

Article preview

Abstract

Introduction

Section snippets

References (67)

Cited by (3)



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Management Strategies Evaluation (MSE) in a mixed and multi-specific fishery based on indicator species: An example of small pelagic fish in Ecuador

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Abstract

Many fisheries around the world have mixed and multispecies characteristics, and controlling the fishing mortality of the respective species assemblages is a permanent problem. Fisheries are tending to move towards ecosystem-based management strategies and models, and given a latent lack of knowledge regarding inter-specific and ecological relationships, a constant search for pragmatic solutions based on exploitation strategy design is necessary. These strategies should reduce the overexploitation risk for less productive stocks and guarantee the sustainability of this type of fisheries in the long term.

In this research we evaluate different Harvest Control Rule (HCR) schemes based on variations in the catch per unit of effort (CPUE) of indicator species in a mixed and multi-specific fishery for small pelagic fish (SPF) in Ecuador. Four Operating Models (OM) are implemented that simulates, under several uncertainty sources, the dynamics of the populations and the fishery controlled by adjustments of the fishing effort of the fleet. These uncertainty sources considered, among others, changes in species' biological traits, productivity shifts and two stock-recruitment

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relationships. The results show that a control rule based on monitoring indicator species and alternating species when one of them reaches $90\%CPUE_{MSY}$, combined with a fishing effort stabilizer, would allow lower overfished risks, as well as a greater stability and long-term sustainability for the fishery. Finally, it is recommended to consider the resilience/productivity capacity of the populations in the design of this HCR type, particularly those less resilient species of the fishery.

Introduction

Small pelagic fish management is a complex task due to the high variability in their productivity scales, their high dependence on environmental conditions, and the important role they play in the trophic chain [1], [2], [3], [4], [5]. This complexity increases in multi-specific fisheries, as the ecological relationships between the species that make up the ecosystems are often unknown [6]. In this context, the development of improvements in fishery management remains a priority in order to guarantee the sustainability of fisheries and the supply of resources for diverse uses in the food industry. Traditionally, fishery management recommendations have been based on mono-specific assessment models; however, a growing body of research is supporting moving towards ecosystem models (e.g. [7], [8], [9]), along with simple, inclusive, and transparent handling procedures [10]. Although this is in permanent development, an increasingly used practice has been to evaluate alternative management procedures through the Management Strategy Evaluation (MSE) approach [11], a methodology which allows testing the robustness of various management procedures against various sources of uncertainty through simulation techniques (e.g. [11], [12], [13]).

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Many fisheries around the world are sustained by mixed (different species caught at the same haul) and multi-species (different species in the same fishery) fishing [14], [15], [16], and they are challenged by the limitations caused by mono-specific management objectives in the catch and biomass of other populations of commercial interest (e.g. [17]). Some authors have explored the impact of establishing multi-specific biological reference points and have determined recommended catch levels (e.g. maximum sustainable yield - MSY) lower than those established with mono-specific approaches (e.g. [18]). Under these conditions, managers must balance the overfishing of less productive stocks with the under-exploitation of larger and more productive stocks [19], [20], [21], which would potentially reduce the fishery yields [22]. On the other hand, maximizing the total yield of a mixed fishery composed of several stocks could generate the overfished of the most diminished and less productive

populations [21]. One approach to address the complexity of managing a multi-species or mixed fishery has been the development of strategies based on monitoring the condition of an indicator species, assuming that this would allow reaching the management objective for the entire assemblage of associated species [23].

