Independent External Review of Patagonian toothfish, *Dissostichus eleginoides*

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Executive Summary

This independent external review of the Patagonian toothfish (*Dissostichus eleginoides*) stock assessment was conducted in Viña del Mar from May 6-9, 2025. Prior to and during the review period we evaluated the assessment methodology, data quality, analytical approaches, and management recommendations for both the artisanal fishing area (APA) north of 47°S and the licensed area (AL) south of 47°S. From these, we noted some key findings:

- Retrospective patterns in biomass were notable, indicating potential systematic bias and overestimation of current stock size
- The data on age compositions show atypical patterns; e.g., several consecutive years with 20-yr old being highly prevalent.
- The model fit the industrial fleet age composition and CPUE indices poorly with consistent over- and under-estimation of specific age groups
- The CPUE index from the artisanal fleet, as is common in all fishery-dependent indices, requires standardization procedures to account for preferential sampling. In particular, the temporal coverage is unbalanced with 85.9% of the data from 1986-2003 and only 12.5% from recent years 2017-2023). This and the lack of covariates for standardization could create biases in trends
- Catch reconstruction uncertainty estimates need refinements and evaluation
- Fishery-independent abundance estimates are lacking. Relying on potentially hyperstable CPUE indices could affect estimates of population trends.
- The "national model" model appears to be most appropriate; the alternative area-specific models appear to lack the appropriate representation of the biology of the stock (considering spawning extent etc.).

Relative to ecosystem considerations, we note that the industrial fleet has successfully eliminated seabird mortality through cachalotera gear implementation since 2008. A similar program should be implemented and verified within the artisanal sector.

In summary, while the assessment has made substantial improvements since the 2015 review, fundamental uncertainties regarding stock structure, data quality, and model reliability persist. The retrospective patterns and unusual age compositions raise concerns about current biomass estimates and recruitment. A precautionary management approach is strongly recommended until these issues are resolved, particularly given the species' potential vulnerability due to their longevity and relatively low natural mortality.

The assessment provides a reasonable basis for management decisions but requires immediate attention to the identified technical issues to ensure long-term sustainability of this valuable fishery resource. Moving forward, we have the following recommendations:

1. Resolve age composition anomalies through investigation of sampling protocols, gear selectivity effects, and biological processes
2. Investigate model fit issues by developing an assessment model using length composition data (combined and then by sex) to reduce the lack of fit of abundance indices, given that length compositions appear more informative and may better represent cohort dynamics.
3. Address retrospective patterns which suggest current biomass may be overestimated
4. Given the uncertainty in biomass and recruitment estimates, it is recommended to use the 15-20th percentile (or some adequate/reasonable percentile using similar methodology) of the biomass distribution for management decisions and fish at 0.75FMSY or lower to account for assessment uncertainties and potential overestimation of stock size.
5. Enhance artisanal fleet data collection through improved logbooks and representative sampling protocols via cooperative programs, given the acknowledged difficulties of sampling this dispersed and diverse fleet across extensive operational areas
6. Quantify marine mammal depredation impacts on catch rate.
7. Develop fishery-independent abundance surveys to reduce reliance on CPUE indices
8. Establish comprehensive tagging program following CCAMLR guidelines to clarify stock structure and connectivity
9. As a research priority in the longer term, we recommend the development of a “Management Strategy Evaluation” (MSE) framework to address structural uncertainties while providing improved transparency in management recommendations.

Introduction

The following report corresponds to the external review of toothfish (*Dissostichus eleginoides*) conducted in Viña del Mar from May 6-9, 2025. The review was based on comprehensive documentation including the *Informe Técnico Final, Convenio de Desempeño 2023, Programa de Seguimiento de las principales Pesquerías Nacionales, Pesquerías Demersales y de Aguas Profundas, año 2023, Sección VI. Pesquería de Bacalao de Profundidad* and the *Informe Técnico de Asesoría Científica, Convenio de Desempeño 2024, Estatus y posibilidades de explotación biológicamente sustentables de los principales recursos pesqueros nacionales, año 2025: BACALAO DE PROFUNDIDAD*, along with detailed presentations provided during the workshop.

The following sections detail the main improvement aspects and comments that were identified through the review of these documents, data presentations, and toothfish stock assessment materials. To evaluate the information presented, topics were loosely organized following the framework recommended in previous reviews.

Description of general distribution

The information on stock distribution was presented clearly and it was confirmed that there are significant gaps in the spatial structure and connectivity of toothfish. This aspect had already been mentioned by Polacheck (2015) in a previous review of this stock. It is recognized that understanding the stock structure is very difficult given the wide distribution of the stock. While tagging and recapture studies have been conducted, these have been more like experiments and there is still no tagging program that allows clarification of the spatial structure and connectivity of toothfish. This aspect should be addressed more thoroughly in the future as it is already a routine part of CCAMLR.

Currently, management has been approached based on fishing units:

- Licensed Area (UPL): South of parallel 47° S to 57°30' S (industrial and artisanal)
- Artisanal Fishing Area (APA): North of parallel 47° S (exclusively artisanal)
- APA Subdivisions: Zone 1 (northern limit to 30° S), Zone 2 (30°01' to 41° S), Zone 3 (41°01' to 47° S)

These units seem to capture the fishing dynamics where there is clearly separation of artisanal and industrial fleets, respectively.

The information presented shows evidence that the APA shows a higher juvenile proportion than that presented by the UPL. Thus, it seems that there is significant spatial non-homogeneity in the distribution of adults and juveniles. However, the length size distributions have been consistent across years for the artisanal fleet.

Tagging studies show that individuals tagged in the UPL can move northward. As mentioned, a tagging program is needed in the APA to better understand the distribution and movement of toothfish. For example, in CCAMLR fish are tagged at a rate of 1-5 individual per ton on a mandatory basis. Life history characteristics relevant to stock assessments.

