Task 1: Review of the available data and papers showing the historical exploitation pattern of the fishery (before and after the implementation of the recovery plan) in relation with the fishing season, with the objective to show the highest juvenile mortality (class 0) in October/November.

## Introduction

In the Mediterranean Sea, fishing for swordfish is carried out from April until December, but it is most intensive from late spring to middle autumn and is heavily exploited by several countries. After 2008, following the Regulation on prohibition on gillnets, Mediterranean swordfish catches are taken almost exclusively from Longline fisheries. As reported in several ICCAT stock assessment groups [1, 3], the main catch is of juveniles, that have not yet spawned and assessment results clearly indicate growth overfishing [22]. According to ICCAT [2], dead discards of undersized swordfish are not consistently reported, with an exception of Spain and Greece, that include in the catch at size tables the discarded fish.

## Previous Studies

In 2001, Di Natale et al., [5] published a paper on possible measures to protect juvenile swordfish in the Mediterranean Sea, taking into account the biological characteristics and the nature of the swordfish fishery in the Mediterranean. They noted that the peak of spawning season of the species in the Mediterranean usually includes the months of June and July, which was also reported by (De Metrio et al. [4]; Megalofonou et al.[12]; Tserpes et al.[20]), followed by a recruitment period in October-January. They also pointed out, that the size frequency distribution caught by fisheries is not well sampled because many sampling programs focus on landings rather than catches. They recommended a closed season between September and February, that could potentially reduce the catch of juvenile swordfish, and suggested a minimum of 2-months duration of the closure.

Following the same assumption on the recruitment period of swordfish, the authors in [19] simulated the effects of a plausible four-month seasonal closure, during the recruitment period (October-January), on all Mediterranean swordfish fisheries. They concluded that annual catch will increase by $6 \%$ in a period of five to six years after the closure and catch reduction in juveniles will reach $18-23 \%$ of their total catch number.

Tserpes et al. in [22], conducted a bio - economic evaluation of seasonal closures during the recruitment period. The authors examined the effects of different duration closures, between two to six months, concluding that in the long term, the benefits regarding SSB could reach up to $140-180 \%$. More specifically, their results showed that gains in the SSB can be expected from the four and six months closure, while the one and two months will not yield to significant rise in SSB.

In [17], the authors studied the longline fisheries in the Mediterranean Sea. Specifically for the case of swordfish fishery in the Eastern Mediterranean Sea and by using Generalized Additive Models, they investigated spatiotemporal fishery patterns and showed that undersized swordfish was the most frequent by-catch species with a frequency of occurrence around $33 \%$ and a significantly higher probability of capture in February (Figure 1). However, the period under study in this report does not include the months October - January because of a closed period for the Greek swordfish fishery was established to protect juvenile fish.


Figure 1: Month effect on the probability of undersized swordfish captures (source: [17])
In the same report, the authors examined the Albacore fishery in the Central Mediterranean, which operates from September to December. The results of the study show that the fishery has a high by-catch rate of swordfish, sometimes higher than that of the target species and the catches are mainly composed of undersized
individuals. Swordfish in particular occurred in about $38 \%$ of the fishing trips. Figure 2 shows the mean weight observations of swordfish catches and Figure 3, shows the model effects of month on swordfish catch probability.


Figure 2: Box-plots of the mean weight observations for swordfish. Horizontal dotted lines indicate minimum landing size -90 cm , (source: [17])


Figure 3: Model effects of month on swordfish catch probability (source: [17])
As the authors noted, the lower selectivity of the albacore fishery is mainly due to its spatio - temporal exploitation pattern, as the peak of the fishing season is in the fall and coincides with the recruitment of swordfish.

According to [11], there is a difference in the reporting of discards since the minimum size regulations came into force in 2014 and 2017. It appears that Greece and Spain are still reporting undersized dead fish, while other countries, such as Italy present different exploitation pattern before and after the MLS regulation.

