CICIMAR OCEÁNIDES
ISSN 2448-9123
https://cicimaroceanides.mx
Centro Interdisciplinario de Ciencias Marinas
https//doi.org/ 10.37543/oceanides.v39i1.306

Vol.39 No. 1
Enero - Junio
2024

MEXICAN PINK ABALONE (*Haliotis corrugata* WOOD, 1828) FISHERY MANAGEMENT STRATEGY EVALUATION: A DATA-LIMITED APPROACH

Vargas-López, Víctor Gerardo[1], Francisco Javier Vergara-Solana[1,2], Luis César Almendarez-Hernández[1*]

[1]Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, Av. Instituto Politécnico Nacional S/N, Col. Playa Palo de Sta. Rita, C.P. 23096, La Paz, Baja California Sur, México. [2]Universidad Autonoma de Baja California Sur, Departamento Académico de Ciencias Marinas y Costeras, Apartado Postal 19-B, km. 5.5 Carretera al Sur, C.P. 23080, La Paz, Baja California Sur, México. *Corresponding author: lalmendarez@ipn.mx

ABSTRACT. Management procedures (MP) were evaluated to address alternative management of the pink abalone (*Haliotis corrugata*) fishery in the Mexican Pacific. This assessment utilized the Method Evaluation and Risk Assessment (MERA) platform within the context of management strategy evaluation (MSE). This species has been a crucial component of the abalone fishery in Mexico, with a history dating back to the 19th century. Since 1996, fishery authorities and fishermen have noted a decline in the stock biomass. In response, they implemented various strategies and efforts to address the situation. However, despite these measures, the stock has yet to recover satisfactorily. Eight MP were evaluated, and two corresponded to the *status quo* (current catch and effort). The simulation results suggest that relying solely on effort-based MP falls short of meeting the management objectives set in the reference points (Biomass and Yield). In contrast, alternative strategies involving different quota allocation strategies (e.g., based on the depletion level) demonstrated superior performance and a higher likelihood of meeting management objectives. Despite incorporating fishery information, the existing management procedures could have performed better in the simulation. Therefore, it is crucial to assess and implement alternative management strategies that are more likely to succeed.

Keywords: simulation testing, management procedure, limited information, harvest control rules, fishery improvement.

Evaluación de estrategias de manejo para la pesquería de abulón amarillo mexicano (*Haliotis corrugata* Wood, 1828): un enfoque con datos limitados

RESUMEN. Se evaluaron estrategias de manejo (EM) para abordar el manejo alternativo de la pesquería de abulón amarillo (*Haliotis corrugata*) en el Pacífico mexicano. Esta evaluación utilizó la plataforma de Evaluación de Métodos y Evaluación de Riesgos (MERA, por sus siglas en inglés) en el contexto de la evaluación de estrategias de manejo (EEM). Esta especie ha sido un componente crucial de la pesquería de abulón en México, con una historia que se remonta al siglo XIX. Desde 1996, las autoridades pesqueras y los pescadores han observado una disminución en la biomasa del stock. En respuesta, implementaron diversas estrategias y esfuerzos para abordar la situación. Sin embargo, a pesar de estas medidas, la población natural de abulón amarillo no se ha recuperado satisfactoriamente. Con base en esto, en el presente trabajo se evaluaron ocho EM, dos de las cuales corresponden al estado actual de manejo pesquero (captura y esfuerzo actuales). Los resultados de la simulación sugieren que depender únicamente de MP basados en el esfuerzo no logra cumplir con los objetivos de manejo establecidos en los puntos de referencia (Biomasa y Rendimiento). En cambio, estrategias alternativas que involucran diferentes estrategias de asignación de cuotas (por ejemplo, basadas en el nivel de agotamiento de cada banco) demostraron un rendimiento superior y una mayor probabilidad de cumplir con los objetivos de manejo. A pesar de incorporar información sobre la pesca, los procedimientos de gestión existentes podrían haber funcionado mejor en la simulación. Por lo tanto, es crucial evaluar e implementar estrategias de manejo alternativas que tengan mayor probabilidad de éxito.

Palabras clave: pruebas de simulación, estrategia de manejo, información escaza, reglas de control de captura, mejora de la pesquería.

Vargas-López, V. G., Vergara-Solana, F. J., Almendarez-Hernandez, L. C. (2024). Mexican pink abalone (*Haliotis corrugata* Wood, 1828) fishery management strategy evaluation: a data-limited approach. *CICIMAR Oceánides*, 39(1), 31-45.

INTRODUCTION

Abalone landings are relatively small compared to global fishery production (Cook, 2023; FAO, 2022). However, despite their relative contribution to global landings, they are an essential source of income for several regions worldwide due to being one of the most valuable seafood in the market (Cook, 2023; Hernández-Casas *et al*., 2023). Among wild abalone producers, Australia contributes 69% of the catches, while Mexico contributes 9%, with Mexican abalone being considered a product of the highest quality (Hernández-Casas *et al.*, 2023).

In Mexico, this fishery holds significant historical, economic, and social importance, being exploited for over 100 years, and serving as the main reason for the foundation of various northwest fishing communities (Ramade-Villanueva *et al.,* 1998; Ponce-Díaz *et al.*, 2000; Searcy-Bernal *et al.*, 2010). The fishery comprises five species, with green abalone (*Haliotis fulgens*) and pink abalone (*Haliotis corrugata)* contributing the majority of the catches, 70.8% and 28.9%, respectively (Sierra Rodríguez *et al.*, 2006; Searcy-Bernal *et al*., 2010). The distribution of these two species overlaps as they share the same habitat. Nevertheless, *H. corrugata* can be found at greater depths (3-30 m) than *H. fulgens* (3-20 m deep; Guzmán del Próo, 1992).

However, like global trends, abalone catches in Mexico have tended to decrease, dropping from

Fecha de recepción: 20 de diciembre de 2023
Fecha de aceptación: 04 de junio de 2024

≈6,000 mt in the 1950s to ≈150 mt in 2019 (Carballo & Muciño Díaz, 1996; Morales-Bojórquez *et al.*, 2008; Cook, 2023; Vergara-Solana *et al.,* 2023; Hernández-Casas *et al.*, 2023). Given this trend, the fishery has officially been recognized as a deteriorated fishery (DOF, 2023). The government and other stakeholders are now committed to its recovery (Smith *et al*., 2022; Vargas-López *et al.*, 2023a).

In this context, the resource is managed under a comprehensive co-management regime that includes Territorial Use Rights for Fisheries (TURFs), a minimum legal size, Total Allowable Catch (TAC) for each fishing zone, limitations on fishing effort, temporary reproductive closures, fishing gear specifications, stock enhancement activities, and community surveillance programs. It is noteworthy that voluntary no-take zones have been established in some areas. Some cooperatives have decided, in collaboration with fishing authorities, not to use all their fishing quotas or to cease abalone fishing in specific regions (Morales-Bojórquez *et al.,* 2008; Searcy-Bernal *et al.,* 2010; Cunningham, 2013; Smith *et al.,* 2022; DOF, 1993; 2023).

Despite this comprehensive management system, the downward trend in catches has not been reversed (Hernández-Casas *et al.*, 2023; DOF, 2023; Vergara-Solana *et al.*, 2023). While there is a possibility that environmental changes may prevent the fishery from recovering to historical levels, there is evidence of recovered fishing banks (Ponce-Díaz *et al.*, 2003; Smith *et al.,* 2022). Moreover, due to the increased price of this seafood, stemming from its limited wild-captured supply, it is estimated that a profitable fishery can be maintained with small catches that do not compromise recovery efforts (Vergara-Solana *et al.,* 2023).

To ensure a rational exploitation of this deteriorated fishery (with changes in the population's productivity), it is necessary to design and implement tailored management procedures (MP) to specific fisheries management objectives (DOF, 1993; Holland & Herrera, 2009; DOF, 2023). MP are a cohesive set of measures that tactfully manage a fishery (Dowling *et al.,* 2015).

