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Food security or economic profitability? Projecting the effects of climate and socioeconomic changes on global skipjack tuna fisheries under three management strategies

Sibylle Dueri[a,*], Patrice Guillotreau[b], Ramón Jiménez-Toribio[c], Ricardo Oliveros-Ramos[a,d], Laurent Bopp[e], Olivier Maury[a,f]

[a] IRD (Institut de Recherche pour le Développement), UMR 248 MARBEC, Sète, France
[b] Institut d'Economie et de Management de Nantes, LEMNA, University of Nantes, France
[c] MEMPES, University of Huelva, Spain
[d] Instituto del Mar del Perú (IMARPE), Peru
[e] Laboratoire des sciences du climat et de l'environnement (LSCE), IPSL, CEA-UVSQ-CNRS, UMR8212, Gif-sur-Yvette, France
[f] ICEMASA, Departement of Ocenography, University of Cape Town, South Africa

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ABSTRACT

We investigate the interactions between anthropogenic climate change, socioeconomic developments and tuna fishery management strategies. For this purpose, we use the APECOSM-E model to map the effects of climate change and commercial fishing on the distribution of skipjack tuna biomass in the three oceans, combined with a new bioeconomic module representing the rent or profit of skipjack fisheries. For forcing, we use Representative Concentration Pathway (RCP) 8.5, the highest emission scenario for greenhouse gas concentrations presented in the IPCC's Fifth Assessment Report (AR5), and the IPCC Socioeconomic Shared Pathway (SSP) 3, which is characterized by low economic development and a strong increase in the world population. We first investigate the impact of climate change on regional skipjack abundance, catches and profits in three oceans (Atlantic, Indian and Pacific) in 2010, 2050 and 2095. We then study the effects of three management strategies (maximum sustainable yield or MSY, maximum economic yield or MEY, and zero rent or ZR) on the future distribution of fishing fleets between oceans and on global economic rent.

Our model projections for 2050 and 2095 show an increase in global skipjack biomass compared to 2010 and major changes in its distribution, impacting local and regional fishing efforts. The Pacific Ocean will continue to dominate the skipjack market.

In our modeling of management strategies, the currently predominant MSY strategy would have been unprofitable in 2010, due to a decreased catch per unit effort (CPUE). In the future, however, technological developments should increase fishing efficiency and make MSY profitable.

In all the scenarios, a MEY strategy is more profitable than MSY but leads to the lowest catches and the highest prices. This raises ethical questions in a world where food security may become a top priority.

In the scenarios where MSY generates an economic loss (e.g. 2010), a ZR strategy allows global stocks to be exploited at high but still profitable levels. Conversely, in the scenarios where MSY is profitable, (e.g. 2095) ZR leads to overfishing and smaller global catches.

We conclude that the most appropriate management strategy at any time is likely to change as environmental and socioeconomic conditions evolve. The decision to follow one or other strategy is a complex one that must be regularly reviewed and updated.

1. Introduction

Fisheries contribute to society by supplying protein-rich food, providing employment and promoting economic growth, but this comes at a cost. The increasing exploitation of marine resources

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[*] Corresponding author.
E-mail address: sibylle_dueri@hotmail.com (S. Dueri).

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has intensified the stress on marine ecosystems through overfishing, pollution and habitat degradation (Garcia and Rosenberg, 2010). This is compounded by anthropogenic climate change, which is also modifying the physical, chemical and biological environmental conditions of the oceans (Brander, 2010; Sumaila et al., 2011). A healthy outlook for fishing will depend on our ability to conserve fish stocks by limiting these stressors (Garcia and Grainger, 2005; Perry et al., 2010). Beyond a certain threshold, the resilience of marine resources breaks down.

The earth system models used to simulate climate change project warmer sea temperatures, ocean acidification, large changes in dissolved oxygen concentrations and some modifications to oceanic current patterns and intensities (IPCC, 2013; Chapters 6 and 12). They also project a generalized increase in surface ocean stratification, reducing the supply of nutrients to surface waters and diminishing primary production, the basis for marine food webs (Bopp et al., 2013). All these changes affect the structure, productivity and functioning of marine ecosystems (Lefort et al., 2014; Cheung et al., 2009) and shift the habitats of marine species (Cheung et al., 2010). Furthermore, these changes are expected to modify the distribution and abundance of exploited fish species (Dueri et al., 2014), impact the productivity of fisheries (Sumaila et al., 2011; Barange et al., 2014) and increase variability in marine socioecological systems (Perry et al., 2010). Existing projections of global catches for the next 50 years show a poleward displacement from tropical waters to higher latitudes (Cheung et al., 2010). At the same time, demographic growth is expected to increase food demand, including for sea products, thereby intensifying pressure on marine resources (Garcia and Rosenberg, 2010).