## Data analysis

ICCAT's statistics database includes information on both observed and extrapolated catch at size by country and time period (month, qurter, year). Based on [11], an examination of the percentage of the catch that is age class 0 by month is conducted for the countries of Spain, Greece and Italy. For Spain and Greece all the available time series of observed catch at age is being used while for Italy the time series before the application of the regulation in 2014. The reference table for the analysis can be found in (ref. ICCAT table T2SZ). A data cleaning process was performed in order to keep only Mediterranean swordfish stock, observations for lower-jaw fork length (LJFL) and Longliners as the operating gear. Age class 0 is determined according to the VBGC [21], selecting all the fish below 72 cm LJFL following the bio-economic study of [22].

Even though table T2SZ consists of observations on catch at size and not catch at size raised to the total landings, the ratio age0/catch, immature/catch will remain constant by country and time period and this ratio will be a sufficient indicator on how class of age 0 is distributed through out the year. In [11] an analysis was performed, using the observed catch at size, to estimate total dead discards and inform the stock assessment.

In Figure 4 the percentage of age 0 in the catch in numbers is presented, with Spain and Greece exhibiting the highest ratio in November of 13 and $22 \%$ respectively while Italy has its highest percentage in October of $17 \%$.


Figure 4: \% of age 0 fish in numbers in the catch


Figure 5: \% of age 0 fish in numbers in the catch

In some cases Italy has reported observed sizes by quarter. In Figure 5 percentage of age 0 in the catches is presented for Italy, clearly indicating the highest percentage on the forth quarter.

Task 2: Review of the last ICCAT stock assessment and explore management scenarios aimed at reducing juvenile mortality to assess the impact that such measures would have on the recovery of the stock and towards achieving the objectives of the rebuilding plan.

## Review of the last ICCAT stock assessment

Last assessment of the Mediterranean Swordfish was performed in 2020 [3]. Three different stock assessment models were applied for the preliminary analysis of the stock status of the Mediterranean Swordfish. One Bayesian State - Space Production model, JABBA [23] and two age structured models, XSA [9, 16] and a4a [13, 14]. Both age structured models used data from 1985 to 2018 and 5 CPUE indices while both showed a declining trend for the SSB and the Recruitment. JABBA model used data from 1950 to 2018 and 4 CPUE indices. After examining the outcomes of the three models, the assessment group decided that the Bayesian State - Space model (JABBA) gave biologically more plausible results and was more suitable for providing scientific advice. The important difference between age structure models and JABBA was that the whole time series from 1950 to 2018 was used as input to the JABBA model. Moreover, according to the expert knowledge of the scientists familiar with the Mediterranean swordfish fisheries, JABBA model explained better the historical evolution of the fisheries.

However, the assessment group noted that JABBA model [24] showed a systematically negative pattern in biomass process error over the most recent period, which was inline with the strong negative trends in recruitment residuals of both XSA [18] and a4a[10] models. Other factors that could cause such patterns include unaccounted fishing mortality of undersized fish, which is also related to the discussion about the currently available discards information reported by CPCs [3, 11]. Dead discarded undersized swordfish considered under-reported and Ortiz M. in [11] presented preliminary estimations for undersized dead discards for the countries that do not report fish below 100 cm since 2010. These estimations of discards were included in all three assessment models. All models indicated that the stock's productivity has been below average for the past decade, which should be taken into account when projecting the stock forward.

The rate of exploitation, estimated by the JABBA model is $F_{2018} / F_{M S Y}=0.93$, which indicates that the stock is being fished slightly below the reference value of $F_{M S Y}$, while the biomass levels were estimated to be below the reference value with $B_{2018} / B_{M S Y}=0.72$. According to the projections, catches up to 9000 or 10000 tonnes would result in probabilities higher than $60 \%$ for not expecting overfishing by 2021 or 2022 . For the biomass, the projections showed that it would require the total catch to be below 8,000 tonnes or below 10,000 tonnes to rebuild the stock to $B_{M S Y}$ by 2025 or 2028 respectively, with probability $60 \%$. (Figure 6 )

However, the uncertainty around the number of reported catches, especially for the dead discards, the presence of systematically negative pattern in process error variation of biomass over the years 2005-2016 as well as the low productivity indicated by all three models, could possibly lead to over-optimistic predictions for the future of the stock.