Detailed descriptions, and it is evident that this is a long-lived species with late maturity. The M parameter and the individual growth parameters (sexes combined) used are similar to values used in other stock assessments (Earl & Readdy, 2023). Regarding the age at maturity, there seems to be consensus that the study by Balbontín et al. (2011) appears to be more adequate because it covers the reproductive cycle, size range, and histological analyses. However, that study estimated the size at maturity and then used the growth parameters from Ojeda (year not mentioned) to calculate the age at maturity. This procedure is not ideal and should be reviewed in the short term.

Fishery history

Revisions in harvest policy, and changes in access to the fishery.

The fishery for the stock, including periods of opening/closure of the fishery. The sources do not indicate periods of complete closure for the entire fishery, but rather changes in regime, access, and catch limits over time.

They are mentioned in the stock assessment report, but a clearer temporal description of the milestones is needed to understand this section. The 2013 revision of the LGPA introduced the requirement to include discards in CBA. However, these are only included in the industrial fleet.

Currently, for the APA and AL areas, the analysis of the CBA is conducted by projecting the stock under different constant fishing mortality strategies (FMSY multipliers). It is not clear what the quotas were for the fleets. These should be in the stock assessment report for analysis. Furthermore, it is not clear how the catch quota is determined for each sector. It is not clear what measures are used to control catch and fishing effort. From the presentations it could be confirmed that the artisanal fleet has a restriction on the number of hooks per longline. Apart from catch quotas there appear to be no other restrictions for the fleets.

Currently, the fishery is under Full Exploitation Regime (R. Ex No. 57 of 2003), with closed access and separate quota allocation for the APA and AL areas. Until 2012, the artisanal fleet was not subject to satellite positioning systems, requiring only landing certification by SERNAPESCA for CCRVMA Catch Documentation Scheme (CDS). However, it is not clear how this new information is being used in either monitoring or management.

Data

Summary of new information

Updated information was presented for both monitoring and for the updated information for the stock assessment. This included updated data on landings, age compositions, relative abundance indices, and discards (industrial fleet).

Industrial sector: The monitoring of the industrial sector is characterized by an intensive and detailed approach, focused on the factory longline fleet operating in the licensed area (47°-57°30' S). The main data sources include:

- Onboard scientific observers with high coverage
- Detailed operational records from fishing logbooks

This information has enabled extensive biological and size sampling, including otolith collection and reproductive condition, fishing yield estimates, and detailed distribution of fishing effort by area, depth, and season. Additionally, specific studies have been conducted on predation analysis by marine mammals, mark-recapture and parasitology studies, and discards.

Artisanal sector: The monitoring of the artisanal sector adopts an adaptive approach to address the complexity of a dispersed fleet operating in two main areas: APA (north of parallel 47°S) and UPL (southern licensed portion). The main data sources include:

1. Strategic combination of port sampling and limited trips, achieving in 2023 a coverage of 42% in the APA (337 trips) and 8% in the UPL (8 trips)

When data are collected in situ, there are detailed records of fishing operations, including exact position of sets, depth, effort applied, and yield per set. However, most of the information comes from fisherman interviews where information on fishing zones, trip duration, and operational aspects is collected through structured surveys.

This sector shows logistical difficulties due to fleet atomization, fleet diversity, and extensive operational areas. Additionally, there is limited access to complete biological information. By sampling mainly in port, many specimens are already processed/eviscerated which does not permit sex determination for size sampling and age estimation. Despite these difficulties, size sampling shows significant sample sizes and efforts have been made to estimate reproductive parameters and sex determination with specific sampling.

Data which should be presented as time series, separately by sex and, depending on the assessment.

Total catch, partitioned by strata used in the assessment model, if any.

The industrial sector began with minimal catches until 1988, followed by rapid growth that reached a historic peak near 20,000 tons in 1992. After this historic maximum, an abrupt first contraction was observed until 1997, subsequently stabilizing around 2,000 tons until 2013. In the last decade (2014-2023), industrial catches have reduced and stabilized between 1,000-2,000 tons annually.

The artisanal sector began with very low catches (less than 500 tons) until 1984, experiencing sustained growth until reaching approximately 6,000 tons in 1990. During the period 1992-2003, this fishery maintained high production levels with cyclical fluctuations between 3,500-5,500 tons. Subsequently (2004-2013), it experienced a gradual contraction until stabilizing between 1,500-2,000 tons. In recent years (2014-2023), it has shown fluctuations between 1,000-2,500 tons, with a notable decrease around 2020 (possibly related to the COVID-19 pandemic) followed by a partial recovery.

The presentations did not mention problems with the catch reconstructions but the report states that there is still "the need to revise the historical captures". This suggests that the historical data series currently used may still contain potential issues or uncertainties. These uncertainties were not evaluated in the stock assessment, and this needs a clearer description of the problem. IFOP has conducted a review of official SERNAPESCA landing records for the years 1980 to 2001 and with follow up, using their own monitoring data and expert judgment to align them with fleet categories. However, it is unclear if these catch reconstructions were included in the current stock assessment and how. It is acknowledged that there seem to be significant limitations for performing these reconstructions, but these could be assessed under possible scenarios to evaluate their impact in the stock assessment.

Information on bycatch and discards.

Industrial discards are considered by applying discard factors from available studies (2015 to 2023) to retained catches. However, the data used in the evaluation model does not include corrections for artisanal discards, which are presumed to be insignificant. To be consistent, it needs to be considered to include some hypothesis about discard factors back to 2015 for the industrial discards. Similarly, it needs to be considered to apply discard factors for the artisanal fleet as possible sensitivity scenarios in the near future. These factors could be estimated by the discard team and then discussed by the relevant committees for their inclusion in the stock assessment if necessary.

Catch-at-length (with sample sizes) for fisheries, bycatch, discards, and surveys. For surveys include all known surveys that catch crab.

