Management of the Peruvian anchoveta (Engraulis ringens) fishery in the context of climate change

Chapter · February 2021

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Food and Agriculture Organization of the United Nations

FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

667

ISSN 2070-7010

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Cover illustration: Pietro Bartoleschi

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667

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2021

Required citation:
Bahri, T., Vasconcellos, M., Welch, D.J., Johnson, J., Perry, R.I., Ma, X. & Sharma, R., eds. 2021. *Adaptive management of fisheries in response to climate change.* FAO Fisheries and Aquaculture Technical Paper No. 667. Rome, FAO. https://doi.org/10.4060/cb3095en

ISSN 2070-7010 [Print]
ISSN 2664-5408 [Online]

ISBN 978-92-5-133890-2

Chapter 14: Management of the Peruvian anchoveta (*Engraulis ringens*) fishery in the context of climate change

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Summary

The Peruvian anchoveta (*Engraulis ringens*) is a small pelagic fish endemic to the Peru Current Ecosystem. Anchoveta population dynamics are strongly influenced by environmental conditions: this fishery operates in a complex and highly variable ecosystem, which has resulted in a flexible and adaptive management system closely focused on incorporating near real-time observational data of both the ecosystem and the anchoveta population. In this context, Peruvian anchoveta assessment methods differ from traditional methods in three ways: i) use of a conservative projection horizon to set management limits; ii) use of near real-time direct observations as an initial condition for the projection of harvest scenarios; and iii) inclusion of environmental variability in the projections, using variable population parameters for different environmental scenarios according to the best available forecasts of the state of the ecosystem.

This assessment paradigm – developed within the framework of the natural environmental variability mainly driven by the El Niño Southern Oscillation (ENSO) – is a robust alternative for stock assessments in the context of climate change, where greater sensitivity of populations to environmental conditions is expected. In the same way, the constant and intensive monitoring of the fishery allows the near real-time implementation of additional management measures to protect the resource, facilitating a swift response to the rapid spatio-temporal changes that occur in the interaction of the fishery and the anchoveta. This use of near real-time direct observations to quickly adapt management measures to any departure from the assumptions used for stock assessment and TAC allocation is recommended for highly productive and valuable fisheries.

Fishery context

The Peruvian anchoveta (*Engraulis ringens*) is a small pelagic fish endemic to the Peru Current Ecosystem, with its major abundance within the Peruvian upwelling ecosystem (Figure 1). It has an average lifespan of three years and achieves a maximum total length of 20 cm (Whitehead *et al*. 1988). Anchoveta is a fast-growing species, reaching sexual maturity at one year of age at an average total length of 12 cm (Perea *et al.*, 2011), and being recruited to the fishery at six months at a total length of 8 cm (Oliveros-Ramos and Peña, 2011). Anchoveta is a partial spawner, and off Peru it has two spawning peaks: the main peak is between August and September, and a secondary peak occurs between February and March (Perea *et al*., 2011). Anchoveta diet is mainly zooplankton, especially Euphausiids and large copepods (Espinoza and Bertrand, 2014). Anchoveta population dynamics are strongly influenced by environmental conditions that affect prey availability, natural mortality, growth, recruitment success, and availability to the fishery and predators (Csirke, 1980; Csirke, 1989; Alheit and Ñiquen, 2004; Ñiquen and Bouchon, 2014; Oliveros-Ramos, 2014; Barbraud *et al*., 2018).

