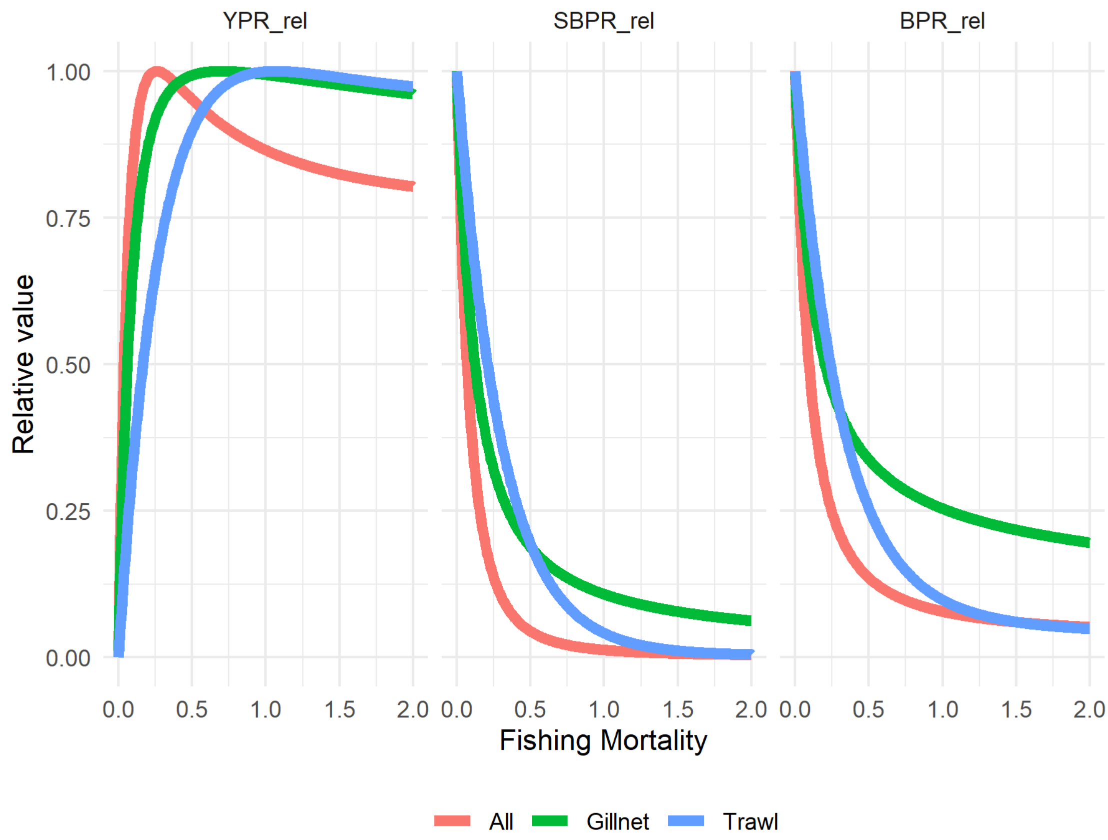

Figure 5.1: YPR, SBPR and BPR curves under different selectivity scenarios

Table 5.1: Key outputs from the YPR and SBPR analyses.

Scenario	F_{max}	YPR at F_{max}	40% $SBPR_0$	F_{40}
All	0.26	261.2	1589	0.10
Gillnet	0.70	300.4	1601	0.18
Trawl	1.07	212.3	1613	0.28

5.1 Sensitivities

In the next section, we ran different scenarios considering alternative values for growth, maturity and natural mortality parameters for Splendid Alfonsino to evaluate the sensitivity of the YPR and SBPR model outputs to different life-history assumptions. For maturity, changes on the assumptions of different L_{50} values only affect SBPR results (Figure 5.2). In addition, the results do not change much for the scenarios of “All” and “Trawl” because the individuals are being selected always before they mature. For the “Gillnet” scenario the outputs of the SBPR analysis change depending on if they are selected before or after they mature (Figure 5.2). Using the highest estimation of L_{50} resulted in a lower F40 than in the base case because the individuals are getting selected by the gillnet fishery before they mature (Figure 5.2).

For growth, changes on the assumptions of different $L\infty$ values affect mainly the YPR results (Figure 5.3). This is because fishing them before or after they reach their maximum growth potential is key in obtaining the maximum yield. The scenario of lower $L\infty$ means that the fish grow faster than the other two scenarios (see Table 2.1), therefore fish are being selected after they reach their maximum growth potential and the YPR curves showed an asymptotic shape (Figure 5.3).

