Ocean & Coastal Management
March 2019, Volume 169 Pages 239-246
https://doi.org/10.1016/j.ocecoaman.2018.12.020
https://archimer.ifremer.fr/doc/00605/71672/

The potential impact of marine protected areas on the Senegalese sardinella fishery

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Abstract :

In the early 2000s, Senegal set up several Marine Protected Areas (MPAs) along its coastal zone with the purpose of biodiversity conservation and to support sustainable management of fisheries. However, the impact of MPAs may vary according to the type of fisheries. In Senegal, the sardinella fishery accounts for 70% of total catches. This fishery is of crucial importance for national food security and employment. Given this importance, it is necessary to evaluate the impact of MPAs, often being considered as a tool for fisheries management. An analytical, dynamic and spatial bio-economic model of sardinella fishery, considering fish and fisher migration, has been developed and scenarios over forty years have been analyzed. The results show that the fishery is economically overexploited and that Senegal could lose about 11.6 billion CFA over forty years of exploitation, i.e. 290 million CFA per year. To achieve an optimal level of exploitation, it would be necessary to halve the current fishing capacity. Implementing MPAs for 10, 20 and 30% of the Senegalese exclusive economic zone lead to slight increases in biomass (1%) and rent (5-11%). In addition, spatio-temporal closures can lead to increased exploitation in unclosed areas, due to the absence of enforcement. Achieving target 11 of the Aichi Convention, i.e., 10% of coastal and marine areas protected per country, will have a reserve effect on the resource but also only lead to weak improvements in economic indicators for the Senegalese fishery. Finally, because the sardinella resource is shared among many countries of the Sub-Regional Fisheries Commission (SRFC), a sub-regional cooperation is necessary for a sustainable management.

Highlights

► The Sardinella fishery is economically overexploited and that the society loses about 290 million CFA per year. ► To reach an optimal level of exploitation, the current fishing capacity should be halved. ► Spatio-temporal closure measures or MPAs lead inevitably to overcapacity in unclosed areas. ► The objective 11 of the Aichi Convention will have a reserve effect on the resource.

Keywords : Small scale fisheries, MPA, Bioeconomic modeling, Fishing capacity, Fishery management, Sardinella aurita, Sardinella maderensis, Aichi targets, West Africa

1 INTRODUCTION

The exploitation of sardinella (*Sardinella aurita* and *Sardinella maderensis*) has a long tradition in Senegal. It expanded with the development of the artisanal purse seine fishery in the 1970s, following an investment into the sector by an FAO project (Dème and Kébé, 2000). Today sardinella catches represent 70% of the total catch of the Senegalese artisanal fishery in volume (Thiaw et al., 2017) and contribute mainly to the supply of the local and regional market (Dème et al., 2012; Ba, 2017; Ba et al., 2017). Sardinella fisheries play a dual role in the Senegalese economy. Through its contributions to food security and employment, it employs more than 25% of artisanal fishers (16 000 fishers) and provides about 70% of Senegal's fish consumption (Ba, 2017).

The sustainability of this fishery is facing many challenges. The overexploitation of the stocks of small pelagic fish is the main one (FAO, 2015; Baldé et al. 2018). In Senegal, the fishery on small pelagics is mainly artisanal, open access and subsidized. Other types of exploitation may compete with artisanal fishing and increased pressure on the resource. These include foreign industrial fishing and national industrial small pelagic fishing. Recently, demand has increased with the establishment of fishmeal industries but also with the opening of new export markets in the sub-region. This situation inexorably contributes to the increase in fishing effort in the area ((Diankha et al., 2018). Sardinella stocks migrate between different EEZs (Exclusive Economic Zone) and are shared between Senegal and its neighboring countries (Morocco, Mauritania, Gambia and Guinea-Bissau). Fishing activity for each of the countries therefore depends on the level of exploitation in other countries. In recent years the exploitation of sardinella has intensified in the neighboring areas of Senegal, due to foreign investment for the development of the national fishing or even the presence of international fleets, mainly Dutch and Russian (Corten et al., 2012). According to the FAO, (2017) 2016 landings in countries sharing the resource is around 125 552 tonnes for Senegal, 91 013 tonnes for Mauritania and 6929 tonnes for Gambia. This also reflects the intensity of the fishing effort in the area.

In parallel with this dynamics, Senegal signed the International Convention on Biological Diversity in 1992 (Anonymous, 1992) and aims to achieve the Aichi biodiversity targets relating to the strategic plan for biodiversity on a global scale for the period 2011-2020. Aichi target 11 calls for a protection of at least 10% of the coastal zone by 2020 (Anonymous, 2014; Thomas et al., 2014). Senegal is committed to setting up a network of marine protected areas to preserve marine and coastal biodiversity, but also to ensure sustainable development of fisheries (Anonymous, 2013). Since the beginning of the 2000s, several coastal MPAs have been created, such as off Saint-Louis (496 km^2), Kayar (171 km^2), Joal (174 km^2), Sangomar (817 km^2) and Abéné (119 km^2) (Anonymous, 2004, 2002). The objective for the choice of these areas is to protect nursery and spawning areas of species with socio-economic interest and also vulnerable species. Most of these areas are located in coastal fishing areas and their implementation limits the access of local artisanal fishers to these fishing areas.

Given the importance of the exploitation of sardinella for Senegal and the potential impact of the establishment of MPAs on its sustainable development through reserve and "Spill over" effects (Harmelin-Vivien et al., 2008), it would be useful to estimate the potential consequences of this management policy on the fishery in the long-term. A bioeconomic model has then been developed and used to test different management scenarios to analyze the dynamics of the fishery over the long term in response to different management measures.

2 Materials and methods

Several data sources were used: (i) the database of the Oceanographic Research Center of Dakar Thiaroye (CRODT) already described by several authors (Barry-Gérard, 1985; Laloë, 1985; Laloë and Samba, 1990; Thiao, 2009), for landing and effort data for purse seine and encircling gillnet fishing units, as well as the ex-vessel prices of their target species; (ii) data on fixed and variable costs of fishing units were obtained from previous studies (Ba et al., 2017); and (iii) data on the sizes and positions of MPAs (Anonymous, 2004, 2014; Brochier et al., 2015).

2.1.1 Size and position of Marine Protected Areas of Senegal

The positions and dimensions (Table 1; Fig. 1) of the various MPAs are derived from "Decree No. 2004-1408 of 4 November 2004 on the creation of Marine Protected Areas" and the Management Plan for the Marine Protected Area. The area of these MPAs represents only 1% of the Senegalese EEZ (Brochier et al., 2015). To achieve the 10% protected area of the EEZ (i.e. Aichi target 11) a very significant increase in the number or size of MPAs is needed.

Table 1.

The geographical positions and surface areas of the five marine protected areas located along the Senegalese coastline.

Marine Protected Areas	Land positions		Sea Positions		Surface
	Latitudes	Longitudes	Latitudes	Longitudes	
Abéné	13° 02’.3N	16° 44’.5W	13° 02’.3N	16° 49’.5W	119 km²
	12° 55’. 3N	16° 45’.3W	12° 55’ .3N	16° 50’ .3W	
Joal-Fadiouth	14 ° 04’.5 N	16 ° 46’.7 W	14 ° 04’.5 N	16 ° 51’.7 W	174 km²
	14 ° 13’.0 N	16 ° 52’.2 W	14 ° 13’.0 N	16 ° 57’.2 W	
Kayar	14 ° 59’.1 N	17 ° 04’.8 W	15 ° 01’.6 N	17 ° 10’.8 W	171 km²
	14 ° 53’.1 N	17 ° 10’.5 W	14 ° 55’.6 N	17 ° 16’.5 W	
Saint-Louis	15 ° 58’.5 N	16 ° 31’.5 W	15 ° 58’.5 N	16 ° 48’.5 W	496 km²
	15 ° 50’.0 N	16 ° 31’.5 W	15 ° 50’.0 N	16 ° 48’.5 W	
Sangomar	14°03’36 N	16°58’48 W	14°03’36 N	16°46’12 W	817 km²
	13°46’48 N	16°58’48 W	14°03’36 N	16°40’12 W	