Age compositions based on otolith readings were presented for the artisanal and industrial fleets. The sample sizes appear to be adequate, and the age estimation also appears to be reasonable given the life history and the specimens sampled.

The age/size structure of the stock has a direct influence on in recruitment variability. One of the main sources of information are the age compositions. However, the age compositions of the industrial fleet appear to have unusual patterns. For example, in some years (e.g., 2021 and 2022) an unusually stable age structure is observed in the exploited population, characterized by a high proportion of individuals in the 30+ year age group and little interannual variation in the representation of age classes between 15 and 30 years. This stability in age compositions suggests a sustained accumulation of long-lived individuals and highlights a persistently "flat" or even biased age structure toward older individuals, which is atypical in fisheries under sustained exploitation.

This pattern contrasts with what would be expected in an actively exploited fishery with population dynamics. Under normal conditions, the age structure should show a high proportion of young fish (product of annual recruitment), a progressive decrease in the proportion of individuals as age increases (due to natural and fishing mortality), and low representation of very long-lived fish (25+ or 30+ years). This type of structure is typically lognormal (with a wide distribution to the right), reflecting a constant flow of entry and exit of individuals over time.

The persistence of these age structures could be explained by several factors, which should be investigated more thoroughly:

- Low fishing mortality: The accumulation of old fish could reflect lower exploitation intensity in recent years, allowing older individuals to remain in the stock without being removed.
- Changes or biases in fishing gear selectivity: The observed age structure could be influenced by how fishing gears operate. In particular, the longline could be selecting specific sizes or ages of individuals. For example, if the gear favors the capture of larger or longer-lived fish, it could be generating a biased representation of the population. This effect can confound the interpretation of the age structure from the observations.

- Problems in biological sampling: Biased or non-representative coverage of port or onboard sampling could generate a false signal of stability. Or alternatively, biased or non-representative coverage of the age structure from biological sampling.
- Atypical population structure: The dominant presence of fish from the 30+ group could be due to historically strong cohorts that have survived exceptionally.
- High natural survival rates: Particularly favorable environmental conditions or a decrease in predation pressure (for example, lower presence of marine mammals) could be contributing to greater longevity of individuals present in the population.

Because of these atypical age compositions, it is evident that the model does not reproduce the proportions for certain years and overestimates cohorts. This could affect recruitment estimates and future biomass. Given that these conditions do not fully conform to the expected dynamics of an exploited population, it is recommended to conduct additional research to clarify their causes and evaluate their implications for stock status estimation and biologically sustainable management recommendations.

Catch-per-unit effort time-series (if used in the assessment) and how the data were standardized with diagnostics tables/plots.

The toothfish stock assessment incorporates three relative abundance indices: the industrial fishing index with Spanish longline (1992-2006), the industrial fishing index with cachalotera (2007-2023), and the artisanal fishing index (1986-2023). For the industrial index standardization, Generalized Linear Models (GLM) and Generalized Linear Mixed Models (GLMM) were used with CPUE measured in kg/(hooks x soaking hours) as the response variable. The linear predictor included the fixed effects Year, Month and Zone, evaluating two random effects structures. In general, the database and applied filters and the methodology appear to be adequate and present a good level of resolution and parsimony. For the industrial standardization, a filter was applied to include only data from boats that operated for a minimum number of years and hauls and met a minimum median catch per haul, to better represent targeted effort. For the artisanal fishery, data from trips longer than 30 days outside port were filtered out.

The artisanal index uses data from two sources: the FIP 96-32 project (1986-1997) and IFOP monitoring (1998-2023), with CPUE expressed in kg/day outside port. GLMM were applied including fixed effects of Year, Month, Zone and HP Category, with different random effects structures.

The data used for estimating these CPUE series come from various sources, including information from the industrial database.

The artisanal series shows limitations. Around 30-40% of annual fishing trips are covered. It seems that 85.9% of the data corresponds to the period 1986-2003, while only 12.5% covers recent years (2017-2023), creating an unbalanced representation of the time series. In general, historical data lack important covariates for standardization. Thus, spatial/temporal variations, variations in the recording of different zones and vessel categories reflect changes in sampling more than real fishery patterns. These factors can generate biases in CPUE estimates that confound real changes in resource abundance with sampling process artifacts.

Another important source of uncertainty is interactions with marine mammals which appear to be important in both fisheries. The limited monitoring coverage in this aspect could introduce biases in CPUE estimations, requiring future formal analyses to evaluate their impacts.

Data which may be aggregated over time:

Preliminary analyses of the size compositions presented in the workshop show that these appear to be more informative in showing cohorts through the years compared to age structures. It was mentioned that these are available by sex for the industrial fleet but not for the artisanal fleet since specimens arrive without viscera at port where they are sampled.

The estimation of weights at age do not appear to have been discussed. However, it was commented that there are discrepancies in the weights at length used by IFOP and SERNAPESCA in the weight conversion for the artisanal fleet. If this were the case, the protocols/conversions of both institutions should be standardized to avoid including observation error in the landing estimates.

Information on any data sources that were available, but were excluded from the assessment.

In the IFOP database there are age estimates and maturity sampling from biological sampling. These databases could be cross-referenced to estimate age at maturity directly without using individual growth parameters. While the sexual maturity estimation is macroscopic, it could be an approximation to corroborate the current method and if there are relevant discrepancies, progress must be made in studying this parameter in the short term.

It is possible that reference age sets are available for *Dissostichus eleginoides* that could be requested from CCAMLR (or some age laboratory) to standardize otolith readings. This could serve two purposes: 1) "validate" age estimates with a "known" age set to give credibility to the age estimates 2) conduct a "between readers" age estimation analysis over a sample which could control inter-annual observation errors for the age compositions. Currently only "within reader" age estimates have been performed, which is not entirely ideal. On the CCAMLR website only the datasets for *Dissostichus* mawsoni are found (https://www.ccamlr.org/en/science/otolith-library).