For Natural Mortality, changes on the assumptions of different M values affect mainly the YPR results for the two scenarios of logistic selectivity (“All” and “Gillnet”) (Figure 5.4). If M is higher than the base, the fishing mortality where the yield maximizes increase, and we can fish them harder before they died from natural causes to get the maximum yield (Figure 5.4). The dome-shaped selectivity for trawlers is less sensitive to M values.

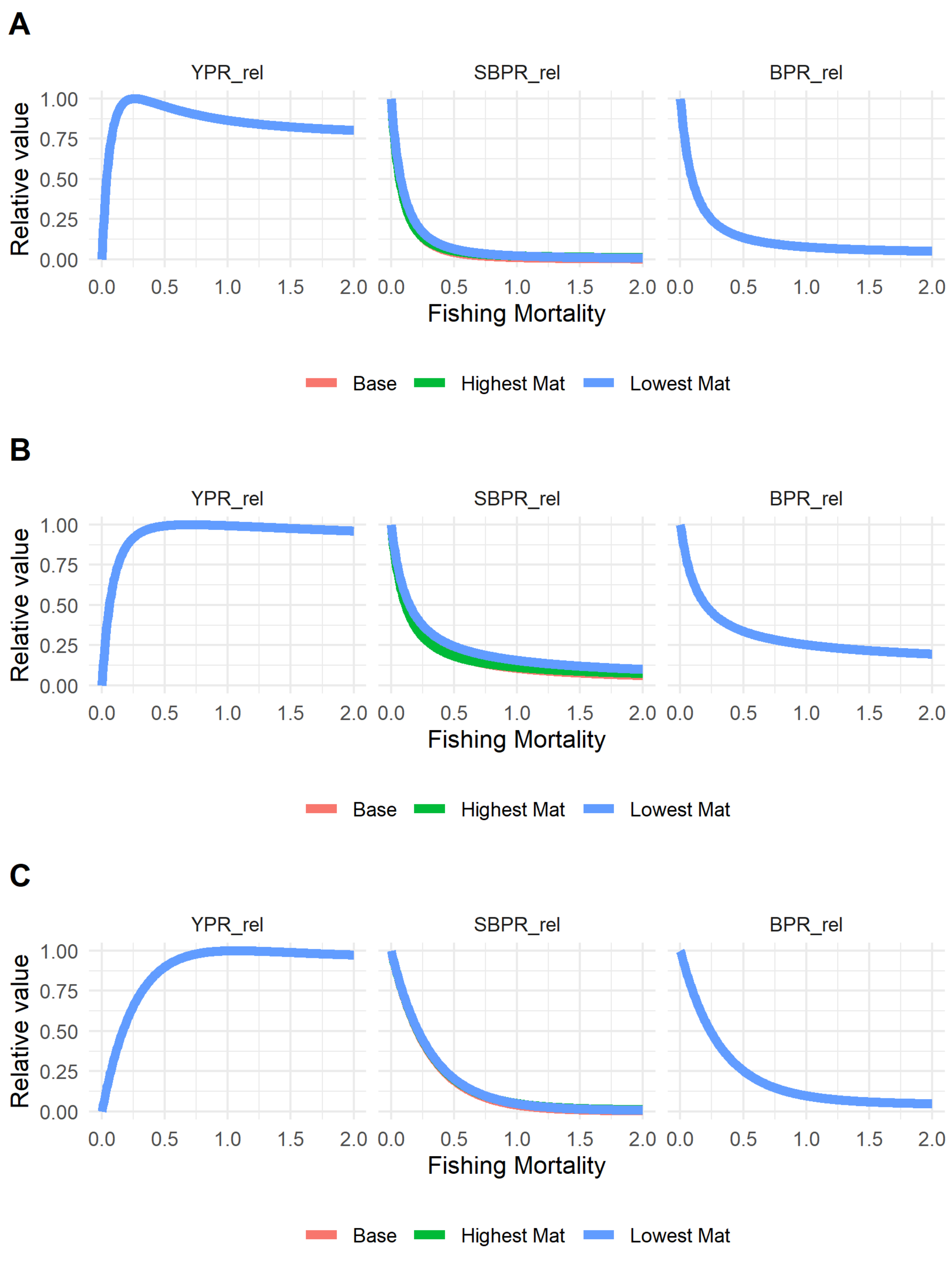

Figure 5.2: YPR, SBPR and BPR curves under different maturity assumptions. A: for both gears combined with a logistic selectivity; B: for the gillnet fishery with a logistic selectivity; C: for the trawl fishery with a dome-shaped selectivity.

