



Competition or cooperation in transboundary fish stocks management: Insight from a dynamical model



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ABSTRACT

An idealized system of a shared fish stock associated with different exclusive economic zones (EEZ) is modelled. Parameters were estimated for the case of the small pelagic fisheries shared between Southern Morocco, Mauritania and the Senegambia. Two models of fishing effort distribution were explored. The first one considers independent national fisheries in each EEZ, with a cost per unit of fishing effort that depends on local fishery policy. The second one considers the case of a fully cooperative fishery performed by an international fleet freely moving across the borders. Both models are based on a set of six ordinary differential equations describing the time evolution of the fish biomass and the fishing effort. We take advantage of the two time scales to obtain a reduced model governing the total fish biomass of the system and fishing efforts in each zone. At the fast equilibrium, the fish distribution follows the ideal free distribution according to the carrying capacity in each area. Different equilibria can be reached according to management choices. When fishing fleets are independent and national fishery policies are not harmonized, in the general case, competition leads after a few decades to a scenario where only one fishery remains sustainable. In the case of sub-regional agreement acting on the adjustment of cost per unit of fishing effort in each EEZ, we found that a large number of equilibria exists. In this last case the initial distribution of fishing effort strongly impact the optimal equilibrium that can be reached. Lastly, the country with the highest carrying capacity density may get less landings when collaborating with other countries than if it minimises its fishing costs. The second fully cooperative model shows that a single international fishing fleet moving freely in the fishing areas leads to a sustainable equilibrium. Such findings should foster regional fisheries organizations to get potential new ways for neighbouring fish stock management.

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1. Introduction

Exploited fish populations performing transboundary migrations is a common situation around the world, as obviously no fish is stopped at or by any country border. Documented examples include shared small pelagic fisheries in the California cur-

rent system between Canada, USA and Mexico (Javor et al., 2011; Lo et al., 2011) as well as in the Canary Current System between Morocco, Mauritania, Senegal, Gambia, and Guinea Bissao (Boely et al., 1982; Brochier et al., 2018), which are both East Boarder Upwelling. Reaching fishery agreements between the countries exploiting same fish stock is a prerequisite for a good, equitable management (e.g. Campbell and Hanich, 2015; Pitcher et al., 2002) in waters under national jurisdiction e.g. to avoid fish stock over-exploitation, to understand change in stock spatial distribution in

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the context of climate change which may quickly disturb the existing equilibria (Miller and Munro, 2004).

From a theoretical point of view, finding a common supra-national policy allowing a sustainable fishing activity simultaneously in all the countries exploiting the same fish stock is not a trivial problem and a topic of high political interest. This issue is usually studied in the literature using the game theory for the economic analysis of international fisheries agreements (e.g. Aguero and Gonzalez, 1996; Ishimura et al., 2012; Pintassilgo et al., 2014). These approaches demonstrated that the full cooperative management by the different countries is necessary to achieve sustainable fisheries, and that the works to optimize fisheries management in the context of climate change (as other issues) need to be conducted in common or at least simultaneously by the concerned countries to be successful (e.g. Ishimura et al., 2012). A key message that emerges from this literature strand is that the self organisation generally leads to over-exploitation of internationally shared fish stocks (Campbell and Hanich, 2015; Pintassilgo et al., 2014; Pitcher et al., 2002). Thus, an international legal framework and regulations must be developed to help the complex system of shared fisheries to avoid the over-exploitation trap (Feeny et al., 1996) and to converge toward the optimum situation of collective maximum sustainable yield.

In this work we use a set of ordinary differential equations (ODE) to explore the situations that can emerge either in the case of independent national fishing fleets (each one fishing only in its own EEZ) in or in the case of a unique international fishing fleet that can freely move between EEZs. In the first case, we consider a management acting on the cost per unit of fishing effort (CUFE) instead of catch quota in the classical approach. The behaviour of decision makers is not explicitly modelled, but is represented by the CUFE applied in each EEZ. Competition occurs when each country tends to minimise CUFE, but we show that fishing agreements can tend to harmonise local CUFEs in order to limit the competition. In the second case, that we called fully cooperative, the CUFE is set constant among the EEZ, and the fishing agreement was assumed to be a negotiation on the share of the international fishing fleet benefits.

Numerous bio-economic models based on ODE were used to explore the optimal harvesting rates in a given fisheries system (e.g. Crutchfield, 1979; Dubey et al., 2002; Merino et al., 2007), but less effort was developed to apply such models to the case of fisheries managed by different governments exploiting the same fish population. Here we assume an ideal situation considering that all the fisheries are effectively regulated (no illegal, unreported, and unregulated (IUU) Fishing (Agnew et al., 2009)). We applied our approach to the case of the North–West Africa fisheries in the South part of the Canary Upwelling System (CUS), using the output of a realistic physical biogeochemical model recently developed for this region (Auger et al., 2016) to describe the environment which forces the fish migrations.