Analytic Approach

History of modeling approaches for this stock

The analysts responded in detail the recommendations from the 2014 peer review (Polacheck 2015). Specifically:

1. Alternative cases on stock structure: analysis presented explored different spatial and fleet considerations:
    a. Single stock between the Pacific and Patagonian platforms,
    b. a case including only industrial catches (AL), and
    c. a case combining industrial and artisanal Chilean catches (APA + AL).
2. Age determination and bias evaluations, particularly from scales. Age composition data for industrial and artisanal catches are now mostly based on the reading of otoliths. However, the considerations mentioned above about ageing and reproducibility should be examined further.

3. Improved transparency and model diagnostics (analysis of estimated versus observed data, residual plots, composition data fits, and sensitivity/uncertainty analyses). The assessment report describes the use of these diagnostics and sensitivity analysis for parameters like *M*, steepness, and maturity.
4. Reference points: The current report established a formal framework for evaluating the stock status against defined reference points.

In summary, the assessment process has made progress in addressing some recommendations, particularly concerning age data quality and the formalization of reference points. However, the fundamental uncertainty regarding the population's spatial structure remains.

The assessment report presented the history of assessment methodology since 2012. We noted these included different hypotheses on population units. The update of the single stock case (Chile + Argentina, Case 1) was discontinued after 2021 due to the cessation of data contributions from the fishery in the Argentine Exclusive Economic Zone (EEZ). For 2025, a national model (APA/AL) has been adopted.

We noted that a review of official SERNAPESCA landing records from 1980 to 2001 was conducted by IFOP in 2004 to correctly assign catches to artisanal and industrial fleets. These revised catch records have been utilized in the models.

The current assessment model has included separated standardized CPUE series for the industrial fleet, reflecting the change from Spanish longline (1992-2006) to cachalotera (2007-2023), and for the artisanal fleet (1986-2023). Thus, the different efficiencies of these gears are accounted for by estimating different catchability parameters in the model.

Since 2015 the AMAK platform was used. This included the use of size composition data. The impact of depredation by marine mammals was evaluated in 2014. The analysis should be updated and included as part of an additional fishing mortality impact (depredation mortality occurs due to the activity of fishing).

The model used was AMAK, an integrated age-structured model. The equations are described in appendix 1. The equations have formatting issues, and some parameters have a mismatch with the actual value used (h=0.6 but the model used 0.75). Some parameter values are described while others are not. A prior distribution for the minimum length is included but not mentioned in the text. The CV growth was estimated but not mentioned in the list of estimated parameters. It would be better to have a standardized table with the parameter estimates and fixed values for the base case. Neither in the text nor in the appendix are the weightings given to the compositions and indices mentioned. During the workshop, we applied the same datasets to a more developed version of AMAK using "JJM". The code and input files and rudimentary R scripts are available at the following repository: https://github.com/jimianelli/baca. In addition to the repository for the JJM framework (to be considered an updated version of AMAK), there is an S3 R class library to evaluate results here. A tutorial on the application was developed and is available here (documented here).

In general, more care is needed to consider the available data (e.g., the size composition information seemed in conflict with the available age-composition data). The above-mentioned repository also includes a short function to help with viewing and processing length frequency data. An example application of the function is shown in Figures 1-4 below based on data provided during the workshop. These data (although preliminary examples), suggest that extending the length dimensions in the model could be reduced since very few fish are present in the catch beyond 150 cm.

We noted that the current assessment results in very low estimates of recruitment variability, especially when compared to other groundfish species. This could be due to the strange pattern of age composition data that for several, sometimes consecutive, years the proportions of fish at age 20 stand out as being prominent without any apparent progression in subsequent years (as age 21, 22, etc). Also, one high value of recruitment seems to occur prior to when age-composition information becomes available. This issue could affect the scale of the underlying stock-recruit relationship and consequently, estimates of fishing mortality impacts on the population

Fishing mortality estimates reveals significant patterns that reflect the development and subsequent regulation of this fishery. Between 1978 and 1990, fishing pressure on this resource was extremely low, with values close to zero. This period corresponds to the exploratory and initial stages of the fishery, when knowledge about the resource and its commercial potential was limited.

Starting in 1991, a dramatic increase in fishing mortality is observed, coinciding with the development of demand in the North American market and government incentives to increase artisanal fishing capacity. This increase reached its peak around 1995, when total fishing mortality approached 0.10, a value significantly higher than the current one but still below the species' natural mortality (M=0.15).

Subsequently, between 1996 and 2006, a sustained decreasing trend in fishing mortality is evident, likely reflecting the implementation of stricter regulatory measures and partial depletion of the most accessible fishing grounds. During this period, the relative contribution of industrial and artisanal fleets to total mortality experienced important variations, with the industrial fleet showing a marked reduction after its peak in 1993-1994.

In the most recent period, from 2006 to 2023, fishing mortality has stabilized at moderate levels, generally fluctuating between 0.02 and 0.05. Current fishing mortality (2023) is estimated at approximately 0.04, distributed between industrial and artisanal fleets, with a slight predominance of the former.

According to the stock assessment report, the toothfish stock is currently in a condition of "full exploitation". The spawning biomass is situated very close to the biomass associated with Maximum Sustainable Yield (B_{MSY}), calculated at 72,154 tons, and above the limit biological reference point established at $0.5B_{MSY}$.

Toothfish recruitment has shown considerable variability throughout the evaluated period and the recruitment deviations show cyclical patterns that need to be investigated. Additionally, recruitments show greater uncertainty at the end of the series than at the beginning or middle of the historical series. This is possibly due to the lack of fit of the age compositions and the industrial CPUE index in recent years. It is not understood or was not mentioned why there is an abrupt increase from one year to the next in the industrial CPUE (Fig. 17).

The fishery history data (catches and abundance indices) provide no information to estimate stock productivity. The stock-recruitment data confirmed this situation.