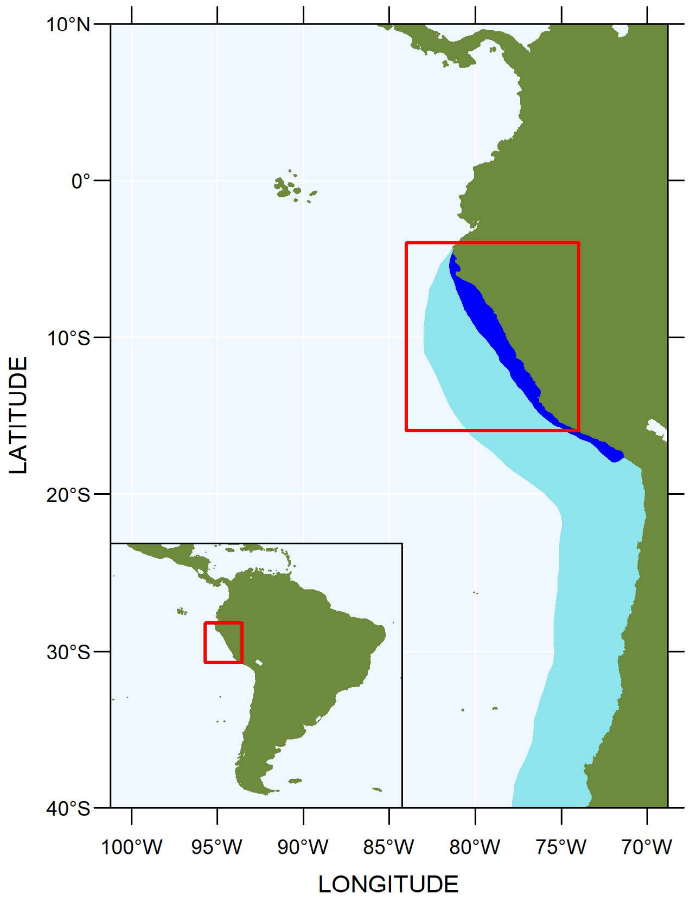

Figure 1. Case study area. The Peruvian upwelling ecosystem (dark blue) is located within the Northern Peru Current Ecosystem (light blue). The distribution area of the northern-central stock of Peruvian anchoveta is bordered in red.

Anchoveta is managed as two stocks within the Peruvian exclusive economic zone (EEZ): the northern-central stock (2°S-16°S) and the southern stock (south of 16°S, shared with Chile). The northern-central stock is the more important in terms of landings and profits, representing more than 90 percent of the landings of anchoveta (PRODUCE, 2018). The biomass of the northern-central stock has fluctuated between 6 and 11 million tonnes in recent years, while the biomass of the southern stock has fluctuated between 250 000 and 2 million tonnes within Peruvian waters.

An industrial fishery has exploited anchoveta since 1950, mainly for the production of fish meal and oil. There have been major fluctuations in the fishery over time: its record landing of over 13 million tonnes came in 1971, before a collapse in the fishery in the early 1970s and a subsequent recovery at the end of the 1990s. Currently, Peru is responsible for more than half of the global production of fish meal and a third of the fish oil (Fréon *et al.* 2014). Additionally, an artisanal fishery harvests anchoveta, mainly for canning. Both fisheries use purse-seines, with the mesh size regulated to a minimum of 13 cm (Yonashiro and Balbín, 2016). The industrial fishery works from 5 nm to approximately 50 nm offshore, while the artisanal fishery works inside the 5 nm limit (Yonashiro and Balbín, 2016).

During recent years, the annual catch of the northern-central stock has fluctuated between 2 and 4 million tonnes. Peru exports around 1 million tonnes of fish meal and 100 000 tonnes of fish oil each year, with a value of more than USD 1 billion (PRODUCE, 2018). Tens of thousands people are directly involved (fishing) in the anchoveta fishery and hundreds of thousands are indirectly involved (in processing and distribution).

Management context

All Peruvian fisheries are managed by the Ministry of Production (PRODUCE), with scientific advice from the Peruvian Marine Research Institute (IMARPE). The management of the northern-central stock of anchoveta is based on two objectives: (1) maintain a stock biomass over 5 million tonnes, and (2) maintain an explotation rate below 0.35 (IMARPE, 2016). Fishing occurs in two seasons each year, and is regulated with a total allowable catch (TAC) and – since 2009 – an individual transferable catch share system. The individual transferable quota (ITQ) of each vessel can only be transferred to another vessel already in possession of an ITQ (so-called 'semi-transferable' quotas), and the fishery is closed to new vessels (Yonashiro and Balbín, 2016). Fishing seasons are limited by full closures during the two main spawning seasons (reproductive closures, Figure 2). Temporal closures (for a minimum of three days) in specific fishing areas, controlled by remote sensing, are implemented during each fishing season in areas with juvenile catches over 10 percent, as an additional measure of protection for the stock (PRODUCE, 2016).