For an effective MP, stock assessments are required to determine the stock's status concerning limit and target reference points (LRP, TRP). In addition, an MP considers measures to control fishing mortality to maintain the stock at TRP (e.g., minimum sizes, closures, fishing gear), as well as Harvest Control Rules (HCR), which are "if X then Y" rules that dictate the course of action in case of changes in stock abundance. Finally, an effective MP requires a monitoring system to assess the performance of management measures concerning social, economic, and environmental management objectives (Rayns, 2007; MSC, 2023).

Having an MP is considered a best practice in fisheries management and is recognized as a tool that facilitates achieving and maintaining stock performance in line with management objectives (Smith *et al.*, 2014). However, insufficient information and technical and financial resources limit the number of fisheries with a tailor-designed MP (Downing *et al.,* 2015). Globally, this process is generally reserved for a few high-value fisheries with extensive data availability and high management capacity (Downing *et al*., 2015). As evidence of this, it is estimated that 22% of the world's stocks are not assessed. In contrast, another quarter of global stocks are considered data-poor fisheries (values that could be underestimated as unreported stocks are not considered) (Walsh *et al.*, 2018).

The widespread lack of MP (and stock assessments), not only in developing countries, highlights that many stocks may be at risk of overexploitation with all its socioeconomic and environmental implications. Therefore, these resources must be assessed and managed appropriately, even with limited data (Honey *et al.,* 2010; Kleisner *et al.*, 2013).

The feasibility of designing and implementing an MP in data-limited situations, is a challenge for many fisheries in order to have a successful harvest strategy that can deliver the management objectives (e.g., Dowling *et al.*, 2015; Walsh *et al.*, 2018; Carruthers *et al.,* 2023). An example of this is the Methods Evaluation and Risk Assessment (MERA, www.merafish.org) tool, which allows for a semi-quantitative questionnaire (supplemented with quantitative data if available) to conduct a Management Strategy Evaluation (MSE) (Carruthers *et al.,* 2023).

An MSE, considered state of the art for MP design, allows, through the parametrization of an operational model, the design and evaluation of the performance (e.g., remaining biomass, catches) of different MP, considering their feasibility of implementation according to the nature of the resource and available data (Holland & Herrera, 2009; Carruthers *et al.,* 2023).

While designing an MP in data-limited situations may imply high levels of uncertainty, a strategy can still be designed to make informed management decisions (Holland & Herrera, 2009). On the other hand, the MP design process, through sensitivity analysis, allows detection where research efforts should be directed to reduce uncertainty in the management system (Carruthers *et al.,* 2023). This information helps to use human and financial resources efficiently (resources that are often scarce).

In this sense, to exemplify the use of MERA to implement an MSE in small-scale, data-poor fisheries, this study explores this tool to design a recovery-compatible MP for the pink abalone fishery that is feasible to implement, considering the available data and the biology of this resource.

MATERIALS AND METHODS

Data

The information on population abundance used comes from stock assessments conducted by the National Fisheries Institute from 1993 to 2017. The database contains the number of organisms per sampling unit (50 m^2), organized through 21,576 vectors with the following information (INAPESCA, 2019): Year, Abundance, Zone, X Coordinate, and Y Coordinate.

Total commercial catch information was obtained from the Progreso Fishing Cooperative database (2020). This catch database spans from 1993 to 2017 and is structured by 35,533 vectors with the following information: Year, Zone, Subzone, Block, X Coordinate, Y Coordinate, Number of Captured Organisms, Live Weight, Depth, and Bottom Type. Biological-fishery parameters were obtained from the work of Vargas-López *et al.* (2023a) (Table 1).

Operational Model Parameterization

This information allowed the construction of a conditioned model on the MERA platform (https://www.merafish.org/) (Carruthers *et al.*, 2023), with which alternative Management Procedures (MP) were simulated. The model's parameterization in the MERA platform is done through two inputs: a mandatory quantitative questionnaire and, optionally, a standardized format of fishery data. In this way, MERA uses the quantitative questionnaire and optional fishery data to build an Operational Model (OM). The OM will automatically condition these data by loading compatible data such as abundance indices, catches, and population parameters.

The OM is the main component of the management strategy evaluation framework (Fig. 1). The OM describes the characteristics of a fishing system and contains all the parameters necessary to simulate population dynamics and the fishery management system. For this, the OM is built from four separate components (i.e., submodels): i) a model of the population dynamics of the target stock; ii) the model to describe the fishing fleet dynamics; iii) parameters describing the monitoring processes and the iv) parameters describing the implementation of the management measures.

Once the MERA model is parameterized, the platform has three modes of operation: i) determination of the stock's status, ii) performance of the management system (once an MP is implemented, it allows evaluating if it is meeting the forecasts), and iii) ma-

Table 1. Description of management strategies evaluated for the *H. corrugata* fishery.

MP	Description	References
	Output - Total Allowable Catch (TAC)	
AVC (Average catch)	The average catch method is simple. The mean historical catch is calculated and used to set a constant catch limit (TAC)	(Carruthers *et al*., 2014)
CurC (Current Catch)	The TAC is the average historical catch over the last year.	(Carruthers *et al.,* 2014)
Itarget 4: (Incremental Index Target MP)	A management procedure that incrementally adjusts the TAC (starting from a reference level that is a fraction of mean recent catches) to reach a target CPUE / relative abundance index. The MP based on TAC with the highest biological precaution while initially controlling 30% of the mean catch in the first year.	(Carruthers *et al.,* 2014; Geromont & Butterworth, 2014)
MCD4010 (Mean Catch Depletion)	The TAC is modified by a harvest control rule in conjunction with the 40-10 rule, which progressively reduces the TAC from 0.4 to zero at 10% unfished biomass depletion.	(Carruthers *et al.*, 2014; Punt & Ralston, 2007)
	Input - Allowable Effort (TAE)	
CurE (Fishing at current effort levels)	The constant fishing effort set at the final year of historical simulations. This MP is intended to represent a 'status quo' management approach.	(Carruthers *et a*l., 2014)
CurE75 (Fishing at 75% effort level)	The constant fishing effort was 75% in the final year of historical simulations.	(Carruthers *et al*., 2014)
DDe75 (Effort-based Delay - Difference Stock Assessment)	A simple delay-difference assessment with U_{MSY} (the fishing pressure expected to generate MSY) and MSY as leading parameters estimates E_{MSY} using a time series of catches and a relative abundance index. The assumption is that knife-edge selectivity occurs at the age of 50% maturity. A variant of DDe where the recommended effort is 75%.	(Carruthers *et al.,* 2014; Hilborn & Walters, 1992)
DTe40 (Effort searching MP aiming for a fixed stock depletion)	Effort is adjusted using a rule that aims for a 40 percent stock depletion. The maximum fractional change in TAE is specified with arguments LB (the lowest permitted factor of previous fishing effort) and UB (the highest permitted factor of previous fishing effort).	(Carruthers *et al*., 2014)