Model Selection and Evaluation

In the sensitivity models, productivity parameters such as h and M were analyzed to understand their impact on management and population parameters. Apparently, the maturity ogive does not have a significant impact compared to the base case. However, it is not clear what the difference is between ogives, but if both are derived from sizes, the question remains about the effect of maturity estimated directly from age. In Table 9 from the stock assessment report, the F_{MSY} value is shown but then F45% in parentheses. It is not clear if the values correspond to F_{MSY} or F45%. This is very important to clarify. The values show very little variability except for case S4, even when steepness was estimated as a free parameter.

The sensitivity scenarios do not include any analysis for the relative abundance indices. The CPUE may be hyperstable. Thus, this needs to be explored more thoroughly. In addition, it could be useful to explore alternative model structures in CPUE standardization such as depth effects.

Residual analyses for age compositions and indices were shown. These analyses show residual patterns, but no thresholds are shown. Carvalho et al., (2021) show some guidelines to assess residuals and thresholds. It suggests that these should be included to examine the performance of the model and give advice.

More importantly, the retrospective analysis shows important variations in depletion and biomass changes, indicating uncertainty in the estimation and possible overestimation. A “rule of thumb”, proposed by Hurtado-Ferro et al., (2015), suggests that values of ρM that fall outside (-0.15 to 0.20) for SSB for longer-lived species indicate an undesirable retrospective pattern. It seems that the values estimated for toothfish are outside of this range.

Stock projections

For the national approach, which integrates data from both the artisanal fishing area (APA) and the licensed area (AL), key aspects of how projections are performed with the AMAK model included:

- Medium term (5 years) and the long term (50 years).
- Different scenarios of constant fishing mortality rate
- Future recruitment (age 3) was simulated using a Beverton-Holt stock-recruit relationship and specified value of steepness, and
- The selectivity was based on estimates from the most recent year (2023) in the assessment.

We note that the long-term projections provide insights on relative fishing mortality results *given the assumptions specified* but fail to illustrate a realistic range of uncertainties.

Provision of catch advice

A particularly relevant aspect for the sustainable management of toothfish is the determination of the optimal level of fishing mortality. According to the 2025 toothfish stock assessment report, the FMSY value is 0.068. This value appears to be reasonable. According to Hilborn, the optimal exploitation rate (empirical) for a fish population can be expressed as a proportion of its natural mortality (M), through the formula $u = X \cdot M$, where X is a multiplier that varies according to the biological characteristics of the species and its exploitation pattern (Walters & Martell, 2020). However, the value of X depends fundamentally on the relationship between the age at which fish become vulnerable to fishing and their age of sexual maturity. For species that are captured substantially before reaching reproductive maturity, Hilborn recommends X values equal to or less than 0.6. This recommendation is especially pertinent for toothfish in the Chilean fishery, particularly in the artisanal sector.

The available biological evidence indicates that toothfish reaches sexual maturity between 8 and 12 years for females, and between 6 and 10 years for males. However, the selectivity of the artisanal fleet is concentrated mainly on individuals between 6 and 9 years, which means that a significant proportion of captured specimens, especially females, have not yet had the opportunity to reproduce. This situation exemplifies precisely the scenario where low X values are necessary.

Applying this framework to toothfish with its natural mortality established at M=0.15 and considering an X value between 0.4 and 0.5 (appropriate for a long-lived species captured prematurely), the fishing mortality level recommended by Hilborn would be in the range of 0.06 to 0.075. This range is notably congruent with the F_{MSY} value currently estimated for this fishery (0.068).

However, it is unclear if this value is the estimated value for Fmsy or its proxy.

While the current fishing mortality (F=0.068) remains around the empirical F_{MSY}, it should be remembered that F_{MSY} is the fishing mortality rate that results in B_{MSY} on average. Due to difficulty in estimation because it is sensitive to recruitment variability and other structural assumptions used in the assessment, F_{MSY} should be considered as a limit. For example, fishing at $0.75F_{MSY}$ (or even lower) was found to result in higher stock size (125%-131% of B_{MSY}) at "the expense of relatively small forgone yields" (94% of MSY or higher) (PEW, 2016). For data-limited toothfish fisheries in the Southern Ocean there are generally no fishery-independent data on the status of the stock a harvest rate of 4% is used (CCAMLR, 2023).

This buffer provides an additional safety margin that could be especially valuable considering the history of population reduction of this species and the inherent uncertainties in biomass estimation since there is evidence of retrospective patterns. Maintaining a precautionary approach seems prudent, particularly in view of the vulnerability of toothfish to premature exploitation and its limited recovery capacity due to its life history strategy characterized by slow growth and late maturity.

The toothfish fishery is managed using "output control" or quota systems. A problem with this approach is that if current biomass is overestimated, very high quotas can be set despite the applied fishing mortality rate being reasonable. This quota can even be compensatory, meaning it increases even when the stock declines. This situation can go unnoticed since there is no fishery-independent abundance index. Thus, a “hyperstable” CPUE (Hilborn & Walters, 1992) could give the impression that the stock remains stable while the stock declines. Note that the fit of the industrial fleet CPUE (Fig. 17 of the stock assessment report) is not particularly satisfactory and there are retrospective patterns in biomass estimation despite using flexible selectivity that accommodates process error.

In addition to what is described above, there are some empirical methods to avoid/remedy compensatory fishing mortality. A precautionary approach for toothfish could base management decisions on more conservative estimates of population size. The scientific literature (Hilborn & Walters, 1992) recommends using the 15-20% percentile of the probability distribution for vulnerable species. For toothfish, this would mean adopting a biomass estimate approximately 15-20% lower than the point estimate. This approach, when multiplied by the selected exploitation rate (such as 0.75FMSY or lower), would generate appropriately precautionary catch advice. This would provide added resource protection against assessment uncertainty. This risk management approach explicitly recognizes the tendency of stock assessment models to be "overconfident" (underestimate real uncertainty) for various methodological and practical reasons.