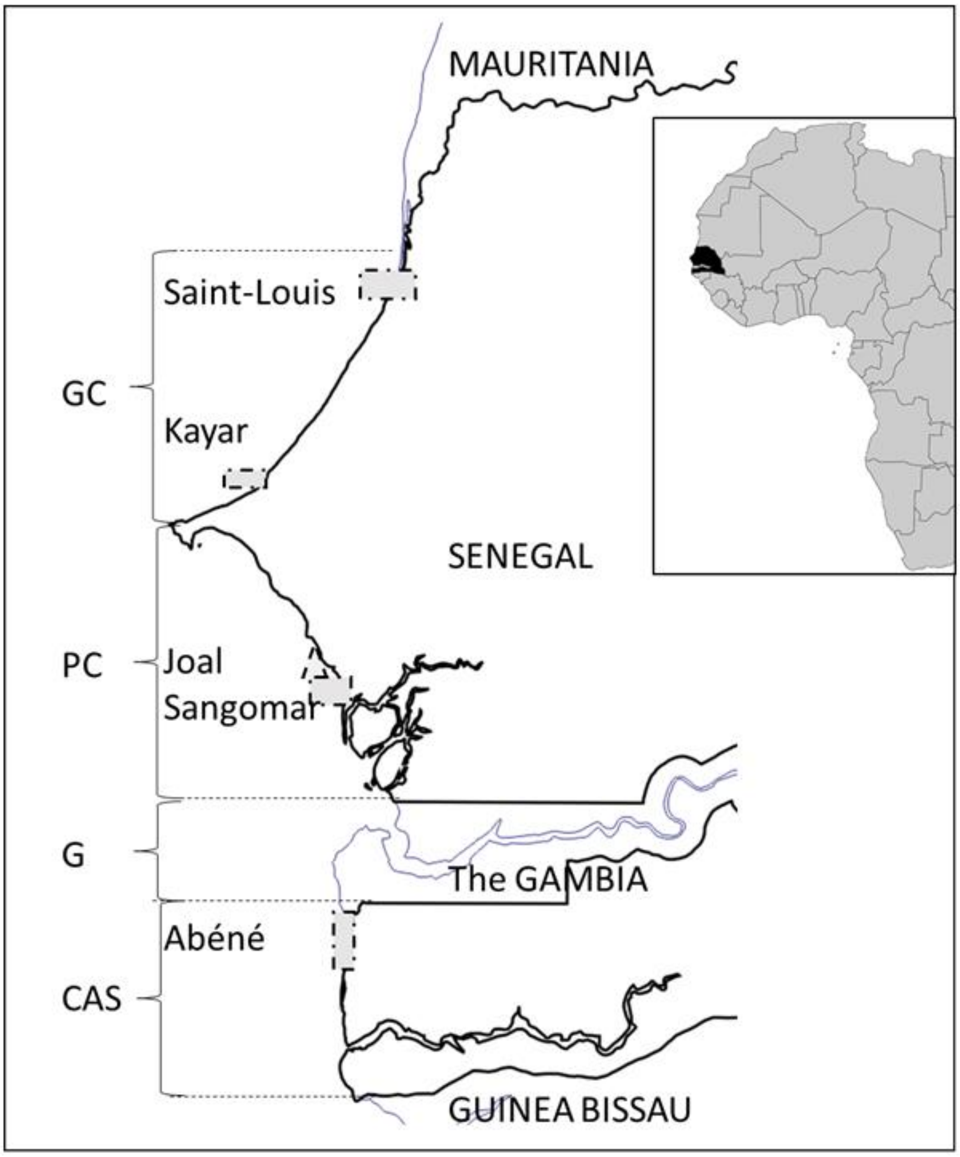

Figure 1: Marine protected areas (grey area in dashed line) located off the coast of Senegal. The Saint-Louis and Kayar MPAs are on the Grande Côte (GC), the Joal and Sangomar MPAs are on the Petite Côte (PC) and the Abéné MPA is located in the Casamance area (CAS). Between the PC and CAS is Gambia (G) considered in the model as non-participating to the sardinella fishery.

2.1.2 Principle of the model

The bioeconomic model of the small pelagic fishery proposed here is multispecies, multi-fleet and spatially explicit. The resource is composed of *Sardinella aurita* and *S. maderensis*, aggregating in large fish schools (Brehmer et al., 2007), and the fleets targeting these schools are composed of two types of artisanal fishing units called "purse seine (PS)" and "encircling gillnets (EG)". The modeled fishing zone is the Senegalese coastal area where these fishing units operate. It is divided into Grande Côte (GC), Petite Côte (PC) and Casamance (CAS) (Fig. 1). Fishing areas outside the Senegalese EEZ, where part of the resource is seasonally present, are Mauritania (Nordex), Gambia (G) and Guinea Bissau (Sudex). The exploitation of the resource outside Senegal's waters is not explicitly modeled but determined through a fishing mortality rate defined in the initial simulation parameters. The model has monthly time steps and allows for long-term simulations (up to 40 years).

The biological component of the model is analytical, based on a simulation of monthly cohorts, the size of which depends on initial recruitment, and natural and fishing mortalities. Fishing mortality is determined by the dynamics of fishing effort, which is itself a function of past economic performance, technological change and management measures. The exogenous parameters of the model (price, costs, recruitment, growth and natural morality) are either determined before the start of the simulation or redefined during simulation as specified from a parameter file.

Fishing effort, catch and price data used for the parameterization of the model are collected using a sampling protocol, detailed in several works (Laloë and Samba, 1990; Pech et al., 2001; Thiao, 2009). The stratified random sampling has been constantly improved since the 1970s (Thiao, 2012; Thiao et al., 2012) and is conducted regularly in the main landing sites along the Senegalese coast where more than 90% of the catches are landed. The main landing centers are: Saint-Louis, Kayar, Yoff, Soumbédioune, Hann, Mbour and Joal. The data were structured by months, landing site and fishing gear. The model is developed on the Vensim® modeling platform.

2.1.3 A multi-species, multi-fleet and spatially explicit model

The model is an analytical age-structured, multi-cohort model. The model is inspired by the pioneering work of Thompson and Bell (Thompson and Bell, 1934), Beverton and Holt (Beverton and Holt, 1957) and Laurec and Le Guen (Laurec and Le Guen, 1981). Biological parameters for both Sardinella species were obtained from Fréon (1988) and Camarena Luhrs (1986).

Both exploited Sardinella stocks are analytically modeled with monthly cohorts and the biological part of the model is presented as "supplementary material" in annex 1.5. The fishing effort dynamics is determined through functions of outputs from the economic module. The choice of this type of model was motivated firstly by the migratory behaviors of the species and the fleets but also by the aim of testing different management scenarios such as spatial and temporal closures.

The dimensions and the parameters of the model are detailed in the supplementary material (annex 2, 3, 4).

2.1.4 Fishing effort dynamics

Fleets spatiotemporal dynamics is determined by the availability of the resource in time and space and endogenous economic results. Fleet dynamics is the result of different phenomena. First of all, the determination of the yearly fishing capacity, *i.e.* the total number of boats in the fleets and the fishing effort.

2.1.4.1 Determination of the capacity of fishing

The fishing capacity '*UP'*, which is constant within each annual interval is considered endogenous because of the open access characteristics of the artisanal fishery.