Figure 6: Trends of relative stock biomass and relative fishing mortality of Mediterranean swordfish under different TAC scenarios, based on the projections of JABBA model runs. (source: [3])

## Building Management Scenarios and biological projections

Two different management scenarios were investigated in order to demonstrate the effect of reducing juvenile mortality of the Mediterranean swordfish. The base case scenario was to project the status quo situation forward by implementing two different harvest strategies described below, and making two different assumptions for the productivity of the stock. The second scenario consisted of reducing fishing mortality on juveniles and repeating the same analysis as the base case scenario to compare the results.

The bio-economic projections were conducted using the FLBEIA [7] framework. All projections were through the year 2035 with the first projection year in 2019. FLBEIA is a simulation toolbox implemented as an $R$ library [15] that facilitates the development of bio-economic impact assessments of fisheries management strategies. Eight different scenarios were evaluated over the period 2019 to 2035 . The basis of the analysis was to test the reduction of juvenile mortality against the status quo scenario. In order to assess the impact of this reduction, different assumptions were made about recruitment and harvest strategies, resulting in eight different scenarios.

## Harvest Strategies

## Constant catch (CC)

According to the Recommendation by ICCAT (16-05), for the year 2017, a Total Allowable Catch (TAC) was set to 10,500 tonnes and over the period 2018-2022 the TAC should be gradually reduced by $3 \%$ each year. Following this recommendation, a harvest strategy was implemented by setting TAC as mentioned, up until 2022, and keeping it constant from 2022 to 2035 at 9016.7 tonnes (See Table 1).

| year | TAC |
| :---: | :---: |
| 2019 | 9879.45 |
| 2020 | 9583.07 |
| 2021 | 9295.57 |
| $2022-2035$ | 9016.71 |

Table 1: TAC for years 2019-2035

## Annual TAC (AT)

In order to demonstrate better the effect of reducing juvenile mortality on the projection of the stock, another approach for the Harvest Strategy was implemented. An annaul TAC was applied, targeting to reduce $F$ to $F_{M S Y}$ as follows:

$$
T A C_{y}\left\{\begin{array}{ll}
0.97 \cdot T A C_{y-1}, & \text { if } F_{y-1} \geq F_{M S Y} \\
1.2 \cdot T A C_{y-1}, & \text { if } F_{y-1}<F_{M S Y}
\end{array}, \text { where } y \in\{2020, \ldots, 2035\}\right.
$$

and for the change of the amount of catch in order to achieve the $F$ target a threshold of $\pm 10 \%$ was set. For the intermediate year (2019) fishing mortality was set equal to the terminal year of assessment, $F_{2019}=F_{2018}$.

It should be pointed out that when referring to TACs, only landed catches are considered (i.e landings) and thus discards are not included. The same holds for the economical projections.

## Stock Recruitment Relationships

Two different stock recruitment relationship were used to project the stock forward in time. The one was a Beverton - Holt, as the one that was used for the two age structured models of the ICCAT's assessment and the other one was to assume a constant recruitment over time, equal to the geometric mean of the last decade. The later, was used in order to account for the low productivity of the stock that was identified in all three different stock assessment models.

## Biological Data Input

Mediterranean swordfish is considered a unique stock in the boundaries of Mediterranean See and so a single stock model was implemented in FLBEIA framework. From the XSA final runs, the one that included the estimated discards was selected to perform biological projections. The reason for selecting XSA assessment results to initialize the FLBEIA model was that in order to account for a reduction on juvenile fishing mortality, an age structure model is required. Moreover, XSA was the model that was used in previous Mediterranean

Swordfish assessments. In addition, compared to JABBA model that was selected for advice by the ICCAT assessment, XSA resulted in less optimistic results on the perception of the stock status, which gave the opportunity for a more conservative approach to the analysis.