To reduce the need for added precaution due to these uncertainties will require investment (e.g., research surveys, tagging studies, etc.) or measures that better control fishing effort ("input control"). Many of these are being applied in CCAMLR and should be analyzed as possible complementary measures for toothfish management in Chile.

Data Gaps and Research Priorities

Artisanal logbooks need to be improved. The current index (kg/days out of port) is considered not ideal considering that an important fraction of the quota is allocated to the artisanal fleet. It needs more resolution to take into account spatial and temporal effects, soaking time, etc. The difficulty of monitoring and sampling for this fleet is acknowledged. Therefore, it is recommended that cooperation programs be strategically established to improve the collection of information.

It is likely that sampling procedures need to be reviewed to ensure representative sampling. In other words, if only 30-40% of annual fishing trips can be covered, this needs to be representative sampling of the fleet as much as possible. Similarly, it is necessary to develop a framework and procedures for joint and effective collaborative biological data collection (size, sex and maturity), and basic research (e.g., tagging). This framework should be considered a very high priority. IFOP already has some collaboration from the artisanal sector and this needs to be enhanced.

As mentioned above, it is encouraged to explore age-length stock assessment models as the length data may be more informative for estimating the strengths of different cohorts, after careful evaluation (Minte-Vera et al 2017). It is necessary to resolve the possible inconsistencies with aging and estimating catch-at-age data across time for the industrial fleet and evaluate whether using length composition data is appropriate. This appears to be a very high priority and essential for any future assessment.

It seems relevant to establish a cooperative tagging program for both fleets. CCAMLR has detailed guidelines. For example, a rate of tagging per ton and the fish tagged need to be representative of the catch (i.e., not limited to juveniles). Experiments have already been done but implementing an ongoing and comprehensive tagging program is recommended as it is routine in all CCAMLR subareas.

Given the large uncertainties involving spatial structure, data, and recruitment dynamics that are currently impacting assessment results and management recommendations, it is recommended to develop a comprehensive operating model within an MSE framework. This would allow for developing harvest strategies that are more robust to uncertainty and providing better management recommendations for this stock.

A major weakness in this fishery assessment is the absence of fishery-independent abundance estimates. The assessment relies entirely on CPUE indices, yet the dangers of relying solely on CPUE are well documented. Additionally, CPUE interpretation and standardization are problematic due to insufficient data on critical factors affecting catch rates, particularly for the artisanal fishery. Obtaining fishery-independent abundance estimates is essential for reducing structural uncertainties and providing robust management advice, so it should be considered a very high priority. Again, this could be carried out with collaboration from the artisanal and industrial sectors.

Ecosystem Considerations

A critical ecosystem consideration in the toothfish fishery is the interaction between marine mammals and fishing operations, particularly depredation by sperm and killer whales on longline catches. While abundant evidence documents these interactions, it seems that there is insufficient data exists to quantify the magnitude or spatiotemporal trends of depredation effects. It was mentioned that individual haul depredation rates can be very high, but the overall impact assessments suggest relatively small effects, though this may be confounded by several factors including incomplete observations when fish are entirely removed from hooks, behavioral responses by fishermen (such as gear switching, delayed hauling, and relocating fishing grounds), and the potential learning behavior of killer whales that may reduce cachalotera gear effectiveness over time

The current stock assessment does not directly account for marine mammal depredation. However, this represents a substantial source of unaccounted uncertainty, as ignoring depredation means actual fishing mortality rates and catch rates would be underestimated if missing catches were properly accounted for. Incorporating alternative hypotheses about depredation could be included as part of an operating model framework and would help test the potential consequences of this oversight and improve assessment robustness.

Historically, seabird mortality was a significant environmental concern in the Patagonian toothfish fishery. Traditional Spanish longline fishing systems posed substantial risks to seabirds, which would interact with baited hooks during gear deployment, resulting in incidental mortality. However, the Chilean fishing industry successfully addressed this issue through the development and implementation of the "cachalotera" or trotline system. The technical report confirms that the cachalotera system demonstrates "excellent performance with respect to seabird mortality" and has "completely eliminated seabird mortality typically observed in operations with the Spanish system".

While the industrial Patagonian toothfish fishery has successfully eliminated seabird mortality through the cachalotera system since 2008, the artisanal sector appears to represent an unexamined issue that requires immediate attention. For example, there is no documented implementation of seabird mitigation measures in artisanal operations. This should be clarified as the artisanal fleet still uses traditional longline gear without proven mitigation technology, and limited observer coverage creates potential unreported seabird interactions.