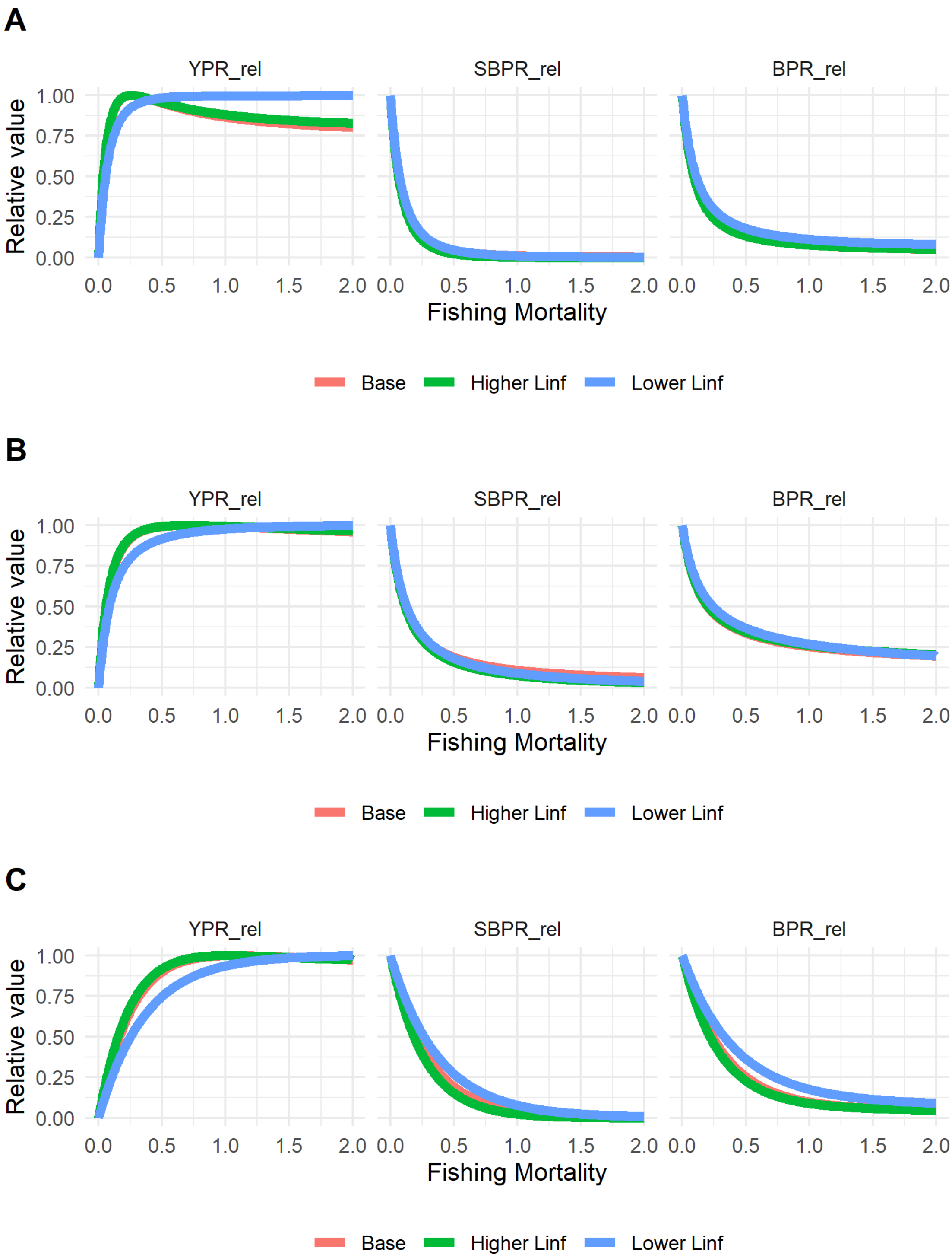

Figure 5.3: YPR, SBPR and BPR curves under different growth assumptions. A: for both gears combined with a logistic selectivity; B: for the gillnet fishery with a logistic selectivity; C: for the trawl fishery with a dome-shaped selectivity.