The parametrization of the FLBEIA model for the biological input was based on the average of the last three years of the assessment output and included stock numbers by age, natural mortality, maturity and mean weight of fish by age in tonnes (See Table 2). The spawning season was set to the middle of the year, as several studies suggest [4, 12, 20].

| age | stock.numbers | natural.mortality | maturity | mean.weight..t. |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 773799 | 0.20 | 0.00 | 0.01 |
| 1 | 604745 | 0.20 | 0.00 | 0.01 |
| 2 | 425241 | 0.20 | 0.15 | 0.02 |
| 3 | 245632 | 0.20 | 0.65 | 0.03 |
| 4 | 108883 | 0.20 | 1.00 | 0.05 |
| 5 | 57097 | 0.20 | 1.00 | 0.06 |
| 6 | 6824 | 0.20 | 1.00 | 0.09 |

Table 2: Biological input for FLBEIA
As mentioned above, two different stock recruitment models were chosen for the projections. A Beverton Holt and a recruitment equal to the geometric mean of the last decade. The main source of uncertainty in the projections is the component of uncertainty in the two different Stock Recruitment models that were calculated using FLR framework. In Figure 7 the values of recruitment for both cases are presented along with their $90 \%$ and $75 \%$ confidence limits. The recruitment is fluctuating around the two main assumptions of productivity, Beverton - Holt and geometric mean respectively.


Figure 7: Recruitment projections based on the two different stock - recruitment models, Beverton - Holt and Geometric mean, along with $90 \%$ and $75 \%$ uncertainty intervals. Vertical black line indicates the first projection year, 2019

For the population dynamics of the stock, an age structure population growth (ASPG) was assumed and used for the projections as described in FLBEIA manual [7]. Reference points were derived from the final XSA assessment and are presented in Table 3.

| Fmsy | Bmsy |
| :---: | :---: |
| 0.355 | 60376 |

Table 3: Reference points

## Fleet Data Input

Similar to the biological input, for the fleet input to the FLBEIA model, the average of the last three years of assessment was used to initialize the catch data. Catch data are divided into landings and discards. Since discards data were not available by age in the stock assessment output, all age 0 fish and $80 \%$ of age 1 fish were assigned to discards in order to be able to make projections and discards ratio forecasts. For the purposes of this analysis, a single fleet model was assumed and effort data were derived from the T2CE table published on the ICCAT website [8] and is measured in days at sea. As for the effort model a Simple Mixed Fisheries Behavour (SMFB) model is considered [7]. Since more than $95 \%$ of the total Mediterranean swordfish catch is associated with longline (LL) fisheries following the gillnet ban, only vessels using LL were considered. For the catch production function a Cobb - Douglas model was chosen for the analysis. Information on average price by age was taken from the FAO European price report[6]. FAO's prices are divided by weight category as seen in Table 4. These prices do not reflect the average price of swordfish throughout the Mediterranean, so any analysis of the profitability of the fisheries in the scenarios is relative rather than absolute. Prices are considered fixed for the projected years.

| Weight | price.EUR |
| :---: | :---: |
| $<12$ | 10.50 |
| $13-18$ | 10.50 |
| $19-25$ | 10.50 |
| $>25$ | 7.01 |

Table 4: FAO prices in euros per fish and weight

## Results

## Biological Projections

The following results are based on the two Harvest Strategies implemented in FLBEIA framework. A constant catch (CC) and an annual TAC (AT), as described above. The Figures 8, 9 and 10 show the evolution of projected catch, biomass and fishing mortality based on the Constant Catch (CC) harvest strategy.

## Constant Catch (CC)



Figure 8: Catch projections for CC harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean, along with uncertainty intervals for $90 \%$ and $75 \%$. Vertical black line indicates the first projection year, 2019

As mentioned before the constant catch harvest strategy, which is presented in Table 1 refers to landed fish and excludes dead discards, which is why a slight difference between the two scenarios is present.