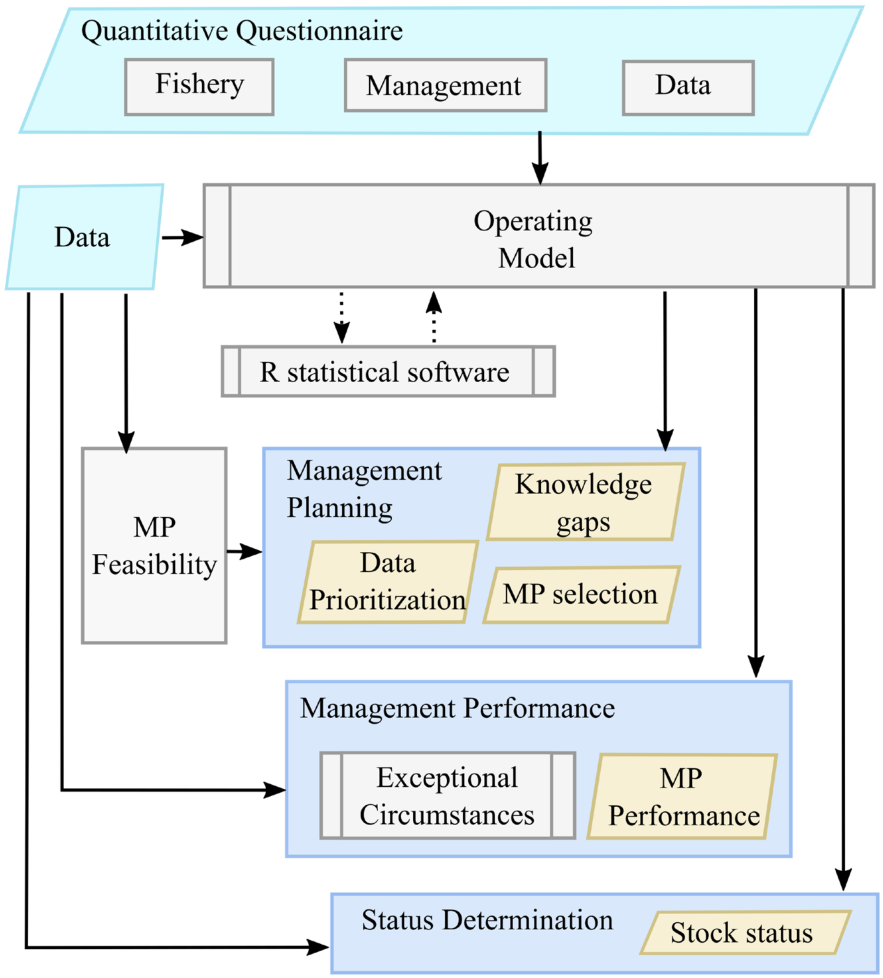

Figure 1. MERA components and workflow (Carruthers *et al*., 2023).

nagement planning (allows simulating and comparing different management strategies). For this study, mode iii) management planning was employed.

MERA Questionnaire

The quantitative questionnaire contains 30 questions, of which 19 focus on fishery dynamics, seven on the management system, and four on the types and quality of available data. A thorough literature review was conducted to complete the questionnaire, experts were consulted, and information from the fisheries authorities responsible for research and stock assessment was gathered. The questionnaire was answered by relying on the most dependable data, insights from scientific literature, and expert judgment regarding the fishery in the study area (APPENDIX).

Management Procedures or Strategies

MERA allows testing tailored MP but also includes over 100 pre-coded MP ranging from those data-limited (e.g., management procedures like size limits or management procedures such as length limits) to data-rich ones (e.g., assessments of populations adjusted to abundance indices and size composition data). These MP can suggest strategies for managing the fishery in the form of catch limits, fishing effort limits, size limits, spatial closures, or combinations thereof.

The pink abalone fishery has two official MP in place (DOF, 2023): 1) a variable annual catch quota by zone and species (MP Output) and 2) control of fishing effort (MP Input). In this regard, only viable MP, defined as those applicable and verifiable in the fishery, were tested (i.e., based on catch and effort limits). Eight MP were evaluated for the pink abalone fishery (MP Input = 4; MP Output = 4). Two are established as *status quo*, current catch, and current effort. The other MP were selected based on their ability to meet biomass (B) limits and target reference points relative to the maximum sustainable yield (B_{MSY}). Additionally, we considered the likelihood of achieving a significantly higher yield (Y) compared to the current yield (Y_{curr}) (Table 2).

Table 2. Probabilities of the selected MPs achieving the LRP and the TRP over the first 10 years of simulation. MP type refers to its classification: Total Allowable Catch (TAC) and Total Allowable Effort (TAE). Probabilities are colored as follows: Green = >90%; Orange = >40% and Red= <40%.

Simulation for Current Fishery Condition

MP	MP Type	Mean Prob. Biomass > 50% BMSY(Year 1-10)	Mean Prob. Biomass >BMSY (Year 1-10)
AvC	TAC	67.2	39.1
CurC	TAC	71.9	42.2
CurE	TAE	57.8	26.6
CurE75	TAE	60.9	32.8
DDe75	TAE	10.9	6.2
DTe40	TAE	62.5	35.9
Itarget4	TAC	84.4	48.4
MCD4010	TAC	90.6	54.7

Simulation and MP evaluation.

Each MP was simulated several times using the OM. The closed-loop simulation continually projects the stock and fishery into the future through iterative steps. It involves simulating data, deriving management recommendations from MP, and evaluating the effects of these recommendations on the stock. Consequently, the user must choose a management interval (the duration before new management advice is computed) and the specific MP to be assessed in the simulation. The number of simulations used for MSE analyses was 96; this number is likely to rank MP performance reliably (Carruthers *et al*., 2023). In each simulation, a unique sample of operating model parameters is sampled based on the ranges specified in the MERA questionnaires.

A data-conditioned model was implemented in this study case, so an individual model fit is done on each simulation. The management interval (years between management implementations) was two years. In addition to the questionnaire, fishery data was uploaded, which allows the operational model to be fitted using all available information, which in this case were Annual Catch data, Annual Effort data, and Annual relative abundance index data. Based on the control rules for this fishery, an effort conditioning approach is applied in tandem with catch data, wherein the model endeavors to align with the catch data by essentially employing an approach based on the catch per unit effort index (I = C/E). When the fishery data matrix is uploaded, MERA replaces the pertinent data and information in the questionnaire with the data from the fishery data matrix. Afterward, MERA uses the fishery data matrix to adjust the operating model, ensuring it accurately represents the current state of the fishery.

Sources of Uncertainty

MERA assessed the primary sources of uncertainty influencing the simulation outcomes for each MP. Parameter inputs derived from responses to the MERA questionnaire, the fishery data matrix, and the operational models utilized within MERA introduce uncertainties, leading to variations in the probability projection of long-term yield. Uncertainty plots are presented for the chosen MP to pinpoint the sources of uncertainties influencing the variability in the projection of the long-term yield as a percentage (%LTY).

The findings of this research aim to provide valuable insights to fisheries managers and stakeholders regarding the management strategies that are simulated to possess a substantial likelihood of attaining key objectives, including sustaining population biomass and maximizing fishery yield. Furthermore, this sensitivity analysis suggests to decision-makers where to concentrate research efforts to reduce uncertainty in the management system.

RESULTS

Selection of MP

We had identified eight MP with potential for the *H. corrugata* fishery in the Mexican Pacific. Table 2 illustrates their performance during the initial simulation years. Among these strategies, MCD4010 consistently achieved the Limit Reference Point (LRP) for biomass, while DDe75 showed the least favorable results. The remaining MP performed with probabilities ranging from 50-85%. Regarding the Target Reference Point (TRP) for biomass, only three strategies had a probability exceeding 40%. Once again, MCD4010 emerged as the top performer. Notably, strategies based on Total Allowable Catch (TAC) demonstrated superior performance in reaching both LRP and TRP

(Table 2). DDe75 showed the poorest performance due to the possibility of exceeding the recommended catch level despite a reduction in effort. The remaining 25% of the effort can achieve high levels of catch in tons. Simply modifying the effort is insufficient to achieve a positive outcome in the expected biomass levels in the short and long term.

Yield-Biomass Trade-Offs

In the long-term simulations (Fig. 2), MP Itarget4 and MCD4010 were the best performers, with a high probability ($p>0.9$) of exceeding the LRP ($B>50\%B_{MSY}$) and a $p>0.6$ of exceeding the TRP ($B>B_{MSY}$). DTe50 is the output MP, which had the highest probability ($p>75$) at the LRP, but at the TRP, the probability dropped close to 50%. While DDe75 had a high probability ($p>70$) of exceeding the biomass LRP, it had a very low probability ($p<0.2$) of being above the yield at MSY.

