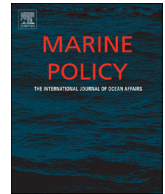




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# Can overexploited fisheries recover by self-organization? Reallocation of fishing effort as an emergent form of governance



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## ABSTRACT

Owing to high costs and difficulties in implement control, fisheries are less regulated than terrestrial activities. In areas of weak governance, self-regulation is often the rule. Understanding the underlying bio-economic mechanisms that drive such fishery systems is crucial for decision making on how to support real fishermen communities. Fishing effort reallocation occurs when economic yield drops, suggesting a feedback between fishermen's mobility and local overexploitation. The nature of this feedback is addressed here by using a bio-economic modelling approach applied to a Senegalese fishery. The white grouper is a highly valued commercial fish that has suffered intense exploitation in Senegal and was predicted to collapse due to a lack of fishery regulation combined with high demand. Surprisingly, our analysis of landings and associated price variability suggests that a slow recovery of this fishery is now underway. Motivated by this finding, two models were implemented that account for artisanal fishermen's mobility and variable prices. Both models provided the same insight: fishing effort mobility combined with variable fish prices induced a shift from local overexploitation to sub-regional sustainable exploitation. Considering that fishing effort mobility has steeply increased in recent years, this mechanism might have significantly contributed to the recent observed trends in prices and landings for this fishery. More generally, these bio-economic models suggest that spatial reallocation of fishing effort acts as emergent governance in under regulated areas that allows, in some cases, the recovery of an overexploited species.

## 1. Introduction

### 1.1. Marine boundaries, fishermen's mobility and self-organization

Self-organization at the fisherman community level is suggested to be an important factor to avoid the “tragedy of commons”, *i.e.*, the depletion of the common fish resource [12]. Indeed, co-management should improve management efficiency because of increased legitimacy in the implementation of rules [36]. Self-organization processes in artisanal fisheries include changes in target species and mobility between fishing sites (*e.g.*, [46]).

Mobility is a primary characteristic of marine fisheries that has not been adequately considered in the establishment of marine boundaries, leading to spatial mismatches between legal-political-management boundaries on the one hand and ecological or socio-cultural ones generated by fish and fishermen on the other [50]. This has been shown to

frustrate management efforts and to have negative impacts both on the fishermen's wellbeing and fish stock health (*e.g.*, [47]). Fishermen's mobility is observed at global scale, with distant international water fisheries often the sites of illegal activity [2,32,51,52]. At the sub-regional scale (Mauritania to Sierra Leone vs. regional scale Morocco to Nigeria) mobility is observed in small-scale fisheries, and is often also in a context of illegal activity since local policies are not adapted to address this reality. Nevertheless, in the case of shared fish stocks, collaborative management at regional or sub-regional level is recommended, ideally by allowing for international fishermen mobility [43]. Despite difficult conditions, fishermen's mobility may be an increasing phenomenon due to climate change [25].

The drivers of fishermen's mobility are diverse, involving social, economic or ecological processes. Among these, reductions in landings caused by local overfishing and the search for market were identified as the most frequent factors triggering migration [44]. Therefore, it has

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been suggested that trans-boundary migration by fishermen, which is particularly well studied in Africa (e.g., [58,13]), can be an interesting strategy for fish resource management [5].

Thus, there is a feedback mechanism between local over-exploitation and fishermen's mobility. Whether this feedback is positive or negative is the problem addressed in this paper. Fishermen's mobility can be seen as one of the means of self-organization of the fishing effort spatial distribution. However, fishermen's mobility is frequently seen as an extension of the over-exploitation problem rather than as an efficient fishery self-organization with positive management outcomes. Based on a case study focused on an artisanal fishery in Senegal, the present work aims to contribute to the understanding of the impacts of fishermen's mobility within the context of increasing over-exploitation of fish stocks worldwide.

### 1.2. The case study: unexpected change in Senegalese white grouper fisheries

In North West Africa, Senegal is the only country that has a long-standing artisanal fishing traditional (the other major fishing nation in West Africa being the Ghana; [4]). The highly productive Canary Eastern Boundary Upwelling system [3,49,8] that covers the entire Senegalese coastline sustains very large fish populations. Several exploited fish species in Senegal perform large migrations and their stocks are shared between Senegal and the neighboring countries, mainly Mauritania to the north and Gambia and Guinea-Bissau to the South [15,26], which suggests coordinated sub-regional management [23].

The Senegalese waters began to be depleted of fish in the 1970s, which drove the Senegalese fishermen to fish in neighboring countries under bilateral fishing agreements, or illegally (Fig. 1; [13,33]). Migrating fishermen often choose to temporarily or permanently settle in these neighboring countries, but most continue to land the main parts of their catches in Senegal, where market demand and prices are higher [45,4].