Figure 9: Biomass projections for CC harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean, along with uncertainty intervals for $90 \%$ and $75 \%$. Vertical black line indicates the first projection year, 2019. Dashed horizontal line indicates $B_{M S Y}$

In Figure 9 the projection of the biomass of Mediterranean swordfish is presented for CC Harvest strategy. In all cases, $B_{M S Y}$ would recover by 2030 . In particular, for the Beverton - Holt ( BH ) stock recruitment model assumption and for the base case (BC) scenario $B_{M S Y}$ would be achieved by 2024 while for scenario were juveniles are protected (JP) will be achieved by 2023. For the Geometric mean (GM) recruitment model and the BC scenario $B_{M S Y}$ should be reached by 2027 and for the alternative scenario by 2025 . It seems that by reducing catch in such low levels, the stock is able to recover relative quickly.

Figure 10 presents $F$ for CC Harvest strategy. In this case and especially for BH stock recruitment assumption, the pattern seems almost the same for both scenarios. For BH stock recruitment and BC scenario $F \leq F_{M S Y}$ would be reached by 2023, while for JP be reached by 2022 . For GM recruitment, in both BC an JP scenario, $F$ will be just below $F_{M S Y}$ by 2023.


Figure 10: F projections for CC harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019. Dashed horizontal line indicates $F_{M S Y}$

## Annual TAC (AT)

Figure 11 presents projections of the catch for AT harvest strategy.Due to dependency of catch at each year from the status of the stock at the previous year, the differences between the two scenarios and between the two recruitment models are more evident.


Figure 11: Catch projections for AT harvests strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean, along with uncertainty intervals for $90 \%$ and $75 \%$.

Figure 12 presents the projections of biomass for AT harvest strategy, in this case the recovery of biomass towards $B_{M S Y}$ is slower than the CC harvest strategy, which is expected because greater amounts of catch are allowed through out the projections. For the BH recruitment model and BC scenario biomass would have
recover by 2028 while for the JP by 2025. For the GM recruitment model and BC scenario biomass will reach close to $B_{M S Y}$ by the end of the projection while for the JP scenario biomass will surpass $B_{M S Y}$ in 2030. In this harvest strategy the benefits of reducing juvenile mortality are more evident since for the larger amounts of catch the biomass seems to recover quicker.


Figure 12: Biomass projections for AT harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019, Dashed horizontal line indicates $B_{M S Y}$

Figure 13 presents the $F$ projections for AT harvest strategy. As it is expected, they all follow the same pattern, declining towards $F_{M S Y}$, which is achieved in all cases by 2030 .


Figure 13: F projections for AT harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019, Dashed horizontal line indicates $F_{M S Y}$

By reducing fishing mortality on juvenile fish, the biomass recovers more quickly than under the status quo scenario. In addition, under the annual TAC regime, where the TAC is calculated each year based on the status of the stock, a larger catch can be taken while the stock remains healthy. However, these simulations rely heavily on a number of assumptions about the status of the stock at the start of the simulations. These include, for example, the amount of catch that is actually taken from the sea, the reporting of discards, and biological assumptions such as the productivity of the stock as expressed by the two recruitment models. These assumptions introduce several sources of uncertainty into the model that cannot always be measured and incorporated into the model's simulations.

Task 3: Estimate the economic impact that different management scenarios can have on the fisheries, and the potential benefits in the short (1-3 years), mid (5 years), and long (10+) term.

## Economic Projections

Various economic indicators were calculated based on publicly available data. Due to lack of information on effort, prices per country, and fixed and variable costs (i.e. wages, fuel costs and consumption) across the Mediterranean sea, this analysis is mainlly relative. In particular, each economic indicator that is being presented, is evaluated by comparing it to the baseline scenario (status quo), given some default values like the numbers of days at sea and the prices taken from FAO. Therefore, the values presented in the figures and table are the percentage changes in respect to the base case (BC) scenario:

$$
\text { percentage change }=\frac{E I-E I_{B C}}{E I_{B C}} \times 100
$$

$E I$ refers to each economic indicator presented below. Similar to the biological indicators, the following results are based on the two different harvest control rules, constant catch (CC) and annual TAC (AT).