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Appendix

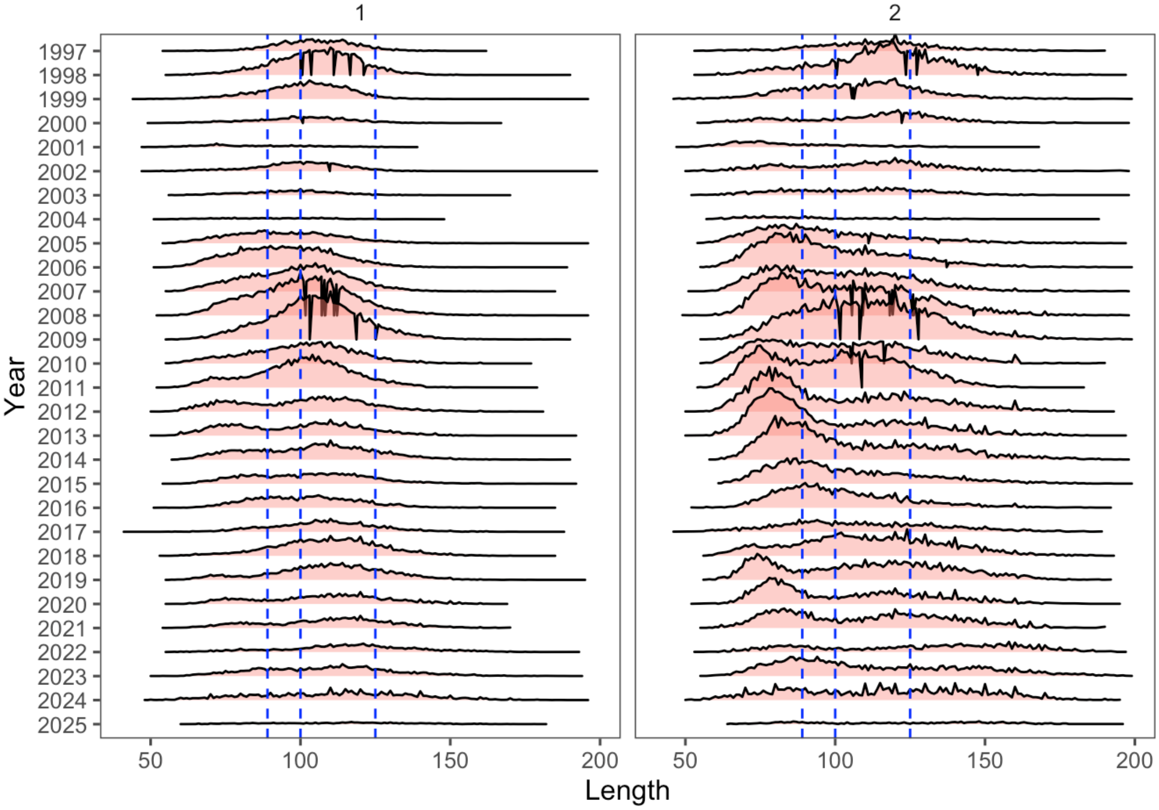

Figure 1. Example plot of Chilean sea bass length frequency from the artisanal fleet. Vertical scale is the number of samples. Data were aggregated by 1-cm bins.

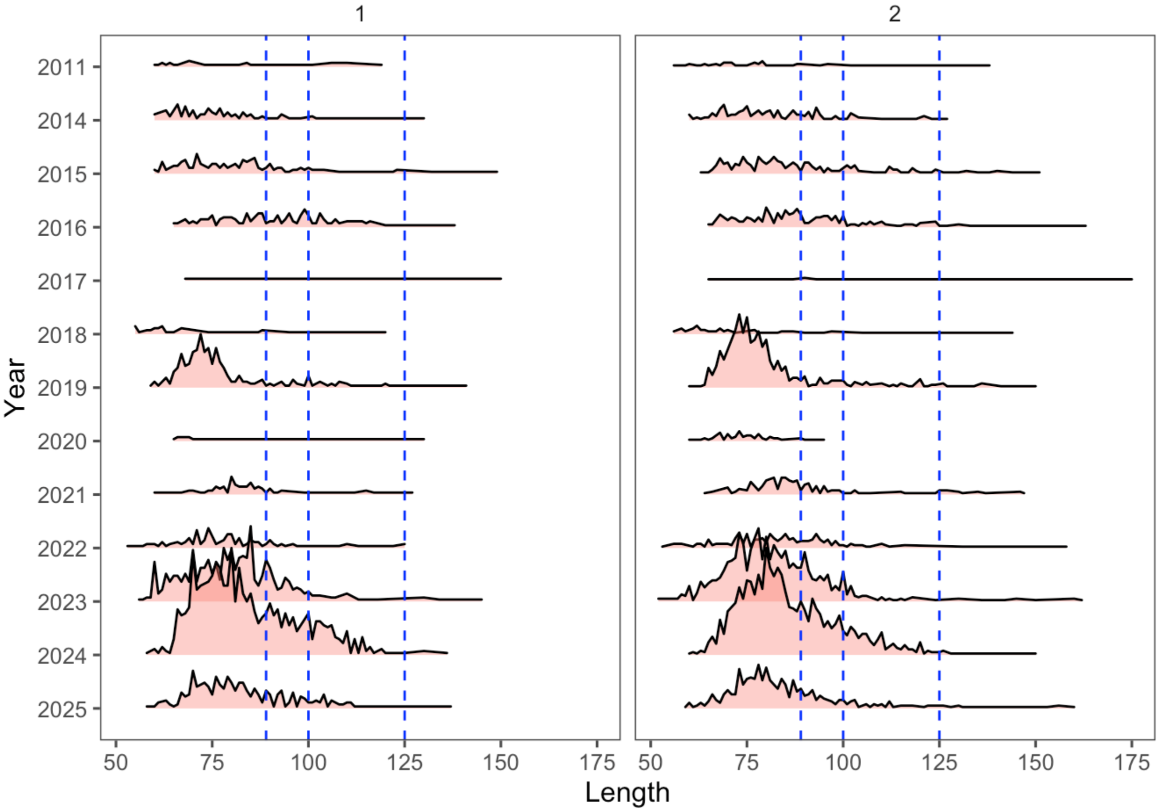

Figure 2. Example plot of Chilean sea bass length frequency from the artisanal fleet. Vertical scale is the number of samples. Data were aggregated by 1-cm bins.