Biomass Projections

Under current fishery conditions, all selected MP, except curE, maintained biomass levels above the LRP over the long-term simulation of 50 years (Fig. 3). However, almost all output MP (AvC, CurC, ITarget4 and MCD4010) have relatively higher uncertainty, as shown by the blue and light blue shades (probability intervals) In addition, AvC, CurC, Itarget4, and MCD4010 were the MP that could perform better in terms of stock recovery, as they presented higher probability values in all simulations to be above the biomass TRP in the long term. This indicates that catch quota recommendations should be maintained, and could be complemented with other approaches (such as Itarget4 or MCD4010). It is important to note that MCD4010 is adjusting the allocation of catches, whereas the catches are reduced if the spawning stock is below 40% of B_0. This MP's reduction is linear, from 0 at 0.4B0 to 100% at 0.1B0.

Long-Term Yield Sources of Uncertainty

There may be significant uncertainty regarding the inputs in management methods. To address this, errors were introduced to the "true" simulated values of the operating model, simulating inaccurate information about these quantities. Since these inputs are crucial in determining the relative effectiveness of the methods, they are assigned ranges that are considered representative of the level of uncertainty in a data-limited context. Responses to the MERA questionnaire, the fishery data matrix, and the operational models used in MERA contribute to uncertainties, causing variations in the probability projections of long-term yield. Uncertainty plots for the selected MP are provided to identify the uncertainties influencing the variability in the long-term yield projection (Fig. 4).

The costs of uncertainties are presented in Figure 4. On the left side of each of the graphs, the questions in the questionnaire that had the greatest effect or degree of impact on the yield are shown. The question number of the MERA questionnaire is labeled on the X-axis. For instance, within the MP CurC, the primary factor contributing to uncertainty is F7- Historical catchability, emerging as the foremost contributor to uncertainty across all MP, accounting for 23%. Nevertheless, considering that an examination of catchability can be undertaken through data on abundance and the efficiency of capture methods by divers, it is strongly advisable to concentrate research and analysis endeavors on this particular source. Notably, this uncertainty factor was consistently observed across all MP that uses TAE. It is imperative to consider the insights of (Arreguín-Sánchez, 1996), who emphasizes that the determination of fishing mortality hinges on the interplay between resource abundance and the effectiveness of the fishing gear. This is a pivotal consideration, as it will be influenced not solely by the type of fishing gear but also by the fishermen's expertise, understanding, and fishing approach. In this context, the variation present in this coefficient directly impacts the yield associated with each management procedure.

DISCUSSION

There are two approaches to evaluating management strategies: experimentation and numerical simulation. Experimentation, which involves applying different management approaches to the natural system, has practical limitations that often make this approach unfeasible in most fisheries. The ability to detect changes in the system within relevant timeframes may be limited (Walters, 2007). Experimentation can be costly, given the expenses associated with data collection, but especially the opportunity costs, in terms of revenue, catch, and biomass, of delaying the implementation of an appropriate management measure (Walters, 2007; Mangin *et al.,* 2018). So, any implemented management measures to manage a fishery should have a high degree of certainty of working.

On the other hand, numerical simulations, based on the parameterization of mathematical models representing the fishery, simultaneously allow *in silico* evaluation of different management recommendations (i.e., implementing a Management Strategy Evaluation) (Smith *et al.*, 1999). Implementing MSE to design and evaluate management strategies is considered best practice in fisheries management but generally requires data and technical capabilities that are only available in some fisheries (Nakatsuka, 2017).

This study shows how data-limited methods, such as MERA, can be implemented as a first approximation to select MP to meet management objectives with commonly available data (Carruthers *et al.,* 2023). This exercise indicates a preference for a TAC-based MP over TAE-based management to achieve better biomass levels for the Mexican pink abalone fishery. Most TAC-based MP are likelier to achieve the defined limit and target reference points for biomass and yields. These results imply that the current practice of allocating annual catch quotas in the fishery should

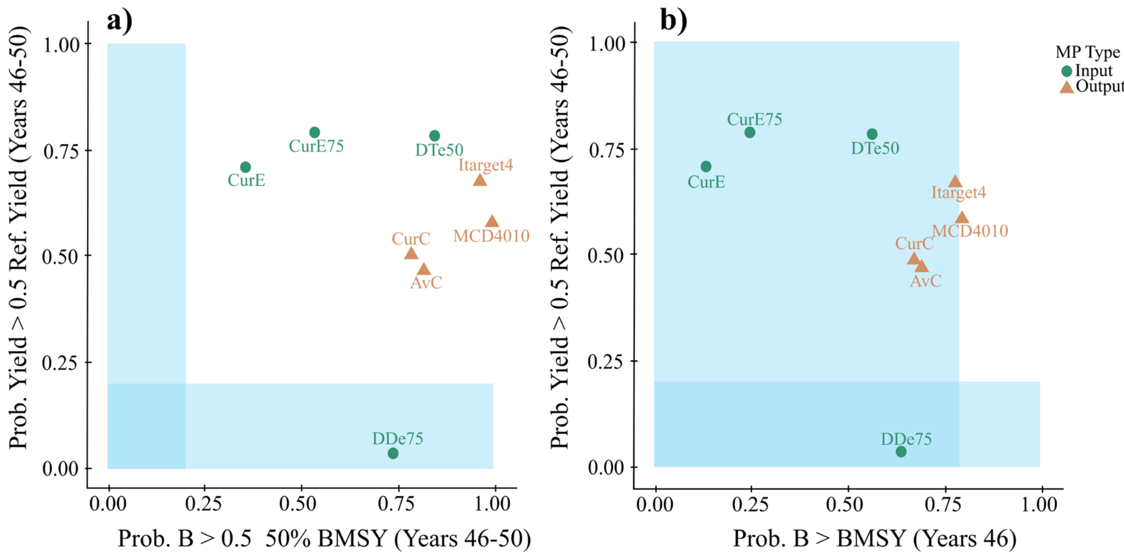

Figure 2. The long-term yield-biomass trade-off of the selected management procedures for *H. corrugata* in the Mexican Pacific. Probabilities of achieving the limit reference biomass ($B > 0.5B_{MSY}$) and (b) the target reference biomass ($B > B_{MSY}$). The y-axis is the probability of achieving more than half the reference (Ref.) yield (i.e., 0.5 B_{MSY}). Input MP is presented in green; output MP is presented in orange. Blue shades show probability thresholds between 0–0.2 and 0–0.8. The top-right region represents better performance, and the bottom-left represents worse performance.

persist, which is compatible with official management tools and is relatively easy to enforce in this fishery (DOF, 2023).

However, according to the results, alternative TAC allocation methods should be thoroughly assessed; by modifying the TAC, the fishery yield can be increased, and this MP is compatible with recovery (Vergara-Solana *et al.,* 2023). The MP Itarget4 and MCD4010 are good proposals to consider. Itarget4 proposes more cautious catch quotas based on available biomass, with a gradual increase linked to CPUE and abundance indices. Conversely, MCD4010 accounts for depletion in the catch quota allocation, following the widely utilized harvest control rule 40-10 (Punt & Ralston, 2007).

By employing operational models and closed-loop simulation tests, the MP evaluation can simultaneously assess the stock, the fleet, and the management dynamics. This approach produces quantitative results regarding the effectiveness of a particular MP, using probabilistic estimates of biomass and yield regarding the fishery limit and objective reference points (Anderson & Seijo, 2010). These estimates play a crucial role in fisheries' decision-making regarding the choice between different management strategies according to the management objectives and the stakeholders' risk tolerance (Huppert, 1996; Anderson & Seijo, 2010).

Because MERA operates with data generated from a questionnaire, the process results in a range of likely parameters to parameterize each MP function. This uncertainty in running multiple simulations (in this case, 96 runs for each MP) using the likely parameters results in a range of possible outcomes for each MP (Carruthers et al., 2023). Regardless of the variability of the results, this approach suggests a trend for the stock and yields for each MP, which is informative for management. Also, this approach makes the management system's uncertainty explicit, allowing management decisions to be made following the precautionary principle (Hilborn *et al.*, 2001).