## Constant Catch (CC)

In Figures 14, 15 and 16, discards, effort and gross revenue percentage changes are presented for the two recruitment models. The percentage change in discards numbers, between the BC scenario and the JP scenario, falls down around $80 \%$.


Figure 14: Percentage change in discard numbers for CC harvest strategy based on the two different stock recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019

Figure 15 presents the percentage change in effort between the two scenarios, BC and JP. Effort is measured in days at sea. In both cases, for the JP scenario, the effort change is more than $5 \%$ by the end of the projections. For the Beverton - Holt recruitment model the reduction is smaller while for geometric mean recruitment, in the mid - term predictions, this reduction reaches up to $16 \%$.

Figure 16 presents the percentage change in gross revenue between the two scenarios, BC and JP. Gross revenue is calculated as:

$$
\sum_{a=0}^{6} l_{a} \times w_{a} \times p_{a}
$$

where $l_{a}$ landings in numbers at age $a, w_{a}$ mean individual weight at age $a$ in tonnes and $p_{a}$ the price per tonne of fish at age $a$.


Figure 15: Percentage change in fishing effort in days at sea for CC harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019


Figure 16: Percentage change in gross revenue for CC harvest strategy based on the two different stock recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019

In the case of CC harvest strategy and for both recruitment models, a small loss of revenue is observed in the JP scenario compared to the BC scenario. Just over $1 \%$ for the BH recruitment and just above $2 \%$ for the GM recruitment model. This loss in gross revenue can be explained by the prices and the fact that, in the long term, the majority of catches in this harvest strategy come from the old ages where the prices fall. However, considering the fishing effort decreases by $5 \%$ to $10 \%$ in the JP scenario, this loss in revenue could be offset by gains in fuel consumption or other variable costs that associated with effort.

## Annual TAC (AT)

Figures 17, 18 and 19 present discards, effort and gross revenue percentage changes.


Figure 17: Percentage change in discard numbers for AT harvest strategy based on the two different stock recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019

Discards percentage change in the case of AT harvest strategy presents almost the same pattern as in the CC harvest strategy with a reduction about $70 \%$ in JP scenario, compared to the BC scenario.


Figure 18: Percentage change in fishing effort in days at sea for AT harvest strategy based on the two different stock - recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019

As far as fishing effort is concerned, the situation is reversed for the AT harvest strategy. In this case, effort increases by about $7 \%$ to $10 \%$ in the long term, which can be explained by the fact that the protection of
juveniles, in AT harvest strategy allows larger catches, which leads to an increase in fishing effort.


Figure 19: Percentage change in gross revenue for AT harvest strategy based on the two different stock recruitment models, Beverton - Holt and Geometric mean. Uncertainty intervals for $90 \%$ and $75 \%$ are also presented. Vertical black line indicates the first projection year, 2019

Gross revenue percentage change in the case of AT harvest strategy shows an increase greater that $10 \%$ in both recruitment models. Followed by the a greater amount of catch the JP scenario seems more profitable than the BC, given that the increase in gross revenue exceeds the increase in effort.

The following Tables 5, 6, 7 and 8 show the percentage changes between the BC scenario and the JP scenario for the various economic indicators for the two different harvest strategies for the short-, medium-, and longterm projections. Short-term refers to the average of the years 2019 to 2021, medium-term refers to the average of the years 2022 to 2025 , and long-term refers to the years 2026 to 2035 .

| $\ldots$ | short.term | mid.term | long.term |
| :--- | :---: | :---: | :---: |
| Discards | $-74.28 \%$ | $-77.76 \%$ | $-77.55 \%$ |
| Effort | $4.8 \%$ | $-9.82 \%$ | $-8.8 \%$ |
| Gross Revenue | $0.13 \%$ | $-0.59 \%$ | $-1.74 \%$ |