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Located on the western coast of South America, Ecuador stands out for its multi-species and mixed small pelagic fisheries, whose fluctuations and productivity are largely determined by the ecosystem of the Humboldt Current and the Cromwell Equatorial Countercurrent [24]. Some of the more important species of small pelagic fish (SPF) are chub mackerel (*Scomber japonicus*), Pacific thread herring (*Opisthonema spp*), Pacific anchoveta (*Cetengraulis mysticetus*), frigate tuna (*Auxis spp*), round herring (*Etrumeus teres*), and shortfin scad (*Decapterus macrosoma*). Fishing of these species began in the mid-70s and currently represents one of the most significant contributions towards the country's national production, accounting for over 25,000 jobs [25,26] and averaging over 200,000 tons of catch per year (Fig. 1). Since 1988, the SPF fishing management has been based on the application of biological closed seasons [27], and since 2016 those closures take place in February and November of each year [28]. Since 2020 additional days by full moon nights were added [29], resulting in increased fleet operation standstills totaling 90 days by year in most recent period. The main fleet is made up of industrial purse-seine vessels that are prohibited from operating within the first eight nautical miles off the coast. The bycatch in this fishery occurs in some small artisanal vessels operating inside this zone, and all this catch goes to the meal industry.

The history of SPF fishing in Ecuador has seen important changes in productivity throughout the years, marked by the alternation of captured species and variations in the recruitment scale [30]. During the 70 s and part of the 80 s, chub mackerel, Pacific thread herring, round herring, and Pacific anchoveta were the predominant captured species. Towards the end of the 90 s, frigate tuna became more relevant in landings, and since 2004 catches of other species such as shortfin scad have intensified (Fig. 1). According to [31], by 2019 most of these stocks were in a state of overfished ($B < B_{MSY}$), although without evidence of overfishing ($F < F_{MSY}$) (Table 1). Given the relevance of this industry for Ecuador and in order to achieve activity sustainability standards [32], in 2021 a Small Pelagic Fish Fishery Action and Management Plan [33] was proposed, along with different candidates for fishery exploitation strategies.

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This research shows the results of a Management Strategies Evaluation (MSE) based on Harvest Control Rules (HCR) for the mixed SPF fishery but considering a mono-specific

the mixed small fishery but considering a mono-specific approach. These HCRs considered different configurations based on the catch per unit of effort (CPUE) variations of some prioritized species as ecosystem indicators. The research proposes a way to perform the fishing effort management in a multi-specific fishery considering empirical population indicators.

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Biological reference points and set of representative species (SRS)

The objective proposed for this fishery is to recover the SPF populations to levels equal to or higher than their biomass in the Maximum Sustainable Yield (B_{MSY}). As a provisional Biological Reference Point (BRP) for fishery management purposes (*proxy*), this reference has been defined as 40 % of the virginal spawning biomass (B_0). This BRP was proposed by considering two key aspects: to provide a reachable short-time objective, and the fact that most of the population statuses are below 30 % B_0 ...

Results

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The projections of catches and biomass showed different levels of variability and tendencies depending on the cases considered. Taking HCR1 as an example, the catches in the long term tend to stabilize when the recruitments are determined by an S/R Beverton-Holt (OM1-OM2) model (Fig. 5a), and decrease in the case of a Ricker (OM3-M4) model (Fig. 5c). This situation occurred regardless of regime change or the option of fishing effort stabilization in the HCR (if $\varphi_y^s > 1$). The decrease in the ...

Discussion

The performance of a management strategy for mixed small pelagic fishery was analyzed, considering the monitoring of the CPUE of indicator species and the control of fishing season durations. Although the $CPUE_{MSY}$ reference values were assumed to be time-invariant, the example demonstrated the relevance of setting clear and understandable operational objectives for stakeholders. Due

to the recurrent lack of data and information regarding the ecological network of the species (e.g. [45]), and ...

Conclusions

Our analyses allow concluding that management based on CPUE variations of indicator species is feasible, and that an adequate control of the fishing effort could generate a sustainable and stable fishery even when not all the species reach the B_{MSY} . This procedure should be accompanied by a permanent review of the performance of the chosen rule (e.g. HCR3), and a progressive incorporation of the results of the annual stock assessment as input for decision making. Likewise, base studies are ...

CRedit authorship contribution statement

Cristian M. Canales: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Conceptualization. **Gonzalo Olea:** Writing – original draft, Methodology, Conceptualization. **Viviana Jurado:** Writing – original draft, Resources, Conceptualization. **Miguel Espíndola:** Writing – original draft, Conceptualization. ...

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