The endogenous effort depends on the investment and the disinvestment at the end of each year. Investment depends on the profit obtained during the past year. At the end of each year ‘a’, a fixed proportion of the total profit is reinvested in the form of new fishing units ‘*NUP’* for each fleet ‘*e’*. In the case of a negative profit ‘*NUP’* will be negative and will correspond to an exit of fishing units. The amount invested ‘*IVT’* at the end of the year is calculated as follows (equation number is set according to biologic component equations presented in:

$$\begin{cases} IVT_{e,a} = PROFCF_{ea}.txi & PROFCF \geq 0 \\ IVT_{e,a} = PROFCF_{ea}.txi1 & PROFCF < 0 \end{cases} \qquad \text{Equation 1}$$

‘*txi’* is the investment rate (reinvested positive profit share) and ‘*txi*1’ the disinvestment rate in case of a negative profit. Given the price of a new fishing unit ‘*PrUP’*, the number of new units is then obtained for each fleet ‘*e’* and year ‘*a’*:

$$NUP_{e,a} = IVT_{e,a} \;/\; PrUP_e \qquad a = a1, a2..., a40 \qquad \text{Equation 2}$$

The number of ‘*UP’* fishing units per fleet ‘*e’* and for year ‘*a’* will be:

$$UP_{e,a} = UP_{e,a-1} + NUP_{e,a-1} \qquad a = a1, a2..., a40 \qquad \text{Equation 3}$$

2.1.4.2 Spatial distribution of fleets

To represent the spatial redistribution of fishing units over time in Senegal, a distribution function guided by the attractiveness of fishing zones is constructed. The latter is equal to the average biomass of each zone in relation to the total average biomass '*BIZS'* in t-1 and t-12, for each species and zone '*zsen'*. The average abundance of each zone is multiplied by the closure variable of zone '*Ferm'* (equal to 0 when closed and to 1 when opened) so that the closed zones (MPA) (thus zero attractiveness), are not targeted by the fisheries.

$$ATRZ_{zsen,\,t} = \frac{\sum_i [(BIZS_{\,i,\,zsen,\,t-1} + BIZS_{i,\,zsen,\,t-12}) * Ferm_{zsen,\,t}]}{\sum_{i,\,zsen,\,t} [(BIZS_{\,i,\,zsen,\,t-1} + BIZS_{i,\,zsen,\,t-12}) * Ferm_{zsen,\,t}]} \qquad \text{Equation 4}$$

The fleet '*UPZ'* per zone '*zsen'* and fishing type '*e'* can then be determined:

$$UPZ_{e,\,zsen,\,t} = UP_{e,\,t}.ATRZ_{zsen,\,t} \qquad \text{Equation 5}$$

2.1.4.3 Determination of the active fleet

A distinction is made between present fleet (fishing capacity) and active fleet '*Fla'* (nominal fishing effort). To move from the first to the second, it is necessary to use the rate of activity '*txact'* per fleet, determined by the short-term profitability of the activity (relative margin on the variable cost).

$$Fla_{e,\,zsen,\,t} = UPZ_{e,\,zsen,\,t}.txact_{e,\,zsen,\,t} \qquad \text{Equation 6}$$

2.1.5 Economic module of the bioeconomic model

2.1.5.1 Fixed and variables costs

Two types of costs are considered. The fixed costs '*CFTOT'* are independent of the activity rate of the fleet but proportional to the fishing capacity (constants inputs, depreciation, maintenance of equipment and insurance). The variable costs '*CVTOT'* are proportional to the active fleet but are also be related to landed quantities

$$CFTOT_{e,\,zsen,\,t} = parCF_e.UPZ_{e,\,zsen,\,t} \qquad \text{Equation 7}$$

Where '*parCF'* are the annual fixed costs per fishing unit.

The cost of landing, which is part of the variable costs, is proportional to the quantity of landings '*CFT'*. '*ParCV'* is the amount of other variable costs per fishing unit and per month.

$$CVTOT_{e,\,zsen,\,t} = Fla_{e,\,zsen,\,t}.parCV_e + CDEB_{\,e,\,zsen,\,t} \qquad \text{Equation 8}$$

2.1.5.2 Labor remuneration

In the fishing sector, the remuneration of labor is generally based on a system with a "pure" or "mixed" share. The first system is the one generally observed in the Senegalese artisanal fishery. In this model, the crew remuneration 'LA' is obtained from the balance to be shared, obtained by the difference between turnover '*REV'* and variable costs '*CVTOT'*, and that is multiplied by the relative share going to the crew '*paramPartPa'*. The annual remuneration by type of fishing '*e'* is obtained from the following equation (where '$tdeb_a$' and '$tfin_a$' are the limits of each annual time interval 'a').

$$LA_{e,\,a} = \sum_{t=tdeb_a}^{tfin_a} \sum_{zsen} \left(\left(REV_{e,\,zsen,\,t} - CVTOT_{e,\,zsen,\,t} \right) . paramPartPa \right) \qquad \text{Equation 9}$$

$$with \quad a = a1,\, a2 \ldots,\, a40$$

2.1.5.3 Vessel owners' profit

The profit '*PROFC'* is the remuneration of private investors (vessel owners). It is equal to turnover *REV* minus the variable costs '*CVTOT'* (common costs shared between crew and owner), fixed costs '*CFTOT'* and labor remuneration '*L*.' The cumulative profit per year '*a'* and fleet '*e PROFC'* is obtained by summing the profit on each annual time interval:

$$PROFC_{e\,,\,a} = \sum_{t=tdeb_a}^{tfin_a}(\sum_{zsen}(REV_{e,\,zsen,\,t} - CVTOT_{e,\,zsen,\,t} - CFTOT_{e,\,zsen,\,t} - L_{e,\,zsen,\,t})) \quad \text{Equation 10}$$

$With \quad \mathrm{a} = \mathrm{a1,\ a2\ldots,\ a40}$

2.1.5.4 The economic rent of the fishery

The economic '*RENT'* corresponds to the private profit corrected for the net transfers between the state and the fishery (taxes '*RED'* less subsidies '*SUB'*). The economic rent is estimated per fleet '*e'* at the end of each annual interval '*a'*.

$$RENT_{e,\,a} = PROFC_{e,\,a} + (RED_{\,e,\,a} - SUB_{e,\,a}) \qquad \text{Equation 11}$$

The discounted economic rent '*RENTACT'* is the sum of the current economic rent multiplied by the discount factor '*FACT'*, obtained from the annual discount rate '*TxActu'*.

$$FACT_a = \frac{1}{(1+TxActu)^a} \qquad \text{Equation 12}$$

$$RENTACT = \sum_a(\sum_e RENT_{e,\,a}.FACT_a) \qquad \text{Equation 13}$$

2.1.5.5 Added value

Gross added value (*GVA*) is the difference between the value of landings and intermediate consumption inputs (all goods and services used during the production process). Net value added (*NVA*) is equal to gross value added less depreciation '*ParAmt'* and subsidies '*SUB'*. It is also equal to the sum of the net remuneration of production factors (private profit and labor remuneration) plus the net income of the

State. Gross added value is an indicator of wealth creation by the fishery (contribution to the national Gross Domestic Product). Unlike rent, it integrates labor remuneration, an important element for poverty reduction, which is part of Senegal's fisheries management objectives (Anonymous, 2002). If the focus of the management of the small scale sector is the social dimension then value added seems to be a more relevant objective than economic rent.

The actual net value added, which can be considered, in a similar way to the actual rent, as an objective function (to be maximized) in long-term management, is obtained by using the actual factor *FACT*:

$$VANACT = \sum_a \left(\sum_e \left(\sum_{t=tdeb_a}^{tfin_a} (VAB_{e,t} - ParAmt_e) - SUB_{e,a}\right) . FACT_a\right) \qquad \text{Equation 14}$$

2.2 Management scenarios

As a first step, the dynamics of the Sardinella fishery has been simulated over forty years, using parameters based on the current fishery situation, to test the consequences of a long-term *status quo* on it. As a second step, the response of the fishery to an increase of fishing capacity (using a fishing capacity multiplier) has been simulated to determine economic and biological optima. Then, the dynamics of the fishery is simulated according to different closures options (size of the MPAs) in the current situation management scenario and in an overexploitation scenario

3 Results

The dynamics of biomass, active fleets, rent, total cost, income, profit, net added value and labor income are used to compare different scenarios. The economic results are evaluated over the long term (40 years) on the basis of their final discounted value (at a discount rate of 5%).

3.1 Consequence of a 40-year *status quo* on Sardinella fishery in Senegal

This scenario is used to show the dynamics of the fishery if current conditions, including free access to the resource and subsidies of fishery, were maintained over the next forty years.