Table 5: Percentage changes in short, mid and long term for CC harvest strategy and BH recruitment model

| $\ldots$ | short.term | mid.term | long.term |
| :--- | :---: | :---: | :---: |
| Discards | $-74.37 \%$ | $-78.48 \%$ | $-78.97 \%$ |
| Effort | $4.27 \%$ | $-12.39 \%$ | $-14.36 \%$ |
| Gross Revenue | $0.17 \%$ | $-0.63 \%$ | $-2.34 \%$ |

Table 6: Percentage changes in short, mid and long term for CC harvest strategy and GM recruitment model

| $\ldots$ | short.term | mid.term | long.term |
| :--- | :---: | :---: | :---: |
| Discards | $-74.01 \%$ | $-74.9 \%$ | $-73.22 \%$ |
| Effort | $5.91 \%$ | $1.72 \%$ | $8.58 \%$ |
| Gross Revenue | $1.23 \%$ | $10.97 \%$ | $13.26 \%$ |

Table 7: Percentage changes in short, mid and long term for AT harvest strategy and BH recruitment model

| ... | short.term | mid.term | long.term |
| :--- | :---: | :---: | :---: |
| Discards | $-73.95 \%$ | $-74.56 \%$ | $-72.9 \%$ |
| Effort | $5.99 \%$ | $3.53 \%$ | $10.29 \%$ |
| Gross Revenue | $1.91 \%$ | $12.25 \%$ | $13.85 \%$ |

Table 8: Percentage changes in short, mid and long term for AT harvest strategy and GM recruitment model

## Conclusion

In general, scenarios implementing juvenile fishing mortality reduction exhibited a quicker recovery of the stock in all cases. This was most evident in the Annual TAC harvest strategy, where catch was allowed to vary depending on the levels of fishing mortality and, given greater amount of catch, the biomass recovered quicker. The Annual TAC harvest strategy is a plausible future scenario because, compared to the Constant Catch, after the recovery of the stock catches are allowed to increase. However, the implementation of the scenarios presented in this report is based in a stock assessment model that carries great uncertainty regarding both the amount of discarded fish in small ages as well as the actual status of the stock compared to reference points. As a model it has not been selected for advice in the last stock assessment group although it is well suited for the purposes of this study. In addition, several economic parameters that are critical to a complete economic projection were not available and various assumptions were made in order to compare the different scenarios. All of the above should be taken into account when interpreting the results of this report. Table 9 summarizes the results of the two different scenarios for the Annual TAC harvest strategy and the geometric mean recruitment assumption. The decision to present these results is based on the fact that the Annual TAC seems more plausible as harvest strategy while the assumption of recruitment fluctuates around the geometric mean of the past 10 years is considered conservative.

| Parameter | Percentage Change compared to BC scenario |
| :--- | :--- |
| Catch | $\sim 10 \%$ increase in the long term |
| Biomass | $\sim 6 \%$ increase in the long term and will reach biomass reference point 5 years earlier |
| Discards | $\sim 70 \%$ reduction for the projection years |
| Discards at age 0 | $\sim 40 \%$ reduction |
| Effort | $\sim 10 \%$ increase in the long term |
| Gross Revenue | $\sim 14 \%$ increase in the long term |