To address environmental variability, which is particularly influential in the Peruvian Upwelling System, IMARPE carries out intensive and continuous monitoring of the ecosystem using remote sensing and in situ observations at sea and on land. Direct observations in the sea are carried out with two to four scientific surveys each year, covering the entire Peruvian coast. These surveys collect oceanographic and ecosystem information, including a hydroacoustic assessment used for the estimation of total biomass, egg and larvae production, size structure of the anchoveta population and reproductive condition. Additionally, during anomalous environmental conditions, a 'Eureka' operation conducts hydroacoustic assessment surveys with data collected simultaneously by several industrial fishing vessels under the coordination of IMARPE.

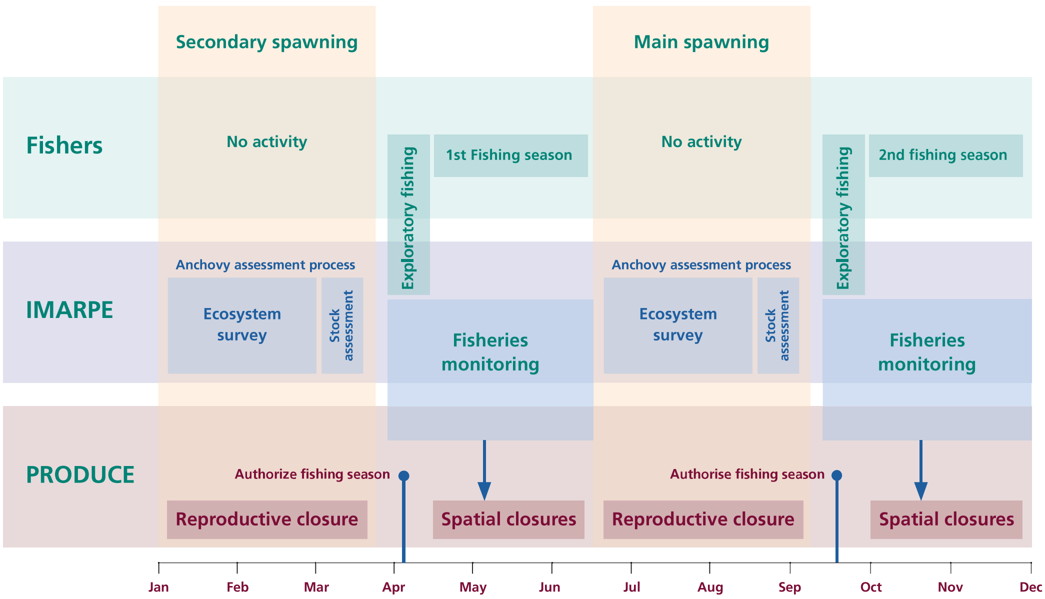

Figure 2. Stakeholder participation in anchoveta fisheries management. Activities related to fisheries management and stakeholders involved are shown.

The Eureka operations are carried out to collect additional information on the distribution and abundance of the stock (Gutierrez *et al*. 2000). Landings and size composition of the industrial fleet are monitored continuously (24/7) at every landing site. Currently, IMARPE and PRODUCE onboard observers collect information from up to 80 percent of fishing trips, with vessel monitoring systems (VMS) mandatory for the industrial fleet.

Stock assessment is carried out by IMARPE, estimating the population structure from the results of the hydroacoustic surveys and projected under several harvest scenarios. Harvest scenarios are projected up to the next reproductive peak, and use different population parameters (e.g. growth, mortality) according to the environmental conditions (favourable or unfavourable) predicted during the period. The results are presented in the form of a decision table (IMARPE, 2016; IMARPE, 2019) used by PRODUCE to set the TAC for the current fishing season.