3.1.1 Effect of the *status quo*: on the biomass and the active fleet

After an initial small increase, the biomass is decreasing over the simulation period, and at the end of the simulation 68% of the biomass is lost (Fig. 2). This decline is faster during the first 20 years, with a 60% biomass decrease. This is mainly due to the increase of the artisanal fleet capacity (Fig. 3). The number of purse seine fishing units is doubling over the total simulation period. For encircling gillnet fishing units, we observe a decrease in their activity over time and their number is divided by more than six at the simulation end.

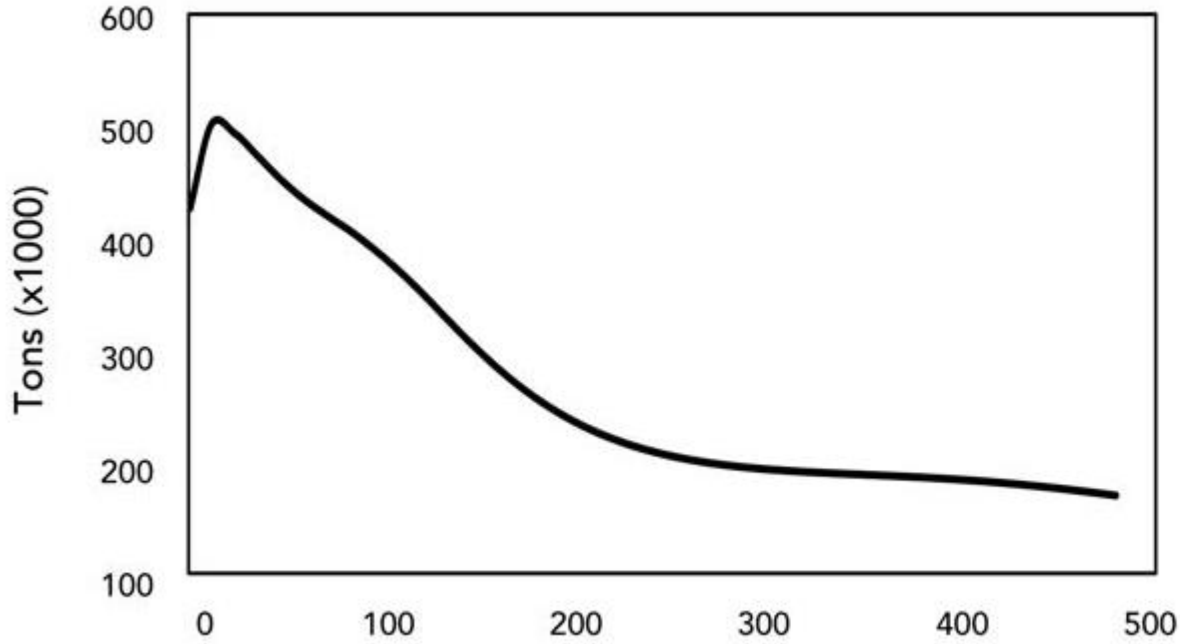

Figure 2: Dynamics of the total biomass of sardinella over the forty years according to the reference situation.

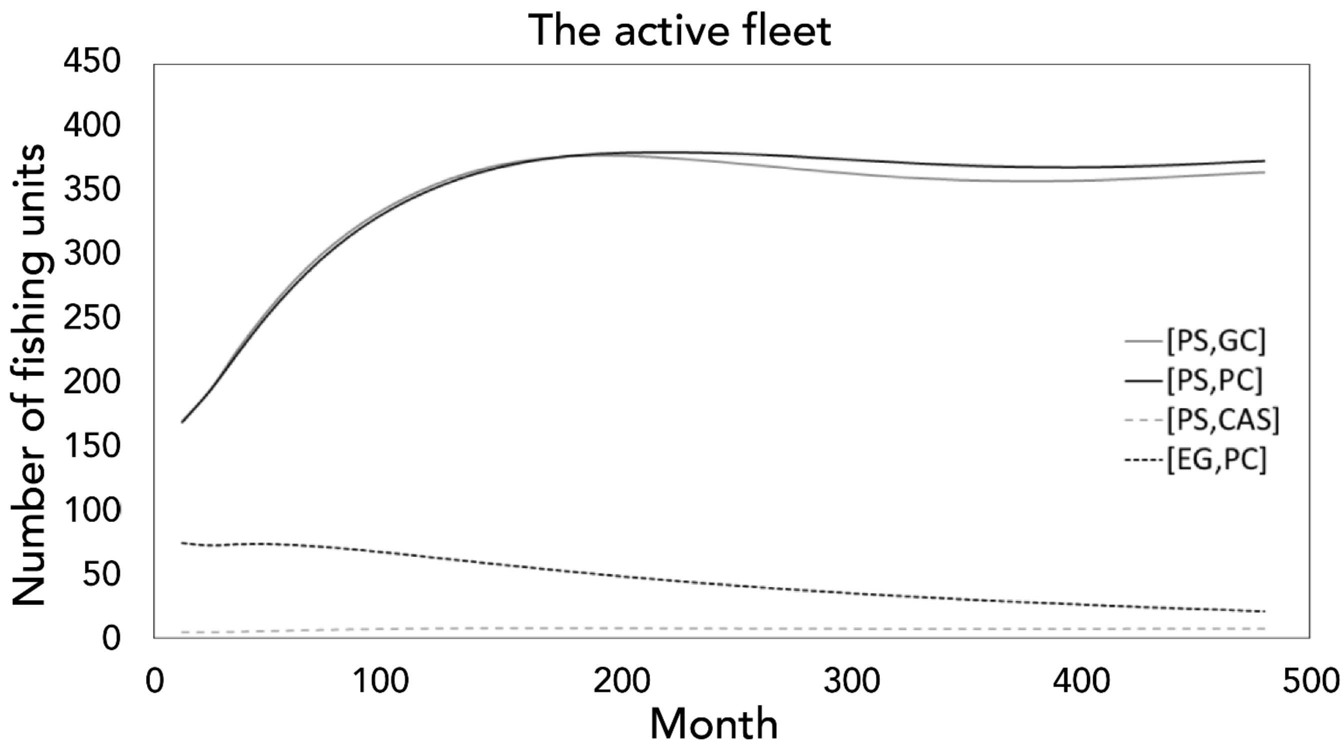

Figure 3: Dynamics of the Senegalese active fleets in the different zones. Black curve = Purse seine (PS) on the Grande Côte (GC); gray curve = Purse seine on the Petit Côte (PC); dotted gray = Purse seine in Casamance (CAS); dotted black = Encircling gillnets (EG) on the Petite Côte (PC).

3.1.2 Response of economic indicators to different levels of fishing capacity

Different fishing capacity scenarios were explored, with different initial fishing capacity (using a multiplier), and taking this values constant until simulation end. A multiplier value equal to 1 corresponds to the fishing capacity level in 2013, i.e., 593 purse seine and 128 encircling gillnets fishing units. The discounted values, over the entire simulation period, for the main economic indicators were obtained as a function of the fishing capacity multiplier in order to determine the different optima according to this control variable.

The discounted income obtained in the reference scenario (i.e. for a fishing capacity multiplier equal to 1) is equal to 722 billion FCFA, corresponding to an annual catch level of 313 200 tons. This is clearly less than the achievable maximum (758 billion FCFA) corresponding to a capacity multiplier equal to 1.4 (Fig. 4). In the current fishing capacity situation, the fishery does not reach its maximum sustainable yield (MSY) and is not be biologically overexploited.

In the same simulation (fishing capacity multiplier equal to1) for economic rent, profit and net value added (NVA), the fishery is not in a state of total dissipation of economic wealth (i.e. these indicators still stay positive). The profit equal zero when the capacity multiplier is set to 1.85, and the 'NVA' equal zero when the capacity multiplier equals to 1.9.