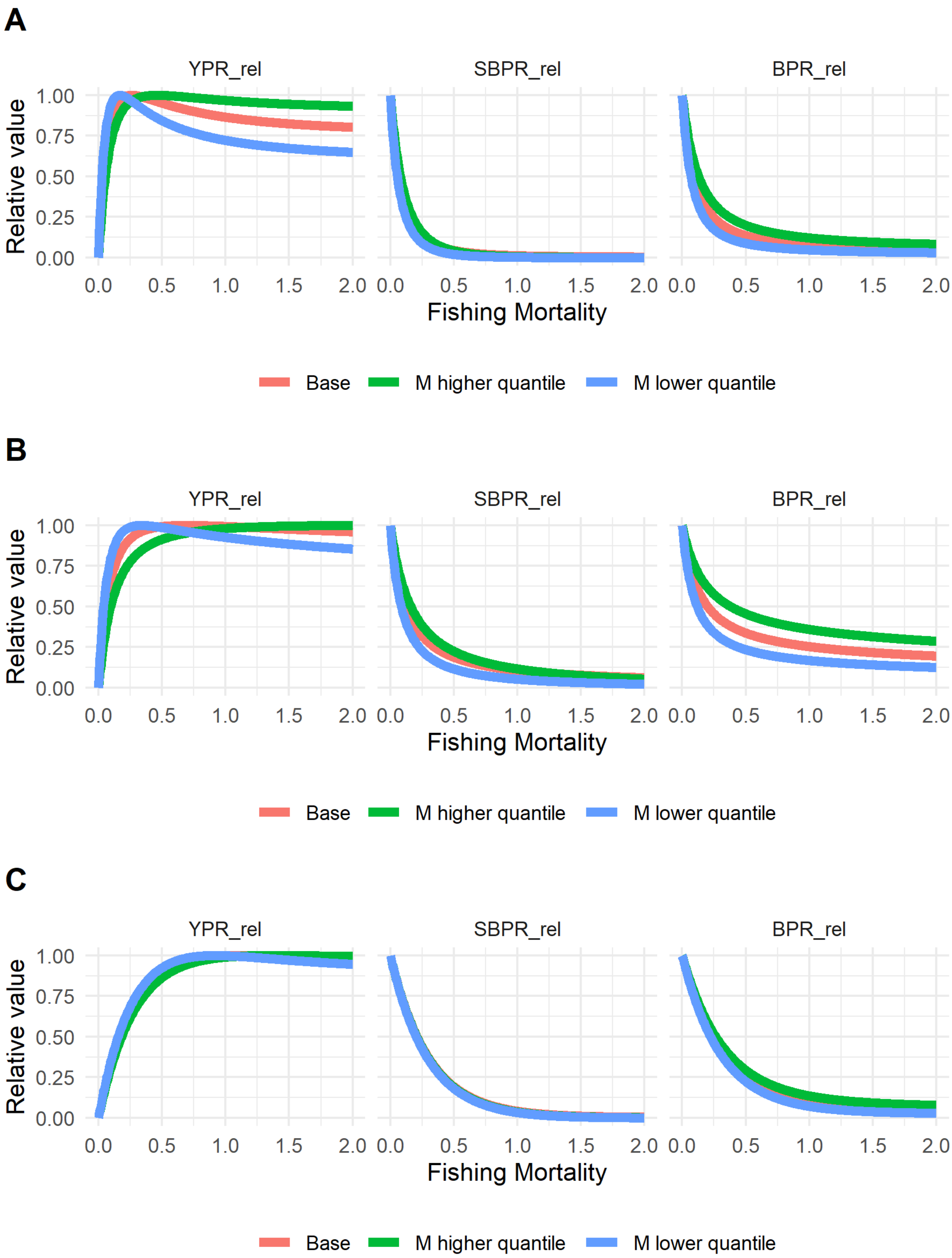

Figure 5.4: YPR, SBPR and BPR curves under different Natural Mortality assumptions. A: for both gears combined with a logistic selectivity; B: for the gillnet fishery with a logistic selectivity; C: for the trawl fishery with a dome-shaped selectivity.

5.2 Example of estimations of YPR for different values of SL_{50}

We decided to show an example of a plot that is sometimes used to determine minimum size regulations for fisheries management. In this case we used a logistic selectivity example with the life history information for the base case models described before. Assuming a logistic selectivity the Figure 5.5 shows that the maximum yield would be obtained at a SL_{50} 350 cm for Splendid Alfonsino. However, the main fishery for this species is trawling that has been shown not to have a logistic selectivity and selecting individual much smaller than this size.