By pinpointing a MP anticipated to fulfill management objectives, even without exact biomass or yield estimates, authorities and resource users can focus on enhancing data collection. This will lead to the development of more effective management strategies explicitly tailored to stock recovery in this case (Vergara-Solana et al., 2023). In this sense, the results obtained in MERA can help efficiently use the fishery management agency resources because, through sensitivity analysis, it is possible to know where monitoring and research efforts should be concentrated to improve the assessment (Carruthers *et al.*, 2023). For example, in this study case, if Itarget4 and MCD4010 are used to improve the results, research efforts should focus first on obtaining better estimates of future mixing and stock depletion.

Future mixing is determined by the degree of stock mixing in/out of the future hypothetical spatial closure or, in this case, between adjacent fishing concession zones. The degree of the spatial mixing of the fish stock is represented as the probability (P) of a fish leaving the spatial closure (e.g., MPA, fishing concession zone) between years. Juvenile or adult abalone movement is minimal. In this sense, if any spatial mixing were to occur, the larval dispersion of the abalone would determine it. Abalone stocks

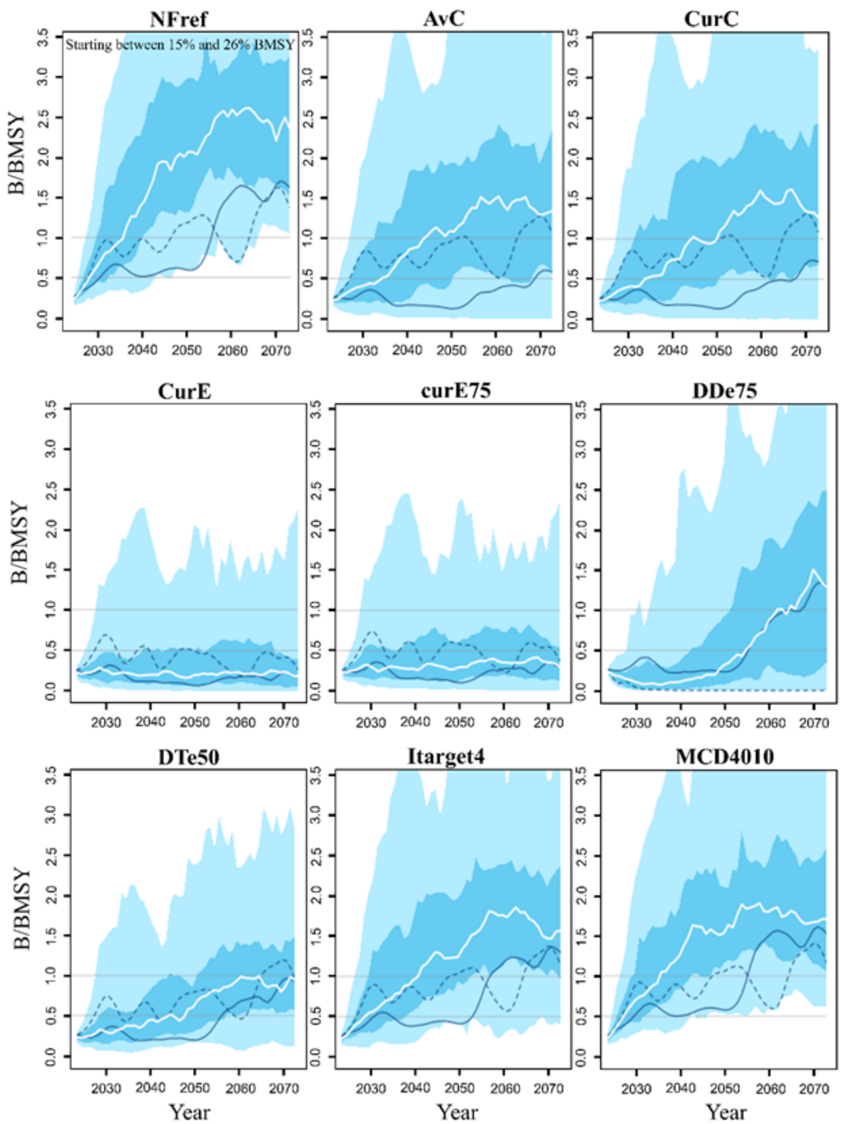

Figure 3. Estimated biomass compared to target and limit reference points and yield projections relative to MSY levels. The 90% and 50% probability intervals are shown in blue, the solid white line represents the median, and the dark blue lines depict two example simulations. The horizontal gray lines mark the target (B_{MSY}) and limit (50% B_{MSY}) reference points.

rely on the natural supply of larvae in self-recruiting populations, larval connectivity in metapopulations, and hatchery produced larvae in regions where larval restoration is needed (Vargas-López *et al.,* 2023a). This statement aligns with the current perspective on recruitment, which is primarily influenced by self-recruitment rather than supply from other local populations (Miyake, 2017). Therefore, while long-distance dispersal may lead to genetic homogeneity (e.g., genetic exchange), it is insufficient for enhancing a fished population or replenishing a depleted one. Various biological factors that could impact abalone larval dispersal can be inferred from future studies, and it is essential to consider these factors to refine this parameter and reduce the cost of uncertainty. As Miyake (2017) states, to better estimate this parameter, efforts should be concentrated on four key elements: spawning, pelagic larval duration, vertical behaviors, and pre-settlement mortality.

In stock depletion, we must recognize that the term represents a condition that could be caused by overfishing that leads to a decline in the abundance of a stock's exploitable segment, preventing it from attaining its maximum productive capacity. (Van Oosten, 1949). Numerous fisheries go through noticeable ups and downs in productivity. A fishery might have commenced in specific scenarios when the fish population was naturally scarce. This parameter allows for specifying this initial depletion. Nevertheless, the default assumption is that, in the first year of the fishery,