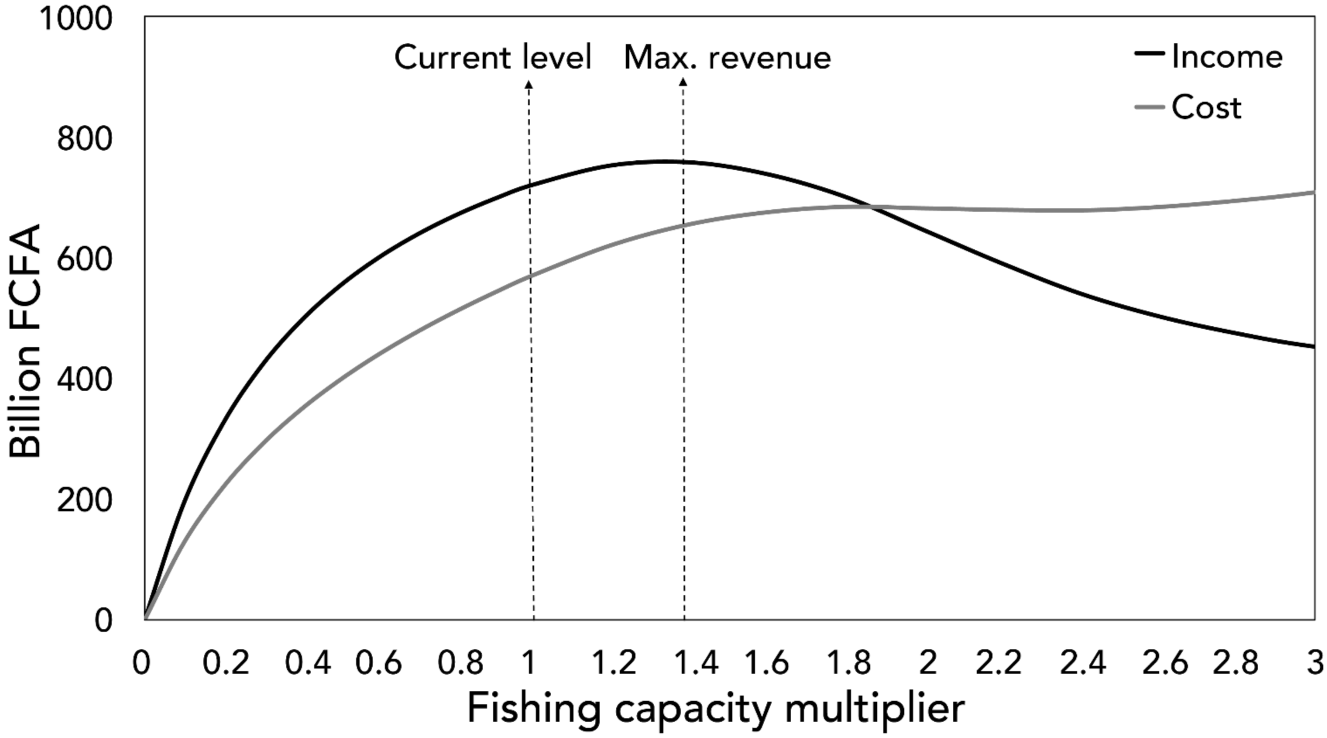

Figure 4: Responses of cost (gray curve) and income (black curve) to different fishing capacity multiplier values

To achieve the level of fishing capacity corresponding to the maximum profit (162 billion FCFA) the current effort has to be decreased by 30%. However, the discounted profit still remains positive (150 billion FCFA) for the current fishing capacity level. An open access equilibrium leading to zero profit is therefore not yet reached.

However, the fishery is currently economically overexploited. The discounted rent (100.5 billion) is lower than the discounted maximum economic yield (MEY) (131.4 billion FCFA), obtained for a fishing capacity equal to the half of the reference capacity level (Fig. 5). The contribution of the fishery to the national economy, the net added value (NAV), achieves its maximum (381.7 billion FCFA) when the fishing capacity is decreased by 30%. (Fig. 5).

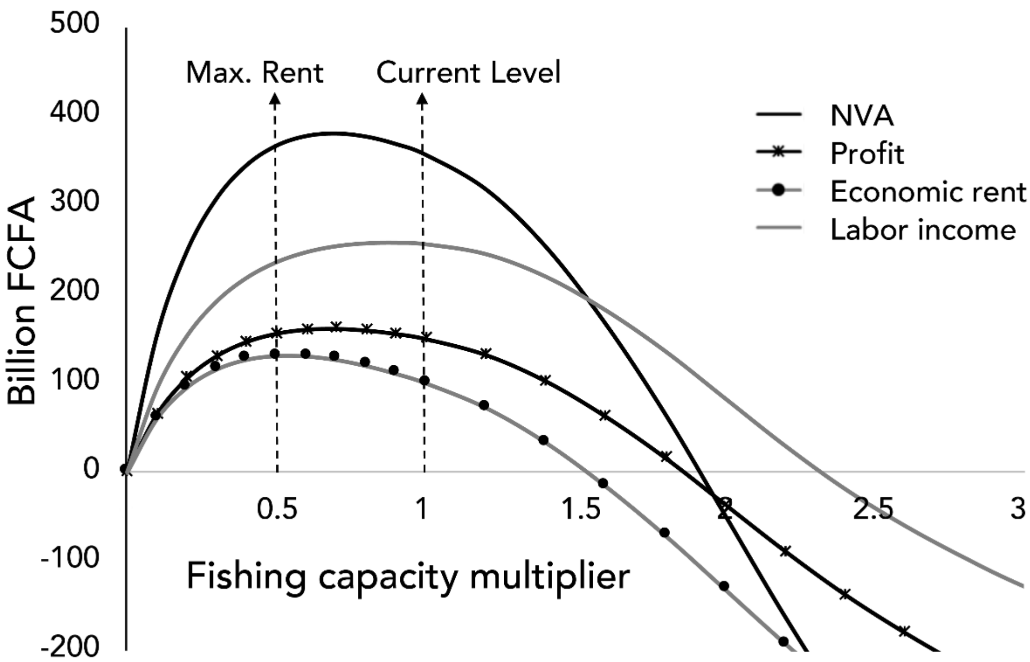

Figure 5: Responses of the main economic indicators to the increase of fishing capacity. Black curve: NVA (Net value added); gray curve: labor income; black curve with cross: profit; gray curve with circle: economic rent.

The discounted labor income (wages of crew members) is maximized with a 10% reduction in fishing capacity (Fig. 5). Thus, if the objective is to guarantee maximal remuneration for fishermen, fishing capacity should thus only be reduced by 10%, still ensuring a positive, but sub-optimal profit for vessel owners. This situation, however, is not optimal for the whole national economy due to a government revenue loss equal to 50 billion FCFA. On the other hand, if one seeks to maximize the contribution of the sector to the national wealth r (discounted NPV), it is necessary to reduce the fishing capacity by 30%. Finally, if the objective is to guarantee maximum remuneration for private investors (vessel owners) a same reduction of 30% would fulfil this objective.

3.2 Consequences of MPA implementation

In the current fishery (including open access in the fishery), closure rates of 10%, 20% and 30% for all fishing areas lead to an insignificant increase in final total biomass of 1%. A closure of 30% of the Petite Côte alone, does not lead to an increase in total biomass (Fig. 6a, b, and c).

For discounted economic rent, closure rates of 10%, 20% and 30% of all fishing zones result in an increase of 10%, 21% and 35%, respectively. The closure of 30% of the Petite Côte only leads to 18% increase in economic rent (Fig. 6a, b, and c).

Concerning labor income, closures of 10%, 20% and 30% of all fishing areas result in increases of 10%, 22% and 36% respectively. The closure of 30% of the Petite Côte only leads to an increase in labor income equivalent to that of a closure of 26% of all fishing areas (Fig. 6a, b, and c).

With overcapacity in the fishery (current fishing capacity multiplied by three), closure rates of 10%, 20% and 30% respectively lead to an increase of 3%, 7% and 9% at the end of the simulation period compared to the reference biomass (capacity multiplier equal to 1) (Fig. 6d, e, and f)). An implementation of marine reserves of 30% of the Petit Côte leads to a 5% increase in biomass. In addition, the trajectory taken by biomass in both cases (overcapacity and current situation) shows that the establishment of MPAs produces a slight reserve effect in the case of Sardinella exploitation.