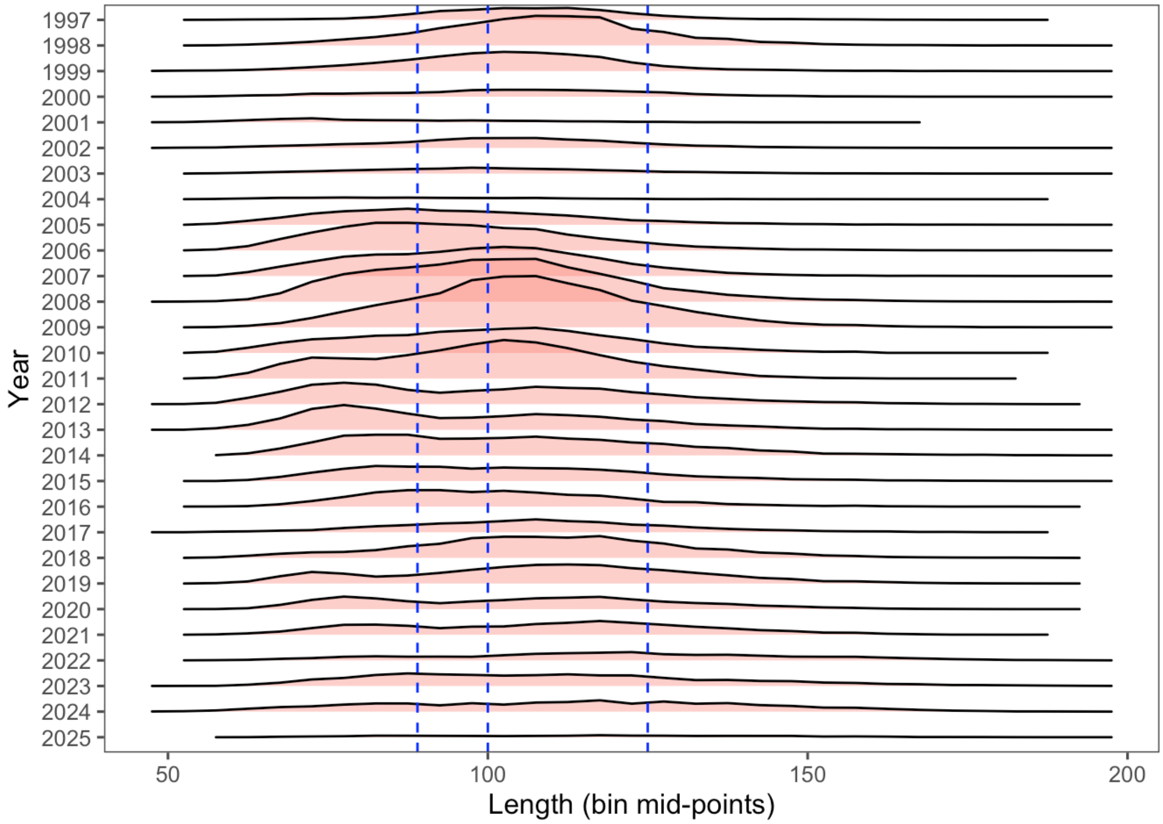

Figure 3. Example plot of Chilean sea bass length frequency from the industrial fleet. Vertical scale is the number of samples. Data were aggregated by 5-cm bins.

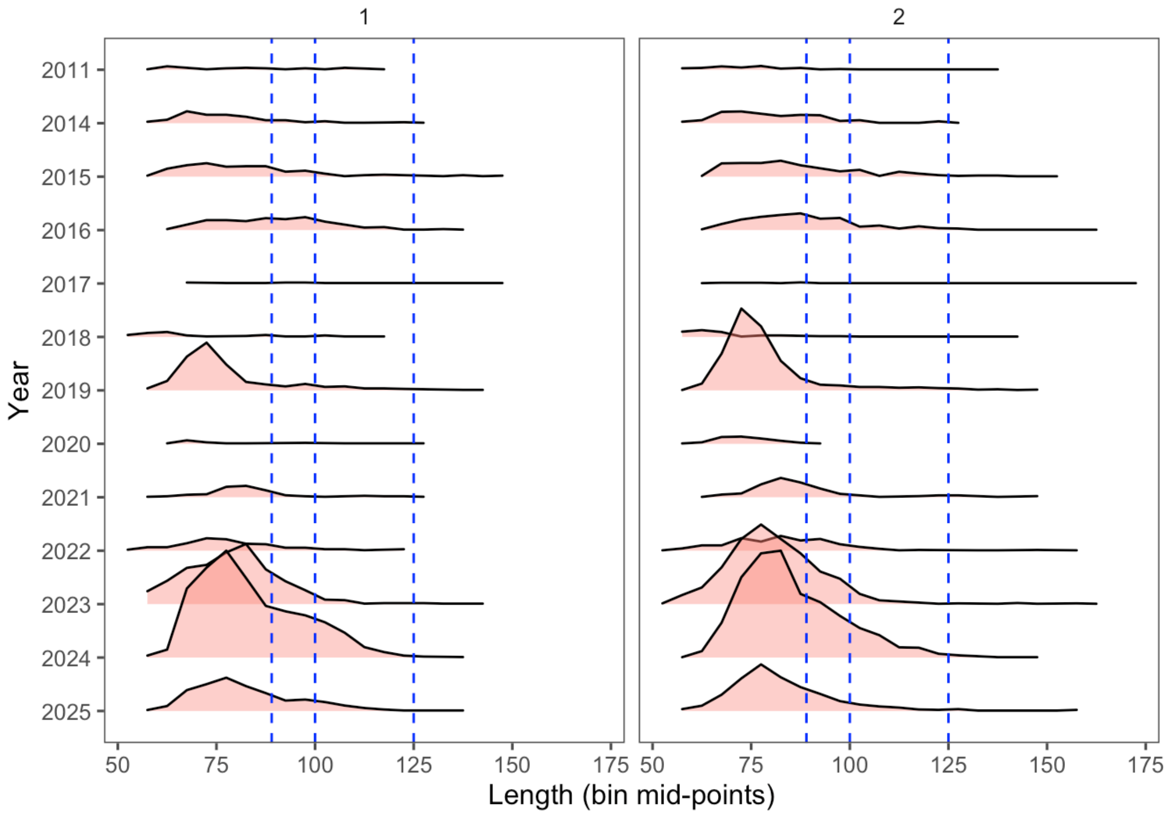

Figure 4. Example plot of Chilean sea bass length frequency from the artisanal fleet. Vertical scale is the number of samples. Data were aggregated by 5-cm bins.