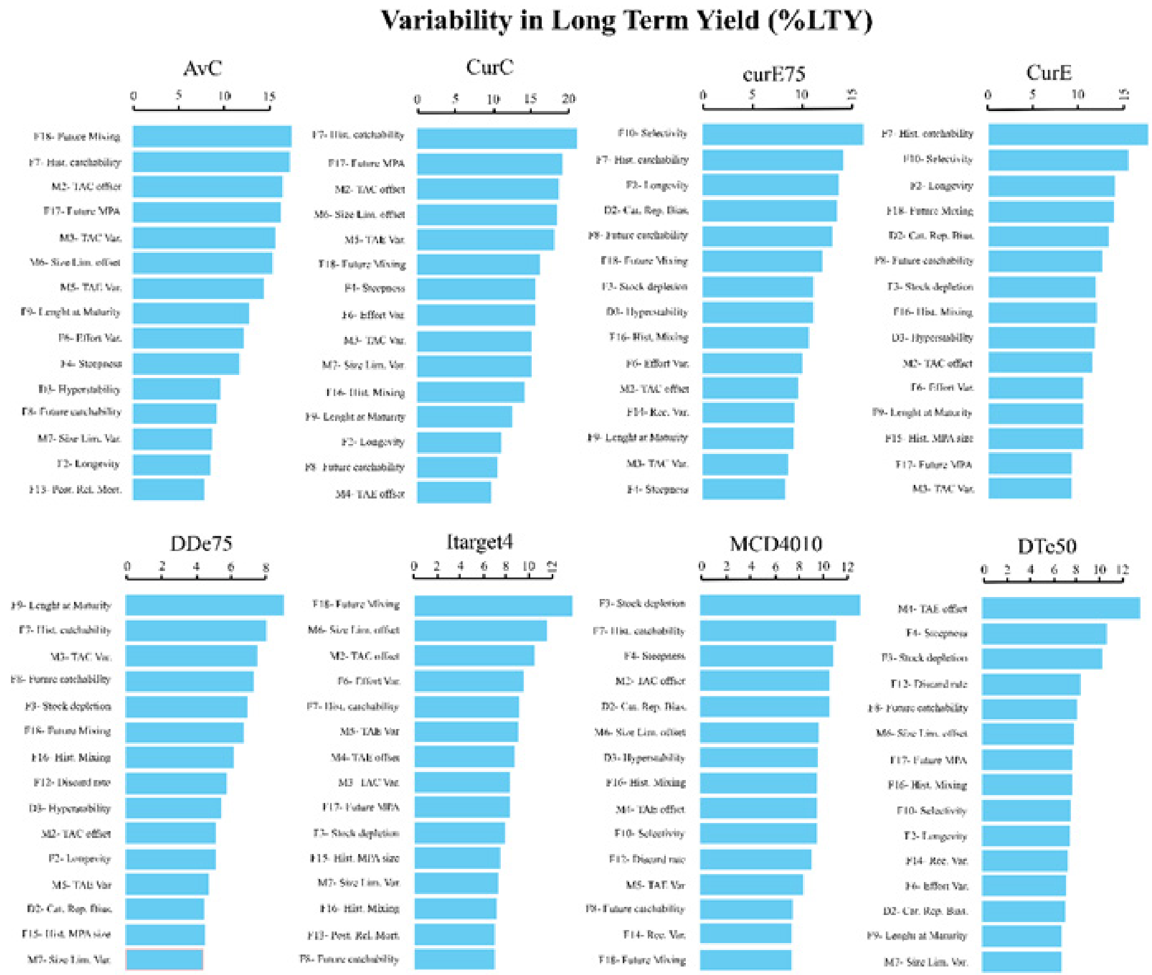

Figure 4. Management procedures and their sources of uncertainty of the long-term yield for *H. corrugata* in the Mexican Pacific.

the population was at asymptotic levels, untouched by fishing. Therefore, research and analysis efforts must focus mainly on identifying with certainty the initial depletion of the stock relative to asymptotic unfished levels.

Meeting the criteria for rebuilding plans requires a substantial increase in the need for technical analyses (Restrepo *et al.,* 1999). Despite that, the MSE is considered the most reliable scientific approach for evaluating MP, the results of the simulations are susceptible to significant uncertainty, such as those coming from assumptions of environmental stable conditions and static trophic relationships (e.g., Punt, 2003; Punt & Methot, 2005; Kininmonth *et al.,* 2022). To cope with this uncertainty, the evaluation (and implementation) of management strategies should be a dynamic and adaptive process; hence, the results of future stock recovery analyses may not precisely align with the expectations derived from the initial recovery analysis, even more so in an uncertain climate environment (Hidalgo *et al.,* 2022, Vargas-López, 2023b). As a result, the allocation of catch quotas and the effort applied to the fishery should be adjusted as needed (Williams, 2011).

The MERA tool includes, by default, over 100 pre-coded MP and allows the creation of customized MP if required (Carruthers *et al.,* 2023). On the other hand, it is essential to note that the platform does not include the effect of environmental variability (and climate change) on stock productivity, which is a forcing variable for abalone populations in northeastern Mexico (Ponce-Diaz *et al.,* 2003; Vargas-López *et al.,* 2021; Vergara-Solana *et al.,* 2023). In addition, the tool does not currently allow the assessment of multispecies or sequential fisheries neither ecological interdependencies.

These complexities can be implemented in the MSE process using a programming language, as the MERA platform is based on R packages (Carruthers *et al.,* 2023). However, the need for coding and parameterization outside a user-friendly platform increases the complexity and limits the tool's accessibility. Nevertheless, as demonstrated in this exercise, MERA is a tool that can quickly generate information to support decision-making and results that can be improved as research efforts are optimized and capacity is built in fisheries.

CONCLUSIONS

The Method Evaluation and Risk Assessment (MERA) is a valuable tool to add to the toolbox of methods for analyzing and managing data-limited fisheries. It can be used to obtain valuable management information that would otherwise be technically difficult to obtain. For example, it can be used to evaluate the effectiveness of management procedures applied to a particular fishery or to assess new MP and their likelihood of achieving management objectives.

As far as the present case study is concerned, the results illustrate the potential of MERA to optimize the management strategy for the Mexican pink abalone fishery. However, we should recall that this is an academic exercise since defining MP requires first defining management objectives (e.g., social, environmental, economic) and agreeing on performance indicators. This process should involve stakeholder participation (also to increase the likelihood of successful implementation). In this sense, the MERA tool, through its interface and ease of use, can facilitate and encourage these participatory processes. Regardless of the MP used in any fishery, the MP should be practical, verifiable, adaptable, aligned with explicit management objectives, and assessed against performance indicators.

ACKNOWLEDGMENTS

The authors are grateful to INAPESCA and S.C.P.P. Progreso, who provided the data. Funding was provided by CONAHCyT Project No. 320501 (Stage 2). The authors thank SNII (Sistema Nacional de Investigadoras e Investigadores). LCAH thanks Instituto Politécnico Nacional for the EDI program and project SIP-20230859.

REFERENCES

Anderson, L. G., & Seijo, J. C. (2010). *Bioeconomics of fisheries management*. John Wiley & Sons.

Arreguín-Sánchez, F. (1996). Catchability: A key parameter for fish stock assessment. *Reviews in Fish Biology and Fisheries*, *6*(2), 221-242. https://doi.org/10.1007/BF00182344

Carballo, L., & Muciño-Díaz, M. (1996). La pesquería del abulón. in *Estudio del Potencial Pesquero y Acuícola de Baja California Sur.* (pp. 15-41). BCS/FAO/INP/UABCS/CIBNOR/CICIMAR/CetMar. https://cibnor.repositorioinstitucional.mx/jspui/handle/1001/888

Carruthers, T. R., Huynh, Q. C., Hordyk, A. R., Newman, D., Smith, A. D. M., Sainsbury, K. J., Stokes, K., Morison, A., Agnew, D., Parma, A., Sobrino, I., & Longo, C. (2023). Method evaluation and risk assessment: A framework for evaluating management strategies for data-limited fisheries. *Fish and Fisheries*, *24*(2), 279-296. https://doi.org/10.1111/faf.12726

Carruthers, T. R., Punt, A. E., Walters, C. J., MacCall, A., McAllister, M. K., Dick, E. J., & Cope, J. (2014). Evaluating methods for setting catch limits in data-limited fisheries. *Fisheries Research*, *153*, 48-68. https://doi.org/10.1016/j.fishres.2013.12.014

Cook, P. A. (2023). Worldwide abalone production: An update. *New Zealand Journal of Marine and Freshwater Research*, 1-7. https://doi.org/10.1080/00288330.2023.2261869

Cunningham, E. (2013). *Catch Shares in Action: Mexican Baja California FEDECOOP Benthic Species Territorial Use Rights for Fishing System* (p. 12). Environmental Defense Fund.

DOF. (1993). *Norma Oficial Mexicana -005-PESC-1993, para regular el aprovechamiento de las poblaciones de las distintas especies de abulón en aguas de jurisdicción federal de la Península de Baja California*.

DOF. (2023). *Actualización de la Carta Nacional Pesquera 2023. Diario Oficial de la Federación: 21/07/2023*.

Dowling, N. A., Dichmont, C. M., Haddon, M., Smith, D. C., Smith, A. D. M., & Sainsbury, K. (2015). Empirical harvest strategies for data-poor fisheries: A review of the literature. *Fisheries Research*, *171*, 141-153. https://doi.org/10.1016/j.fishres.2014.11.005

FAO. (2022). *The state of world fisheries and aquaculture 2022*. FAO. https://doi.org/10.4060/cc0461en

Geromont, H. F., & Butterworth, D. S. (2015). Generic management procedures for data-poor fisheries: Forecasting with few data. *ICES Journal of Marine Science*, *72*(1), 251-261. https://doi.org/10.1093/icesjms/fst232

Guzman Del Proo, S.A. (1992). A review of the biology of abalone and its fishery in Mexico. In: International Symposium on Abalone (1st : 1989 : La Paz, Mexico). *Abalone of the world: Biology, fisheries and culture* (S. A. Shepard, M. J. Tegner, & G. del Proo, Eds.) (pp. 341-360) . Fishing News Books, Wiley-Blackwell.