In the context of an overexploitation, closures of fishing areas lead to an increase in discounted economic rent (Fig. 6d, e, and f). The closures of 10%, 20% and 30% of all fishing zones result in increases of 6%, 13% and 21% of discounted rent, respectively. A closure of 30% of the Petit Côte alone leads to an 11% increase.

The closure of fishing areas leads to a sharp increase in discounted labor income under overexploitation (Fig. 6d, e, and f). Closures of 10%, 20% and 30% of all fishing areas lead to a 53%, 119% and 199% increase in discounted labor income, respectively. A reserve of 30% of the Petit Côte allows a 104% increase.

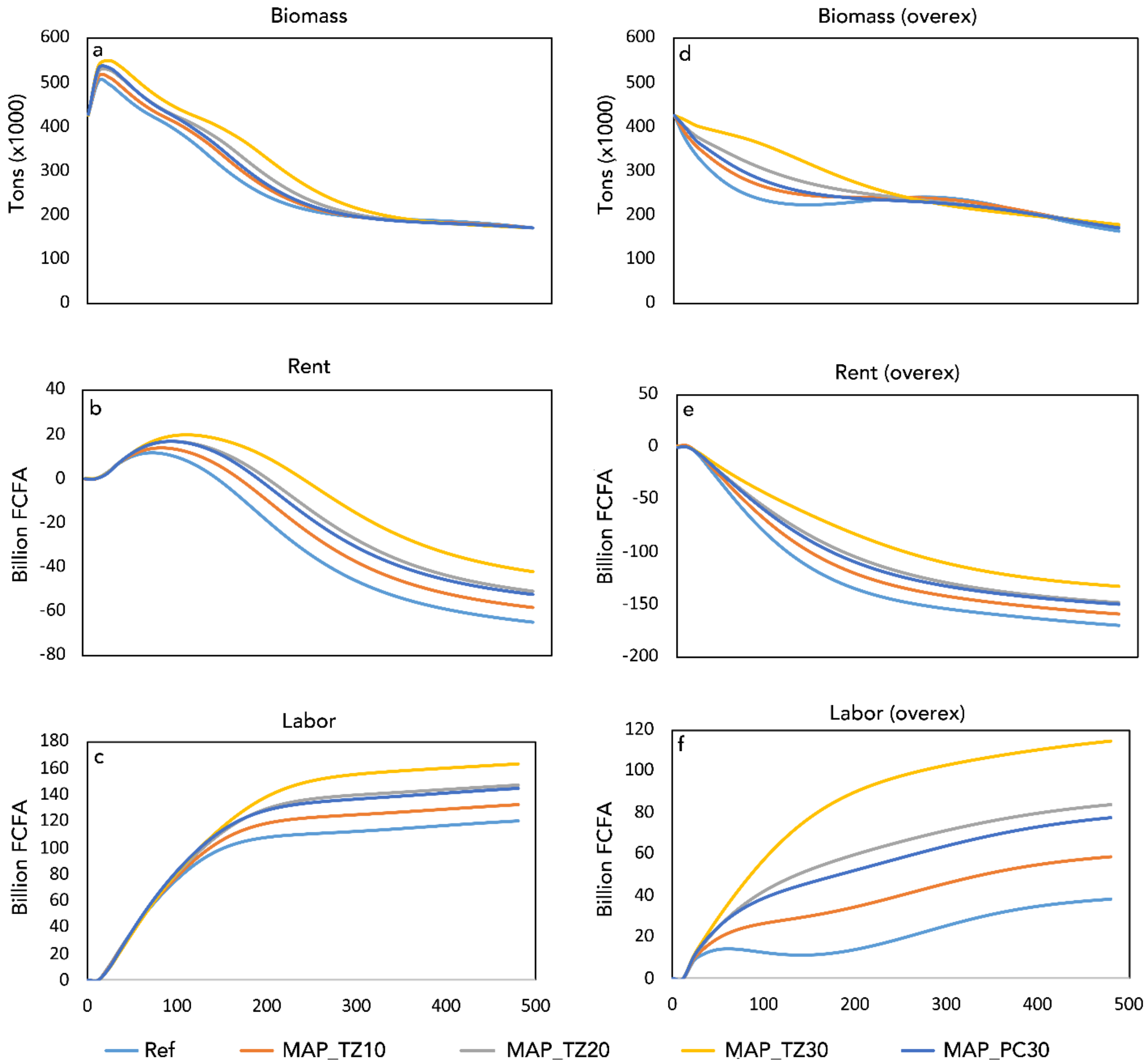

Figure 6: Responses of the biological and economic indicators of the sardinella fishery to closure rates in the current exploitation context (a, b, and c) and in a context of overexploitation of the resource (d, e, and f). ‘Ref’ = current state; ‘MPA_TZ’ = Closure all zones (PC, GC, CAS); ‘MPA_PC’ = Closure ‘Petite Côte’ only; 10%, 20%, 30% = closing rates of fishing areas. ‘Overex’ (overexploited), ‘TZ’ (All Zones), ‘GC’ (Grande Côte), ‘PC’ (Petite Côte), ‘CAS’ (Casamance), ‘G’ (Gambia) and ‘MPA’ (Marine Protected Area). The abscissas are in months.

4 Discussion

4.1 On the state of the Sardinella fishery in Senegal

The analysis of the reference scenario shows that the Sardinella fishery is currently economically overexploited. Compared to the optimal situation, the society loses about 11.6 billion FCFA over 40 years, or 290 million FCFA per year. This is mainly due to the open access regime leading to fleet overcapacity, i.e the capital required to optimize economic indicators, with the exception of labor income, is largely exceeded in the Senegalese Sardinella fishery. These results are consistent with the findings of several authors (Pech et al., 2001; Greboval and Catanzano, 2005; Pauly, 2006, 2007; Teh and Sumaila, 2007; Thiao et al., 2012) which show how open access or chronic subsidies lead to overcapacity, economic losses and a reduction in the exploited natural capital.

This overcapacity was also empirically confirmed by the emigration of purse seine fishing units from Senegal to Mauritania (Corten et al., 2012), in search of more profitable fishing grounds. These migrations were legally permitted through a bilateral fishing agreement (400 fishing licenses for Senegalese purse seine units) between Senegal and Mauritania. This agreement allowed purse seine fishing units to follow the natural migration of sardinella but also contributed to the reduction of overcapacity in Senegalese waters. This fishing agreement was not renewed in 2017, so the Senegalese fishing units returned to Senegal, then increasing overcapacity again.

Sardinella catch has not yet reached the maximum sustainable yield (MSY) and thus can still be increased. But an increase in fishing effort will also be accompanied by an increase in costs difficult to sustain by the artisanal fishery. These findings suggest that the fishery is not biologically overexploited, being in contradiction with the assessments made by CECAF (Fishery Committee for the Eastern Central Atlantic) between 2001 and 2015 (FAO, 2001, 2015).

This difference in results could be explained by several factors including the assessment method used, the spatial coverage of the model and the difficulty of having heterogeneous data in the countries sharing the sardinella stocks. Indeed, the CECAF estimates consider the sardinella stocks from Mauritania to Senegal whereas the model utilized in this study uses only the data available in the Senegalese economic exclusive zone. CECAF also uses a global Gordon-Schaefer model over the entire Senegal-Mauritanian zone, while an analytical model applied on the Senegalese zone is used in this study. However, the scenarios carried out in this study are likely optimistic scenarios, i.e. underestimating effort and harvest, as they did not consider the possibility of an increase in fishing effort in the neighboring countries of Senegal.

4.2 The effect of MPAs on the sardinella fishery

Most studies address the behavior of fishing effort and abundance in pelagic and mobile species (Mesnildrey et al., 2013). This study does not only address these aspects, but also shows the economic efficiency that could be achieved by establishing spatiotemporal closures in an open access small pelagic fishery.

In the current state of the fishery, closures lead to a slight increase in biomass and economic gains in rent and labor income. These results are mainly due to the current overcapacity in the fishery. Indeed, the closure of fishing areas indirectly leads to the decline of fishing capacity in closed areas. In the case of the closure of a single fishing zone, this policy results in a displacement of the fishing capacity into areas open to fishing and subsequently to poor biological and economic results.