Table 9: Summary of the AT harvest strategy and GM recruitment model

## References

[1] Anon. Report of the 2016 iccat mediterranean swordfish stock assessment meeting. Collect. Vol. Sci. Pap. ICCAT 73, 3 (2017), 1005-1096.
[2] Anon. Report of the 2020 ICcat Intersessional meeting of the stock ASSESSMENT METHODS WORKING GROUP, 2020. WGSAM.
[3] Anon. Report of the 2020 iccat mediterranean swordfish stock assessment meeting. Collect. Vol. Sci. Pap. ICCAT 77, 3 (2020), 179-316.
[4] De Metrio, G., and Megalofonou, P. Catch, size, distribution, growth and sex ratio of sword fish (xiphias gladius l.) in the gulf of taranto. Fao fisheries report (fao), FAO, 1988.
[5] Di Natale, A., De La Serna, J., G., D. M., Restrepo, V., Srour, A., and Tserpes, G. On the reduction of juvenile swordfish catches in the mediterranean. Collect. Vol. Sci. Pap. ICCAT 54, 5 (2001), 1529-1533.
[6] FAO. European price report. http://www.fao.org/in-action/globefish/publications/detailspublication/en/c/1295848/, 2020.
[7] Garcia, D., Sanchez, S., Prellezo, R., Urtizberea, A., and Andres, M. Flbeia: A simulation model to conduct bio-economic evaluation of fisheries management strategies. SoftwareX 6 (2017), 141-147.
[8] ICCAT. Access to iccat statistical databases. https://www.iccat.int/en/accesingdb.html, 2018.
[9] Kell, L. T. FLXSA: eXtended Survivor Analysis for FLR, 2020. R package version 2.6.4.
[10] Mantopoulou-Palouka, D., and Tserpes, G. Assessment of the mediterranean swordfish stock by means of assessment for all. Collect. Vol. Sci. Pap. ICCAT 77, 3 (2020), 482-507.
[11] Mauricio, O. Estimation of undersize mediterranean swordfish (xiphias gladius) catches between 2008 2018 for the longline main fleets. Collect. Vol. Sci. Pap. ICCAT 77, 3 (2020), 317-329.
[12] Megalofonou, P. First results on the aging of juvenile swordfish, xiphias gladius 1 . from the mediterranean sea using otoliths. Collect. Vol. Sci. Pap. ICCAT 33 (1990), 163-167.
[13] Millar, C., and Jardim, E. a千a: A flexible and robust stock assessment framework, 2019. R package version 1.8.2.
[14] Millar, C. P., Jardim, E., Osio, G. C., and Mosqueira, I. a4a: A flexible and robust stock assessment framework. Subbmitted to PLOSone $x x$, x (201x), xx-xx.
[15] R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, 2021.
[16] Shepherd, J. G. Extended survivors analysis: An improved method for the analysis of catch-at-age data and abundance indices. ICES Journal of Marine Science 56, 5 (10 1999), 584-591.
[17] Tserpes, G., Garibaldi, F., Ortiz de Urbina, J. M., De la Serna, J., Peristeraki, P., Macías, D., Di Natale, A. M. A., and M.T., S. Catches of pelagic (drifting) longline fisheries in the mediterranean - MEDPEL. Final report of sc no.6, MARE/2009/05-Lot 1, 2014.
[18] Tserpes, G., and Mantopoulou-Palouka, D. Assessment of the mediterranean swordfish stock by means of extended survivors analysis (xsa). Collect. Vol. Sci. Pap. ICCAT 77, 3 (2020), 407-481.
[19] Tserpes, G., and Peristeraki, P. Effects of a seasonal closure of the mediterranean swordfish fisheries on the stock production levels. Collect. Vol. Sci. Pap. ICCAT 60, 6 (2007), 2059-2062.
[20] Tserpes, G., Peristeraki, P., and Somarakis, S. On the reproduction of swordfish (xiphias gladius 1.) in the eastern mediterranean. Collect. Vol. Sci. Pap. ICCAT 52 (2001), 740-744.
[21] Tserpes, G., and Tsimenidis, N. Determination of age and growth of swordfish, xiphias gladius l., 1758, in the eastern mediterranean using anal-fin spines. Fishery Bulletin - National Oceanic and Atmospheric Administration 93, 3 (1995), 594-602.
[22] Tserpes, G., Tzanatos, E., Peristeraki, P., Placenti, V., and Kell, L. A bio-economic evaluation of different management measures for the mediterranean swordfish. Fisheries Research 96, 2 (2009), 160-166.
[23] Winker, H., Carvalho, F., and Kapur, M. Jabba: Just another bayesian biomass assessment. Fisheries Research 204 (2018), 275 - 288.
[24] Winker, H., Kimoto, A., Mourato L., B., Tserpes, G., and Ortiz, M. Development of bayesian state-space surplus production model jabba for assessing the mediterranean swordfish (xiphias gladius) stock. Collect. Vol. Sci. Pap. ICCAT 77, 3 (2020), 508-536.