Hernández-Casas, S., Seijo, J. C., Beltrán-Morales, L. F., Hernández-Flores, Á., Arreguín-Sánchez, F., & Ponce-Díaz, G. (2023). Analysis of supply and demand in the international market of major abalone fisheries and aquaculture production. *Mari-*

ne Policy, *148*, 105405. https://doi.org/10.1016/j.marpol.2022.105405

Hidalgo, M., Bartolino, V., Coll, M., Hunsicker, M. E., Travers-Trolet, M., & Browman, H. I. (2022). 'Adaptation science' is needed to inform the sustainable management of the world's oceans in the face of climate change. *ICES Journal of Marine Science*, *79*(2), 457-462. https://doi.org/10.1093/icesjms/fsac014

Hilborn, R., Maguire, J.-J., Parma, A. M., & Rosenberg, A. A. (2001). The Precautionary Approach and risk management: Can they increase the probability of successes in fishery management? *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(1), 99-107. https://doi.org/10.1139/f00-225

Hilborn, R., & Walters, C. J. (2013). *Quantitative fisheries stock assessment: Choice, dynamics and uncertainty*. Springer Science & Business Media.

Holland, D. S., & Herrera, G. (Ta) E. (2009). Uncertainty in the management of fisheries: Contradictory implications and a new approach. *Marine Resource Economics*, *24*(3), 289-299. https://doi.org/10.1086/mre.24.3.42629656

Honey, K.T., Moxley, J. H., & Fujita, R. M. (2010). From rags to fishes: Data-poor methods for fishery managers. In: *Managing Data-Poor Fisheries: Case Studies, Models and Solutions*. (R.M. Starr, C.S. Culver, C. Pomeroy, S. McMillan, T. Barnes & D. Aseltine-Neilson, Eds.) (pp. 159-184).

Huppert, D. (1996). *Precautionary approach to fisheries* (FAO Fisheries Technical Paper, pp. 103-128). https://www.fao.org/3/w1238e/W1238E05.htm

INAPESCA. (2019). *Base de datos electrónica del proyecto Bentónicos del INAPESCA*. Instituto Nacional de Acuacultura y Pesca.

Kininmonth, S., Blenckner, T., Niiranen, S., Watson, J., Orio, A., Casini, M., Neuenfeldt, S., Bartolino, V., & Hansson, M. (2022). Is diversity the missing link in coastal fisheries management? *Diversity*, *14*(2), 90. https://doi.org/10.3390/d14020090

Kleisner, K., Zeller, D., Froese, R., & Pauly, D. (2013). Using global catch data for inferences on the world's marine fisheries. *Fish and Fisheries*, *14*(3), 293-311. https://doi.org/10.1111/j.1467-2979.2012.00469.x

Mangin, T., Cisneros-Mata, M. Á., Bone, J., Costello, C., Gaines, S. D., McDonald, G., Rodriguez, L., Strauss, C. K., & Zapata, P. (2018). The cost of management delay: The case for reforming Mexican fisheries sooner rather than later. *Marine Policy*, *88*, 1-10. https://doi.org/10.1016/j.marpol.2017.10.042

Miyake, Y., Kimura, S., Horii, T., & Kawamura, T. (2017). Larval dispersal of abalone and its three modes: A review. *Journal of Shellfish Research*, *36*(1), 157-167. https://doi.org/10.2983/035.036.0116

Morales-Bojórquez, E., Muciño-Díaz, M. O., & Vélez-Barajas, J. A. (2008). Analysis of the decline of the abalone fishery (Haliotis fulgens and H. corrugata) along the westcentral coast of the baja california peninsula, mexico. *Journal of Shellfish Research*, *27*(4), 865-870. https://doi.org/10.2983/0730-8000(2008)27[865:AOTDOT]2.0.CO;2

MSC. (2023). *Working Towards MSC certification: A practical guide for fisheries improving to sustainability*. Marine Stewardship Council.

Nakatsuka, S. (2017). Management strategy evaluation in regional fisheries management organizations − How to promote robust fisheries management in international settings. *Fisheries Research*, *187*, 127-138. https://doi.org/10.1016/j.fishres.2016.11.018

Ponce Díaz, G., Lluch Cota, S. E., Bautista Romero, J. J., & Lluch Belda, D. (2003). Caracterización multiescala de la temperatura del mar en una zona de bancos de abulón (*Haliotis* spp.) en Bahía Asunción, Baja California Sur, México. *Ciencias Marinas*, *29*(3), 291-303. https://doi.org/10.7773/cm.v29i3.156

Ponce-Díaz, G., Chávez, E., & Ramade-Villanueva, M. (2000). Evaluation of the green abalone *Haliotis fulgens* fishery in bahía asunción, baja california sur, mexico. *Ciencias Marinas*, *26*(3), 393-412. https://doi.org/10.7773/cm.v26i3.598

Progreso, S. (2020). *Base de datos de captura histórica de la SCPP Progreso*. Sociedad Cooperativa de Producción Pesquera Progreso.

Punt, A. E. (2003). Evaluating the efficacy of managing West Coast groundfish resources through simulations. *Fishery Bulletin*, *101*(4), 860-873. http://hdl.handle.net/1834/31028

Punt, A. E., & Methot, R. D. (2005). The impact of recruitment projection methods on forecasts of rebuilding rates for overfished marine resources. In: *Fisheries Assessment and Management in Data-Limited Situations* (G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, & D. Woodby, Eds.) (pp. 571–594). Alaska Sea Grant, University of Alaska Fairbanks. https://doi.org/10.4027/famdis.2005.31

Punt, A. E., & Ralston, S. (2007). A management strategy evaluation of rebuilding revision rules for overfished rockfish stocks. In: *Biology, assessment, and management of North Pacific rockfishes* (J. Heifetz, J. DiCosimo, A.J. Gharrett, M.S. Love, V.M. O'Connell & R.D. Stanley, Eds.) (pp. 329-351). Alaska Sea Grant College Program, University of Alaska, Fairbanks. https://doi.org/10.4027/bamnpr.2007.19

Ramade-Villanueva, M. R., Lluch-Cota, D. B., Lluch-Cota, S. E., Hernandez-Vazquez, S., Espinoza-Montes, A., & Vega-Velazquez, A. (1998). An evaluation of the annual quota mechanism as a management tool in the Mexican abalone fishery. *Journal of Shellfish Research*, *17*(3), 847-851.

Rayns, N. (2007). The Australian government's harvest strategy policy. *ICES Journal of Marine Science*, *64*(4), 596-598. https://doi.org/10.1093/icesjms/fsm032

Restrepo, V. (1999). Precautionary control rules in US fisheries management: Specification and performance. *ICES Journal of Marine Science*, *56*(6), 846-852. https://doi.org/10.1006/jmsc.1999.0546

Searcy-Bernal, R., Ramade-Villanueva, M. R., & Altamira, B. (2010). Current status of abalone fisheries and culture in mexico. *Journal of Shellfish Research*, *29*(3), 573-576. https://doi.org/10.2983/035.029.0304

Smith, A. (1999). Implementing effective fisheries-management systems – management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science*, *56*(6), 967-979. https://doi.org/10.1006/jmsc.1999.0540

Smith, A., Aguilar, J. D., Boch, C., De Leo, G., Hernández-Velasco, A., Houck, S., Martinez, R., Monismith, S., Torre, J., Woodson, C. B., & Micheli, F. (2022). Rapid recovery of depleted abalone in isla natividad, baja california, mexico. *Ecosphere*, *13*(3), e4002. https://doi.org/10.1002/ecs2.4002