This particularity is essentially linked to the very high mobility of the resource and the fleet. The effect of the MPA on the fishing capacity in a single fishing zone is therefore limited by the mobile nature of the resource and the fleet. This consequence of a closure has also been shown in other fisheries (Hilborn et al., 2004; Garcia et al., 2013; Lehuta et al., 2013; Mesnildrey et al., 2013; Ba, 2017). In order to have a positive effect on both biomass and economic indicators, MPAs should be combined with a limitation of fishing effort, which is not yet the case in Senegal (Ba, 2017). In a more in-depth framework, it appears that the effects of spatiotemporal closures on the resource and on economic indicators are more evident when fishing is in a state of overexploitation. In this case a reduction in effort or fishing capacity can contribute to the increase in total biomass but also an improvement in economic indicators.

In line with target 11 of the Aichi Convention which suggests a closure of 10% of the coastal zone, the model shows that this objective leads to a slight increase in the total biomass of sardinella. Under the assumption of full or overexploitation, this closure rate would lead to an increase in biomass and economic gains. Given that the Sardinella fishery is economically overexploited, any closure of the area necessarily leads to a decline in fishing capacity and therefore an improvement in biological and economic indicators.

One caveat is that in these scenarios, no illegal fishing is assumed to happen in the regulated or protected marine areas. In Senegal since the beginning of the 2000s, several MPAs have been created (e.g., Kayar on the Grande Côte and Joal on the Petite Côte), but without clear effect on the dynamics of the fleet. The number of fishing units, especially purse seine, has not declined in these areas and thus these MPAs seem to be not very effective because of the high mobility of the resources and wide distribution of fishing units. Illegal, unreported and unregulated fishing “IUU” is not considered in this study even though a significant activity in the West African region could be assumed, with a high number of foreign industrial vessels operating in Senegal, neighboring countries and the region in general. Their inclusion in the model will likely increase the assessment of overcapacity of the fisheries. Therefore, we can assume that the results on overcapacity are an underestimation and recommendations regarding the overcapacity are reinforced.

The observation of the weak effect of MPA on the small pelagic fishery in Joal is in agreement with Hilborn and al. (Hilborn et al., 2004) who argue that marine reserves provide few advantages over conventional fishing management tools for fisheries that target a single highly mobile species with little or no by catch. This low impact of MPAs in small pelagic fisheries has also been reported in the pelagic fishery of the Bay of Biscay (Lehuta, 2010; Lehuta et al., 2013). In addition, the closure zone must be large enough to protect breeding stocks of mobile species and to have spillover effects (Hannesson, 1998).

In our case, the number and size of closed areas (MPA size) seems enough to provide positive results on biomass. The results are better than those of the *status quo* but this difference is explained by the fact that in the model, the fishing ban is completely enforced in the closed zone. The increase in fishing costs due to the establishment of MPAs reported by several authors (Hilborn et al., 2004; Boncoeur, 2005; Mesnildrey et al., 2013; Chaboud, 2014) is less obvious in this fishery due to the seasonal migration of fishers and especially because they can change their home port.

Another point is the cost of implementation and monitoring which can be quite high for large MPAs. This cost should have been taken in account to estimate the economic return obtained for the national economy. Due to the absence of data on these MPAs costs, there were not included in our model. Then effective returns to national economy should be slightly less than those obtained in simulations.

5 Conclusion

The available scientific knowledge on the Senegalese artisanal fishery for small pelagic fish has allowed to build a bio-economic model, and to simulate its dynamics over several decades and then to test the impact of different spatial closure options on biological and also economic indicators.

Sardinella fishery is, from an economic point of view, overexploited in Senegal. To reach an optimal level of exploitation, it would be necessary to significantly reduce the fishing capacity. However, this solution remains difficult to implement because it requires fishermen acceptance and compensation for those who agree to leave fishery, as it is the case for fleet decommissioning plans (OECD, 2009). Moreover, the introduction of such measures will likely run up against the cultural nature of small-scale fisheries in

Senegal, which consists mainly of family businesses in small communities where fishing plays an important identity building role.

The spatiotemporal closure measures lead to a decrease in capacity in closed areas. However, in the current context of open access and high sub regional mobility of resources and fleets, this measure leads to a concentration of fishing capacity and effort in areas remaining open to fishing. Thus, Senegal's compliance with target 11 of the Aichi will not have a highly significant effect on the sardinella fisheries.

For the establishment of spatiotemporal closures to have a significant impact on the fishery, closed areas should be large enough to cover an entire breeding area (Hannesson, 1998). This measure is difficult to take because the breeding areas are often very large, sometimes shared between two states and often overlay with fishing grounds. To ensure the sustainability of the exploitation of this resource, the countries concerned should have a common management plan within the maritime zones under the jurisdiction of the Sub-Regional Fisheries Commission (SRFC) member States.

In the event that a *status quo* situation persists, and that the States remain on unilateral or bilateral positions in the negotiations of fishing agreements and the establishment of a common concerted policy, sardinella fishery will always be subject to overexploitation and perhaps even collapse. The absence or weak coordination in the management of resources shared between the different countries will continue to lead to a "race for fish" and thus to the tragedy of common goods (Gordon, 1954; Hardin, 1968; Clark and Munro, 1975; McWhinnie, 2009). It is therefore important to remember that decision-making on this fishery must be sub-regional to be efficient because of the shared nature of the resource.

This work allows to inform decision-making in a sub-regional context by providing scenario of the impact of different regulatory scenarios, playing with the types of fishing units, considering the effort and the dynamics of the fishery in the other countries sharing the same resource. This opportunity would require the standardization of data in all countries sharing the resource. Thus, the natural perspective of our work of interest in terms of fishery management, is to extend our modeling work on the distribution area of both sardinella stocks and thus forester sub-regional collaboration providing to sub-regional and state institutions a management tool built on socio-economic bases and incorporating ecological and marine criteria.

Acknowledgement

We are thankful to the AWA project ("ecosystem Approach to the management of fisheries and marine environment (EAMME) in West African waters") funded by BMBF and the IRD (grant 01DG12073E), which supported the PhD of Aliou Ba, the Preface project funded by the European Commission's Seventh Framework Program (2007-2013) under Grant Agreement number 603521, which supported the postdoc from Aliou Ba and the JEAI LEHAO as well as the AGP project ("Amelioration de la gestion des petits pélagiques en Afrique de l'Ouest" implemented by 'SRFC' sub regional fisheries funded by the Mava Foundation which allowed the redaction of the paper. We are thankful for the professionalism of all ISRA/CRODT technicians working all year long on the main Senegalese landing sites.

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Supplementary material

Annex 1

Biological module of the bio-economic model

Change in the number of a cohort

The variable t is the time of the simulation, i.e. t = 1, 2 ..., 480. The abundance N of a cohort decreases exponentially according to the total mortality rate Z:

$$N_{t+1} = N_t * e^{(-Z_t)} \qquad \text{Equation 1a}$$

The exploited stock for each species *i* is composed of cohorts 'c' appearing at each simulation period t (month). The initial size of a cohort *c* in each zone *z* is equal to the recruitment $\boldsymbol{R}_{i,c,z}$, obtained from the parameter 'ParamR' at the beginning of the simulation. A stock recruitment relationship has never been demonstrated for small pelagics in the Senegal-Mauritania area (Fréon et al., 1978). However, it seems likely that their recruitment may be affected by a reduction of the spawning biomass (spawners) below a critical threshold. Examples such as Peruvian anchovy and California sardine have highlighted the possibility of significant falls in biomass and recruitment (Cury, 1991).