The fishing season starts 15 days after authorization by PRODUCE. Between the authorization date and the beginning of the fishing season, an exploratory fishing trip is supervised by IMARPE (Figure 2). The objective is to update knowledge on the spatial distribution of the resource and particularly to identify areas with a high proportion of juveniles, in order to set temporal closures. The catch during the exploratory fishing is taken into account for the final setting of the TAC.

Climate change implications

The Peruvian upwelling ecosystem is one of the most productive in the world, due to the abundance of nutrients upwelled with the cold waters near the coast that nurture large populations of phytoplankton, zooplankton and fish (Chávez *et al.*, 2008). The sea surface temperature off Peru has shown a cooling trend in recent decades, but Earth system models (ESM) project a warming for the region, higher than the levels of natural variability, after 2050 (Henson *et al.* 2016). In addition, there has been an increase in the frequency of observed coastal warming events since 2002 (IMARPE, 2019). Climate change is expected to have negative impacts on the anchoveta population, due to the warming of the system and a reduction of coastal upwelling and primary productivity (Gutierrez *et al.*, 2019). Coastal warming events, in particular, alter the spatial distribution of anchoveta (Mathisen, 1989; Joo *et al.*, 2014; Castillo *et al.*, 2019; Moron *et al.* 2019), which affects both the interaction of the fishery with the resource and the capacity to collect scientific information for the anchoveta population assessment (IMARPE, 2019).

The potential impact of climate change scenarios on the anchoveta population has been studied for the Peruvian upwelling ecosystem (Oliveros-Ramos, 2018), using an ecosystem model (OSMOSE). The model integrates information on the projected changes in the spatial distribution of fish and plankton production from Earth system models (IPSL CM5A-LR and GFDL-ESM2M) under four climate change scenarios (RCP 2.6, 4.5, 6.0 and 8.5) for the period 2009–2100, assuming historical fishing exploitation rates (2005–2008). These simulations show an expected reduction in the total population biomass of 8.2 percent to 13.9 percent per decade. A similar trend, with biomass below the biological reference point (IMARPE, 2016), was observed during the 1980s after the 1972–1973 El Niño event and the subsequent collapse of the fishery, with recovery observed from the mid-1990s. This historical recovery followed a moratorium on fishing and a cooling of the marine system that progressed to a new colder regime after the 1997–1998 El Niño event (Espinoza-Morriberón *et al.* 2017). Additionally, a southward displacement of the anchoveta population closer to the coast is projected (Oliveros-Ramos, 2018; Gutierrez *et al.*, 2019) under all RCP scenarios considered, as is currently observed during warming events. These alterations in the spatial distribution of the resource can affect fishing activity, since the displacement of the main biomass southward will impact on the spatial distribution of the fishing fleet – and therefore on the fuel costs to reach the fishing grounds as well as to transport the catch to processing plants. Anchoveta catchability could increase with a more coastal distribution: this would also increase the overlap in the distribution of adults and juveniles, as the latter are more coastal and less tolerant of thermal changes (Luján, 2016).

On the other hand, an ecological risk assessement (Ramos, 2017) assigned a medium level of risk to anchoveta in the face of climate change, due to its phenotypic plasticity. Ongoing studies, taking into account the resilience of anchoveta to environmental fluctuations and possible evolutionary adaptations to permanent climatic changes in productivity and ecosystem conditions, may improve the forecast for management of the Peruvian anchoveta fishery and population.