2. Preliminaries

We explore the behaviour of an idealized system of shared fisheries that suits the current knowledge of the ecosystem in the CUS. We consider the fish stock that perform migrations between 12.3°N (Senegal) to 26°N (Morocco). We consider 3 political ensembles within which we assume the fishery regulation could be uniform, the Southern Morocco/Western Sahara (20.77–26°N, hereafter zone 1), Mauritania (16.06–20.77°N, hereafter zone 2) and the Senegambia (Senegal + the Gambia, 12.3–16.06°N, hereafter zone 3) (Fig. 1).

The small pelagic fish carrying capacity from Senegal to South Morocco was estimated to ~10 million tons, including the main fished species namely *Sardina pilchardus*, *Sardinella aurita* and *S. maderensis*, *Trachurus spp.*, *Scomber japonicus*, *Caranx rhonchus*

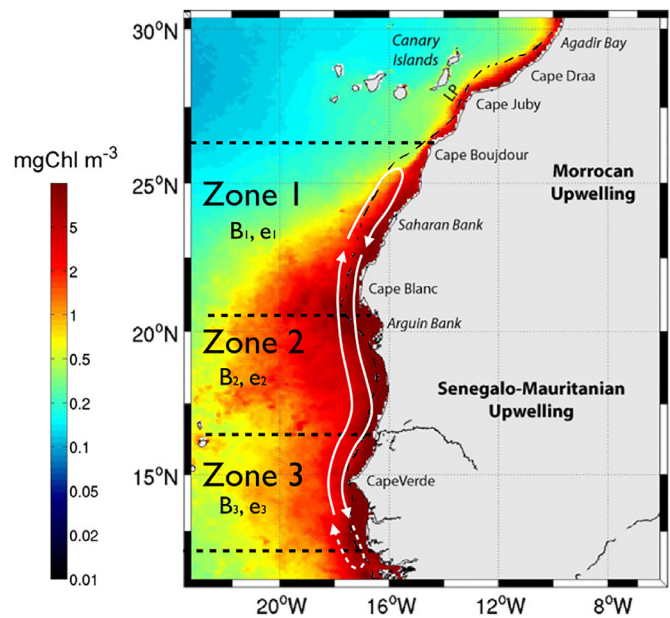


Fig. 1. Illustration of the shared small pelagic fisheries in the South part of the West African Eastern Boundary Upwelling System. The colourbar indicates the mean chlorophyll 'a' (1998–2009) which was used as a proxy for the small pelagic fish carrying capacity. The dotted black line shows the limit of the continental shelf which shelter small pelagic fish in this area. The white arrows indicate the seasonal migrations performed by the round sardinella, the main exploited small pelagic fish species in the region (Boely et al., 1982). The dotted white arrow corresponds to the less documented part of the migration (to Guinea Bissau). B_i and e_i are the biomass and fishing effort in each zone, respectively, i.e., (1) the Southern Morocco/Western Sahara, (2) Mauritania, (3) Senegal and Gambia. Adapted from Auger et al. (2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(FAO, 2012). The carrying capacity is the maximum biomass of fish that can feed and grow in this region in average climatic conditions (1998–2009), according to available food, here estimated by phyto-plankton for the small pelagic fish considered (Aguero and Gonzalez, 1996).

Each of these species has distinct environmental preferendum and thus migration behaviour (Boely et al., 1982), but all together these migrations can be represented by as an ideal free distribution of the total small pelagic fish biomass according to the environment carrying capacity. The fish annual growth (r) was set to 0.88 year^{-1} , as an average of small pelagic fish growth rates in West Africa (FAO, 2012).

According to observations in the CUS, the small pelagic fish habitat is restricted to the continental shelf (Brehmer, 2004; Brehmer et al., 2006). We computed the surface of the continental shelf, delimited offshore by the 200 m isobath, from the bathymetry used by Auger et al. (2016). We found that the part of the Southern Morocco/Western Sahara considered (zone 1) has a shelf of 41 472 km², the Mauritania shelf (zone 2) is 22 720 km² and the Senegambia shelf (zone 3) is 15 040 km². The physical - biogeochemical ocean simulation in this region (Auger et al., 2016) provides the mean annual plankton biomass: 255 014 tons in zone 1, 105 575 tons in zone 2 and 51 632 tons in zone 3. To estimate the carrying capacity in each defined zone, we distributed the total carrying capacity estimated (10 million tons; FAO, 2012) according to the average plankton biomass density (food of the small pelagic fish) in the small pelagic fish habitat of each zone. We found the average local carrying capacity $k_1 = 104 \text{ tons/km}^2$ in south Morocco (zone 1), $k_2 = 45 \text{ tons/km}^2$ in Mauritania (zone 2) and $k_3 = 160 \text{ tons/km}^2$ in Senegambia (zone 3). The total carrying capacity found was greater in zone 1 ($K_1 = 4.3$ million tons), than in

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