The present study focuses on the white grouper fisheries, a demersal species commonly named “thiof” (*Epinephelus aeneus*), that is distributed along the entire northwest African coastline (Cury et Roy 1988; [41]). It is an emblematic fish in Senegal, highly prized by the fishermen because of its high commercial value [53]. It is mainly exploited in Senegal by industrial trawlers and the artisanal fleet (canoes, locally named “pirogue”) using hooks and lines, and longlines. However, the number of industrial boats has been decreasing over recent decades, and artisanal fleets now dominate landings. In the last few decades, the fishermen's mobility has increased and, even though the main part of this artisanal fleet still works along the Senegalese coast, most of the canoes are now operating across the whole sub-region, particularly in Mauritania and Guinea-Bissau, except when fishing agreements are canceled as it was recently the case with Mauritania. Environmental fluctuations have an effect on the seasonal spatial distribution of thiof [26], increasing alongshore sub-population connectivity, which can be expected to become stronger in the context of climate change.

The low growth rate of thiof makes its population dynamics particularly sensitive to fishing pressure; Gascuel and Ménard [31] reported over-exploitation [at least with a fishing effort two times above the maximum sustainable yield (MSY)] status in Senegal based on 1971–1991 time series. In 1994, the demand from developed countries was considerably boosted because of the devaluation (50%) of the regional currency (XOF or Francs CFA; [24]), which led to a quick increase in fishing effort mainly targeting high value species for western countries. As a result, the thiof ex-vessel price became so high that it became highly profitable despite low catch levels [53]. In the late 1990s thiof was overexploited, with ongoing catch decreases despite increasing fishing effort. A decade later, thiof was facing a real risk of collapse along the Senegalese and Mauritanian coasts and a fishing moratorium for this species was recommended (FAO, 2006). Although

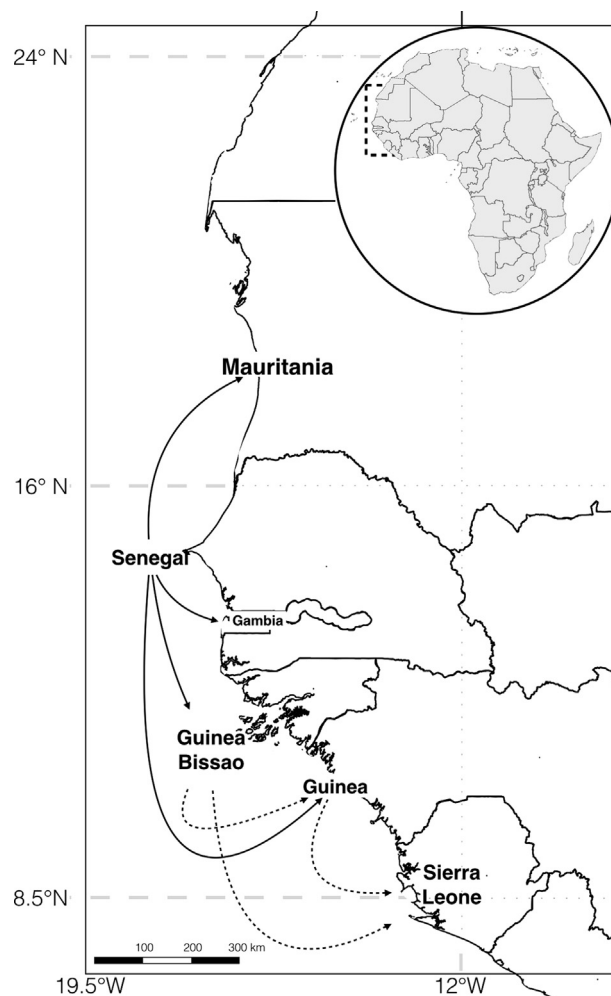


Fig. 1. Main regional migrations of Senegalese fishermen targeting *Epinephelus aeneus* in North West Africa. Dotted lines: secondary migrations due to local conflicts (adapted from Binet et al. [14]).

the moratorium was never implemented, recent data collected by the national Center for Fisheries and Oceanographic Research of Dakar (CRODT) show that since 2007–2008 landings started increasing while the ex-vessel price undertook a downward trend (Fig. 2). A recent assessment survey done aboard the FRV Itaf Deme (2014–2015) also provides preliminary signs of a recovery in abundance (Ndiaga Thiam, CRODT, *Comm. Pers.*; see also [11]). Thus, the question arises as to the identities of the drivers of this unexpected recovery. Could such a nearly-unregulated high-value overexploited stock have recovered as a result of self-organization by fishermen? Can the reallocation of fishing effort at sub-regional scale be considered an emergent fishing “measure” that self-regulates artisanal fisheries? Specifically, the question addressed is to the nature of the feedback effect of migration by Senegalese fishermen on the thiof fisheries. We formulate a conceptual model, implemented in two independent ways, mathematical and individual based, to study this question. The model hypothesis is based on existing knowledge of thiof population dynamics parameters, Senegalese fishermen's mobility, and fish price dynamics.

## 2. Method

### 2.1. Outline of the approach

The approach is based on mathematical and individual based modelling designed to explore the potential effects of fishermen's

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