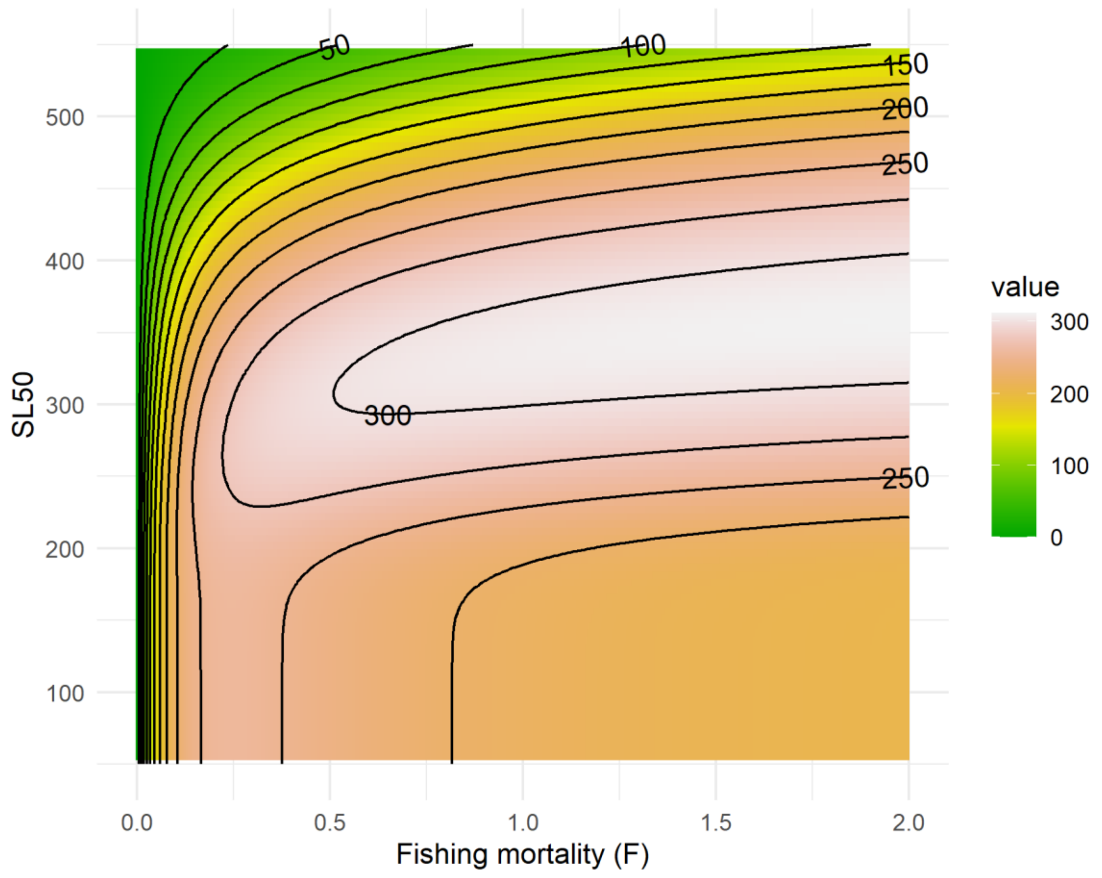

Figure 5.5: YPR for different Lc (SL_{50}) and fishing mortalities (F) for all data

6 CONCLUSIONS

- The results from the YPR analysis for Splendid Alfonsino suggested that, for the scenarios of both fisheries combined, fish are being harvested before they reach the size where yield per recruit is optimized suggesting growth overfishing.

- The results from the LBSPR analysis suggested that Splendid Alfonsino is experiencing recruitment overfishing with low estimated SPR values and high fishing mortality rates above some references estimated from the YPR and SBPR analyses such as F_{40} (Table 5.1). Splendid Alfonsino are being fished before they mature, reducing the abundance of mature individuals and therefore future recruitment.

- The most pessimistic scenario is when using the length data and selectivity coming from all gears combined. However, these results may be biased towards overfishing due to the dome shaped selectivity of the trawl gear which is the main fishery contributing to the Splendid Alfonsino total catch.

- Life history inputs: the analyses conducted here were very sensitive to the life history input parameters, in particular growth for the YPR analyses and maturity estimates for the SBPR analysis. Moreover, growth estimates are essential to estimate *M* from empirical studies. See recommendations from Amoroso et al. (2024).

- Multi-gear fishery: the nature of the fishery, that uses different fishing gears with different selectivities, was the most challenging part of applying data-limited methods such as YPR, SBPR and LBSPR. In particular, LBSPR cannot be used for fisheries with dome-shaped selectivity like the trawl fishery for Splendid Alfonsino, the main fishing gear for this species. This calls for more complex models that could manage different fleets with different selectivity assumptions. Integrated models that use data from different fleets (catch, length, indices of abundance and life-history information) could be an alternative to data-limited assessment to better understand the status of Splendid Alfonsino and improve fisheries management.

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