Skipjack tuna is the most fished tropical tuna with an annual global catch of 2.8 million tons (FAO, 2014), the majority of which is harvested in the Western and Central Pacific Ocean (Williams and Terawasi, 2015). Compared to other tropical tunas (bigeye and yellowfin), skipjack is considered more resilient to exploitation, given its relatively small size at maturity and its high reproduction rate (Stequert and Ramcharrun, 1996; Arrizabalaga et al., 2012; Grande et al., 2014). Skipjack tuna prefers warm surface waters and is therefore mainly caught by surface fishing gear (purse seiners, and pole and line vessels). With a purview covering large portions of the global ocean, four tuna regional fishery management organizations (RFMOs) oversee the conservation of skipjack stocks. In line with the 1982 United Nations Convention on the Law Of the Sea (UNCLOS), most RFMOs use maximum sustainable yield (MSY) as a management target or limit for the exploitation of tropical tuna. However, recent work suggests that a maximum economic yield (MEY) target would be more profitable and sustainable for fisheries (Grafton et al., 2012; Kompas et al., 2010).

Most of the global skipjack tuna catch is used to produce canned tuna, the world's second-largest international seafood trade in terms of value and volume (Campling, 2012). Canned tuna is a relatively low-priced and nutritional source of protein, and one of the most widely consumed forms of seafood in the United States and the European Union (Campling, 2012). Despite the high volumes of goods, cannery-grade frozen tuna is traded in only a few major markets, particularly Bangkok, which is home to the world's largest processing industry (Jiménez-Toribio et al., 2010). The canned tuna business is relatively concentrated at the trading and processing levels, where a few companies negotiate the international price of fish. Some canneries are vertically integrated but most purchase fish through the big trading companies that sell tuna on behalf of fisheries. This supply chain is well described in Campling et al., 2007 and in Miyake et al., 2010. Since most processors are major multinational companies that compare real-time ex-vessel prices in a limited number of marketplaces, we can consider that skipjack tuna is traded on a global market at a single global price, allowance being made for transportation costs (Jeon et al., 2008; Jiménez-Toribio et al., 2010).

The future of fisheries depends on their ability to adapt to climate and social changes. This involves developing management strategies that protect marine ecosystems while supplying protein-rich food to an increasing number of humans and maximizing the economic outcomes (e.g. employment and profits) of the global fish markets. These three components (ecosystem health, food security and economic profit) must be taken into account when evaluating management strategies. It is essential to develop models that can propagate climate signals in the ocean to fish, fisheries and markets (Barange et al., 2010; Murawski, 2011).

In this study, we investigate the interactions between anthropogenic climate change, socioeconomic change and skipjack tuna fishery management strategies. To do so, we use a coupled ecosystem–economic model. This is based on the APECOSM-E model (Dueri et al., 2012a,b, 2014), which represents tuna biomass and fisheries, complemented by a bioeconomic model, which maps the economic rent (or profit) of fisheries and the responsiveness of skipjack prices to changes in harvest levels (Sun et al., 2015). Our environmental forcing uses the IPSL-CM5 earth system model. We consider the effect of climate and socioeconomic changes on the distribution of fishing fleets, as well as their catches and economic profits, in the three oceans where skipjack tuna is fished (Atlantic, Indian and Pacific). A realistic forecast of future ecosystems, prices and markets is beyond the scope of our study. Our objective here is to compare the potential impact of three broad management strategies, using simple scenarios within our model framework. In particular, we address three questions:

1. What is the impact of anthropogenic climate change on the regional abundance of skipjack tuna?
2. What are the consequences on catches and profits?
3. How could different management strategies affect global economic rent and the distribution of fleets between the oceans?

2. Materials and methods

2.1. Global conceptual model and simulation strategy

To investigate the links between anthropogenic climate change, skipjack tuna fishing and the global market, we use the APECOSM-E fishery and ecosystem model, supplemented by a newly developed bioeconomic model (Fig. 1). APECOSM-E is a spatially explicit tridimensional model that represents the size-structured dynamics of the skipjack tuna biomass under the combined effect of climate and fishing. It has already been applied to the Indian Ocean (Dueri et al., 2012a,b) and at a global scale (Dueri et al., 2014). APECOSM-E explicitly models the spatial distribution of the fishing fleets that catch skipjack tuna. It is coupled through catches with the bioeconomic model, in which fishing vessels sell their landings to the global market and obtain revenue in return. The skipjack market price depends on global skipjack catches and other exogenous variables such as economic growth, based on global domestic product (GDP) and world population. The economic rent of a fishery is determined by subtracting total costs from total revenues. Simulations are run on a global scale, taking into account the interactions between tuna biomass and fisheries in the Atlantic, Indian and Pacific Oceans.

A climate change scenario (RCP 8.5, see Section 2.3) and a socioeconomic scenario (SSP 3, see Section 2.5) provide the forcing variables needed to drive the model. The climate change scenario used to force an earth system model defines important environmental factors, such as water temperature, dissolved oxygen