Adaptations and lessons

Stock assessment and management advice

The dynamics of the Peruvian upwelling ecosystem and the interactions between anchoveta and its environment are too complex to ascribe to changes in ocean temperature alone. For this reason, IMARPE uses an integrated approach to monitor ecosystem conditions (physical, chemical and biological) to assess the impacts on the population dynamics of anchoveta, also taking into account the bias that anomalous conditions may produce in the information collected for stock assessment. These changes in the anchoveta assessment process have been reflected in an update of the protocol for explaining the decision table to determine the TAC (IMARPE, 2019). Currently, the most recent forecast of environmental conditions provided by the ENFEN expert panel (National Commission for the Study of El Niño Events) is used to set the population parameters for the TAC projection estimate. Notably, depending on the intensity of the impact that anomalous conditions in the ecosystem may have on anchoveta stock, a more robust or more precautionary approach to the assessment can be chosen (IMARPE, 2019). In addition, during particularly intense ocean warming events, IMARPE considers whether to conduct an extra scientific survey before recommending a TAC, in order to update the information used for management recommendations.

Formulation of norms to regulate harvest and access to resources according to established objectives

Under normal conditions, anchoveta juveniles have a more coastal distribution than adults, allowing the fishery to target the adult population without compromising the juvenile portion. However, during warming events, the increased overlap between adult and juvenile distribution causes an increased harvest of juvenile individuals, potentially compromising the sustanaibility of the population. During the anchoveta assessment process, the number and weight of juvenile individuals expected in the landings during a fishing season (as a fraction of the TAC) is calculated and reported to PRODUCE. This figure, called 'juvenile TAC', provides an additional management criterion that strengthens the protection of juvenile individuals: it allows PRODUCE to close the fishery once the landings reach the juvenile TAC even if the full TAC has not been completed, effectively protecting the more highly mixed population during warming events.

Monitoring, control and surveillance

Since 2016, fishing vessels have reported on their fishing areas and the proportion of juveniles in catches. This data is analyzed by IMARPE to define critical fishing areas with a high incidence of juvenile catch, in order to recommend to PRODUCE the temporary closures of these areas. This measure of protection of the juvenile population is particularly important during warming events where the increased overlap in the spatial distribution of adults and juveniles increases the catchability of the latter. Additionally, an electronic landing monitoring programme has been implemented and a self-sampling procedure for fishing vessels has been promoted, both for fishing effort and biological, population and ecological monitoring (e.g. size structure of anchoveta, bycatch).

Key recommendations

The Peruvian anchoveta fishery operates in a complex and highly variable ecosystem, which has led to a more flexible and adaptive management system strongly focused on incorporating near real-time observational data. In this context, the Peruvian anchoveta assessment methods differ from traditional methods in three ways: i) their use of a conservative projection horizon (less than six months, until the next reproductive period) to set management limits; ii) their use of near real-time direct observations (ecosystem surveys) as an initial condition for the projection of harvest scenarios; and iii) their inclusion of environmental variability in the projections, using variable population parameters for each environmental scenario (favourable, unfavourable or neutral), according to the best available forecasts of the state of the ecosystem during the projection horizon (IMARPE, 2016; IMARPE, 2019). This assessment paradigm, developed within the framework of the natural environmental variability mainly due to the El Niño Southern Oscillation (ENSO), is a robust alternative for stock assessments in the context of climate change, where greater sensitivity of populations to environmental conditions is expected.

In the same way, the constant and intensive monitoring of the fishery has allowed the implementation of additional management measures in near real-time for the protection of the resource. This 'dynamic ocean management' approach (Maxwell *et al.*, 2015) allows a timely response to the rapid spatio-temporal changes that occur in the interaction of the fishery and the anchoveta, allowing a better balance between economic (completion of TAC) and ecological (sustainability of the population through the protection of juveniles) objectives.

In general, managing fisheries under large-scale environmental fluctuations like ENSO is becoming increasingly important under climate change, and explicit consideration of environmental uncertainty is recommended. While the forecasts of environmental conditions improve, the best response to an unfavourable forecast should be analyzed (e.g. Miller *et al*. 2019). Additionally, for highly productive and valuable fisheries, the use of near real-time direct observations to quickly adapt management measures to any departure from the assumptions used for stock assessment and TAC allocation is recommended.

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