Smith, A. D. M., Smith, D. C., Haddon, M., Knuckey, I. A., Sainsbury, K. J., & Sloan, S. R. (2014). Implementing harvest strategies in Australia: 5 years on. *ICES Journal of Marine Science*, *71*(2), 195-203. https://doi.org/10.1093/icesjms/fst158

Van Oosten, J. (1949). A definition of depletion of fish stocks. *Transactions of the American Fisheries Society*, *76*(1), 283-289. https://doi.org/10.1577/1548-8659(1946)76[283:ADODOF]2.0.CO;2

Vargas-López, V. G., Arreguín-Sánchez, F., Gutiérrez-González, J. L., & Seijo, J. C. (2023). Co-management of a high-value species with territorial use rights for fisheries: A spatial bioeconomic approach with environmental variability. *Scientia Marina*, *87*(3), e071-e071. https://doi.org/10.3989/scimar.05335.071

Vargas-López, V. G., Vergara-Solana, F., & Arreguín-Sánchez, F. (2021). Effect of environmental variability on the individual growth of yellow abalone (Haliotis corrugata) and blue abalone (Haliotis fulgens) in the Mexican Pacific. *Regional Studies in Marine Science*, *46*, 101877. https://doi.org/10.1016/j.rsma.2021.101877

Vargas-López, V. G., Vergara-Solana, F. J., & Almendarez-Hernández, L. C. (2023). Environmental related age-specific natural mortality of a high-value species: The case of Mexican green abalone fishery. *Regional Studies in Marine Science*, *62*, 102938. https://doi.org/10.1016/j.rsma.2023.102938

Vergara-Solana, F. J., Vargas-López, V. G., Bolaños-Durán, E., Paz-García, D. A., & Almendarez-Hernández, L. C. (2023). Bioeconomic analysis of stock rebuilding strategies for the green abalone fishery in Mexico under climate uncertainty. *Ocean & Coastal Management*, *243*, 106759. https://doi.org/10.1016/j.ocecoaman.2023.106759

Walsh, J. C., Minto, C., Jardim, E., Anderson, S. C., Jensen, O. P., Afflerbach, J., Dickey-Collas, M., Kleisner, K. M., Longo, C., Osio, G. C., Selig, E. R., Thorson, J. T., Rudd, M. B., Papacostas, K. J., Kittinger, J. N., Rosenberg, A. A., & Cooper, A. B. (2018). Trade-offs for data-limited fisheries when using harvest strategies based on catch-only models. *Fish and Fisheries*, *19*(6), 1130-1146. https://doi.org/10.1111/faf.12316

Walters, C. J. (2007). Is adaptive management helping to solve fisheries problems? *AMBIO: A Journal of the Human Environment*, *36*(4), 304-307. https://doi.org/10.1579/0044-7447(2007)36[304:IAMHTS]2.0.CO;2

Williams, B. K. (2011). Adaptive management of natural resources—Framework and issues. *Journal of Environmental Management*, *92*(5), 1346-1353. https://doi.org/10.1016/j.jenvman.2010.10.041

APPENDIX

Data input to MERA for *H. corrugata* in the Mexican Pacific.

Fishery question		Answers (multiple choice)	Operating model parameter values
1. Fishery description	Provide an overview of the resource including references to supporting information	*Haliotis corrugata* Mexican Pacific Managed by Instituto Nacional de Pesca y Acuacultura	–
2. Longevity	What is the maximum age (*A*) of the species?	Moderate life span	$10 < A < 20$
3. Stock depletion	What is the status of spawning stock biomass compared to unfished levels (D)	Moderately depleted	$0.15 < D < 0.3$
4. Resilience	What fraction of unfished recruitment occurs at 20% of unfished spawning stock biomass (*h*)	Moderate resilience	$0.5 < h < 0.7$
5. Historical effort pattern	How has fishing intensity varied historically (e.g., annual days of fishing)?	Gradual increases	Adjustable skew, magnitude of recent changes and time-series truncation
6. Inter-annual variability in historical effort	What is the magnitude of inter-annual changes in fishing effort (σE) among years?	Not variable	$10\% < \sigma E < 20\%$
7. Historical fishing efficiency changes	What percentage change in fishing efficiency (Δh) can be expected over previous years	Stable	$-1\% < \Delta h < 1\%$
8. Future fishing efficiency changes	What percentage change in fishing efficiency (Δf) can be expected over future years	Stable	$-1\% < \Delta f < 1\%$
9. Length at maturity	What fraction of asymptotic length (*LM*) can 50% of fish be assumed to be sexually mature?	Small Moderate	$0.5 < LM < 0.6$ $0.6 < LM < 0.7$
10. Selectivity of small fish	Relative to asymptotic length, at what size do fish first become 50% vulnerable to fishing (*S*)?	Large	$0.6 < S < 0.8$
11. Selectivity of large fish	What is the selectivity of fish of asymptotic length (*SL*)?	Asymptotic selectivity	$SL = 1$
12. Discard rate	Of the fish that are caught, what fraction are discarded (*FD*)?	Low	$0 < FD < 1\%$
13. Post-release Mortality rate	Of the fish that are discarded, what fraction die due to capture (*FR*)?	Low	$0 < FR < 5\%$
14. Recruitment variability	What is the magnitude of inter-annual changes in recruitment (σR)	Moderate	$60\% < \sigma R < 120\%$
15. Size of existing spatial closure	What percentage of the species habitat is included in existing marine spatial closures (*rh*)?	None	$rh = 0$
16. Spatial mixing in/out of existing spatial closures	Among years, what fraction of fish leave the spatial closure and enter the fished area (*Ph*)?	Very low	$0 < Ph < 1\%$
17. Size of future spatial closures	What percentage of the species habitat is included in proposed future marine spatial closures (*rf*)?	None	$rf = 0$
18. Spatial mixing in/out of future spatial closures	Among years, what fraction of fish are expected to leave the spatial closure and enter the fished area (*Pf*)?	Very low	$0 < Pf < 1\%$
19. Initial stock depletion	At the start of the historical time series, what was the stock level as a fraction of theoretical unfished stock size (D_1)	Moderate	$0.3 < D_1 < 0.5$

Management question		Answers (multiple choice)	Operating model parameter values
Type of fishery management that is possible	Can fishery exploitation be controlled by measure such as Total annual catches (TAC), Total annual effort (TAE).	TAC TAE Size Limit Time-area closures	----
Type of fishery management that is possible	What fraction (FC) of recommended catches are taken by the fishery	Taken exactly.	$90\% < FC < 100\%$
3. TAC implementation variability	Given the offset between catch recommendations and catches of the fishery what is the maximum annual deviation (dC) from this offset?	Constant Not variable	$0 < dC < 1\%$ $1\% < dC < 5\%$
4. TAE offset	What fraction (FE) of recommended catches are taken by the fishery	Taken exactly	$95\% < FE < 105\%$
5. TAE implementation variability	Given the offset between effort recommendations and effort of the fishery what is the maximum annual deviation (dE) from this offset?	Not variable Low variability	$1\% < dE < 5\%$ $5\% < dE < 10\%$
6. Size limit offset	What fraction of a recommended minimum size limit (FS) is taken by the fishery.	Taken exactly	$95\% < FS < 105\%$
7. Size limit implementation variability	Given the offset between recommended minimu m size limits and the minimum size that is taken, what is the maximum deviation (dS) from this offset?	Constant Not variable	$0 < dS < 1\%$ $1\% < dS < 5\%$

Data Question		Answers (multiple choice)	Operating model parameter values
1. Types of data that are available	What data types are collected and processed for making management recommendations using management procedures?	Historical annual catches Recent annual catches Historical abundance index Recent abundance index Fishing effort Size composition data Age composition data Growth Absolute biomass survey	----
2. Catch reporting bias	What is the % difference between the catches reported and those taken (θC)	Reported accurately	$-5\% < \theta C < 5\%$
3. Hyperstability in indices	How linear is the relationship between the index I, and the abundance A, where $I \propto A^{\beta}$	Proportional	$5\% < \beta < 10\%$