To take this possibility into account, the threshold critical biomass 'Blimi' must first be defined, below which recruitment will be affected by a decline in biomass. The threshold of critical biomass is a proportion 'PartBv' (defined as parameter) of virgin biomass 'Bv'. The latter is considered here as a parameter, estimated by simulation in the absence of exploitation of the two sardinella species. The "hockey stick" model is used to take into account the effect of fishing on recruitment. The results of these type of models are considered biologically more plausible than those of the Beverton-Holt recruitment model (Barrowman and Myers, 2000). The value of PartBv used in this study is 0.5.

$$Blim_i = Bv_i \,.\, PartBv_i \qquad \text{Equation 2a}$$

When biomass 'BI' is less than '$Blim$'$_i$, recruitment 'R' tends linearly to 0 when 'BI' tends to 0.

$$\begin{cases} R_{i,c,z} = ParamR_{i,c,z} \quad si\ BI_i \geq Blim_i \\ R_{i,c,z} = ParamR_{i,c,z}.\left(\frac{BI_{i,t}}{Blim_i}\right) \quad si\ BI_i < Blim_i\ et\ a_{i,c,t} = 0 \end{cases} \qquad \text{Equation 3a}$$

Where $a_{i,c,t}$ is the age of the cohort and is by convention equal to 0 at the time of recruitment.

The size of a cohort 'c' at t > tr (the time at which the cohort is recruited) in each zone z is denoted $N_{i,c,z,t}$. It is equal to the population in the same area in t-1 $N_{i,c,z,t-1}$, minus the total mortality in number $D_{i,c,z,t-1}$ and the $\boldsymbol{X_{i,c,z,t-1}}$ export of individuals to other areas and increased the import $M_{i,c,z,t-1}$ of individuals from other areas.

$$\begin{cases} \mathrm{N_{i,c,z,t}} = 0 \quad \mathrm{t} < \mathrm{tr_c} \\ \mathrm{N_{i,c,z,t}} = \mathrm{R_{i,c,z}} \quad \mathrm{t} = \mathrm{tr_c} \\ \mathrm{N_{i,c,z,t}} = \mathrm{N_{i,c,z,t-1}} - \mathrm{D_{i,c,z,t-1}} + \mathrm{M_{i,c,z,t-1}} - \mathrm{X_{i,c,z,t-1}} \quad \mathrm{t} > \mathrm{tr_c} \end{cases}$$ Equation 4a

The mortality in number $\boldsymbol{D_{i,c,z,t}}$ is obtained from the following equation where Z is the total mortality rate:

$$D_{i,c,z,t} = N_{i,c,z,t}.(1 - e^{-\boldsymbol{Z}_{i,c,z,t}})$$ Equation 5a

The total mortality rate *Z* is the sum of the mortality rate $Mortn$ (constant) and the fishing mortality rate F, the calculation of which will be explained below.

$$Z_{i,z,t} = F_{i,z,t} + Mortn_i$$ Equation 6a

For the fishing zones of the Senegalese EEZ 'zsen' the fishing mortality will be determined endogenously (linked to the spatio-temporal dynamics of the fleets) for the outer zones (Nordext, G, Sudext) it will take exogenous values 'Ffix' (defined before simulation).

The fishing mortality *F* is the sum of the fishing mortalities exerted by each fleet *Ff*.

$$\begin{cases} F_{i,zsen,t} = \sum_e Ff_{i,e,zsen,t} \quad z \in \{GC, PC, CAS\} \\ F_{i,z,t} = \sum_e Ffix_z \quad z \in \{Nordext, G, Sudext\} \end{cases}$$ Équation 7a

Fishing mortality per fleet is the product of the active fleet *Fla*, of the catchability *q* and the possibility of fishing in an area or not ($Ferm_{zsen,t}$). Catchability is defined by species i and type of fishing e. It is also a function of the age of the individuals $a_{\mathrm{i,c,t}}$. The parameter $Ferm_{zsen,t}$ is used to indicate the closing rate of a zone.The possibility of seasonal fishing closures affecting the Senegalese fishing zones is foreseen in accordance with the conservation and / or storage policies of certain parts of the exploited areas. The variable $Ferm$ is then between 0 (total closure) and 1 (full opening).

$$Ff_{i,c,e,z,t} = Fla_{e,z,t} * q_{e,i,c,t} * Ferm_{zsen,t}$$ Equation 8a

Evolution in weight of a cohort

W The growth of individuals in each cohort is a function of their age. The individual length L is calculated by means of the von Bertalanffy function**,** L_{inf} is the asymptotic length, k is the growth parameter and t_0 is the theoretical age for which the length is zero.

The individual weight W is then obtained by applying a weight-length relation (parameters α and β). Growth is considered to be identical for all zones:

$$L_{i,t} = L_{infi}.[1 - e^{-k_{i}.(a_{i,t}-t_{0i})}] \quad \text{Equation 9a}$$

$$W_{i,t} = \alpha_{i}.L_{i,t}^{\beta i} \quad \text{Equation 10a}$$

It is then easy to calculate the total biomass per species BI by summing the weight of all the individuals for every '" cohort.

Spatial aspects of the resource

In order to simulate the migration of sardinella, at each time step, the stocks are redistributed between the different spatial cells (different zones) of the model. The stocks are distributed in 6 zones, including three in Senegal (GC, PC and CAS) and three outside (Nordext, G, and Sudext) (Fig. 1).

The monthly migration scheme is introduced by the parameter "*ParamMigr*" which indicates, by species and by month, the emigration rate of the stock present in each zone of origin "*ori*" to each of the possible destination zones "*dest*". The monthly CPUEs for each zone was used as a monthly local abundance index to inform the matrix. The use of monthly parameters requires creating a monthly variable between 1 and 12 which allows to redistribute the seasonal parameters (indexed by "*nmois"*) within each year. The flux of monthly migrations "*FMM"* between zones is obtained from the following equation:

$$FMM_{i,c,ori,dest,nmois,t} = N_{i,c,z,t}.ParamMigr_{i,ori,dest,nmois} \qquad if\ t \geq tr_c$$
$$FMM_{i,c,ori,dest,nmois,t} = 0 \qquad if\ t < tr_c \qquad \text{Equation 151a}$$
$$nmois = mois1, mois2 \dots, mois12 \qquad if\ mois = 1, 2, \dots, 12$$

Where $N_{i,\,c,\,z,\,t}$ is the size of a cohort, ‘ ’’ the species and ‘c’ the cohort.

It is then possible to calculate the immigration and the emigration by zone (it is important to underline here that the elements of the indices ‘z’, ‘ori’ and ‘$dest$’ are the same, which makes it possible to establish a correspondence between these indices):

$$X_{i,\,c,\,z} = \sum_{dest} FMM_{i,\,c,\,ori,\,dest} \qquad (nb\text{: } z\ corresponds\ to\ ori) \qquad \text{Equation 12a}$$
$$M_{i,\,c,\,z} = \sum_{ori} FMM_{i,\,c,\,ori,\,dest} \qquad (nb\text{: } z\ corresponds\ to\ dest) \qquad \text{Equation 13a}$$

The catch dynamics

Catches are only calculated in areas of the Senegalese EEZ, so the ‘*zsen*’ index is used instead of ‘*z* ‘(the ‘*zsen*’ elements are a subset of *z*). The number of deaths due to fishing is equal to the share of fishing mortality ‘*F*’ in total mortality ‘*Z*’, multiplied by the number of total deaths ‘*D*’. The instantaneous catches in weight ‘*C*’ are obtained by multiplying catches in number by weight individual ‘*W*’:

$$C_{i,\,zsen,\,t} = \left(\frac{F_{i,\,zsen,\,t} * D_{i,\,zsen,\,t} * W_{i,t}}{Z_{\,i,\,zsen,\,t}}\right) \qquad \text{Equation 14a}$$

The instantaneous catch by species is obtained by summing the catch *C* by cohort and area.

The cumulative annual catch per species is obtained by summing the instantaneous catches in each of the annual time intervals.

The instantaneous catch by fleet *CF* is calculated by multiplying the daily catch weight *C* by the ratio of fishing mortality of each fleet Ff in the total fishing mortality *F*:

$$CF_{i,\,c,\,e,\,zsen,\,t} = (Ff_{i,c,\,e,\,zsen}\ /\ F_{i,\,c,\,zsen}).C_{i,\,c,\,zsen,\,t} \qquad \text{Equation 16a}$$

Annex 2

The dimensions of the model (subsripts)

Nature	Symbol	values
Type of fishing	e	ST, IND, FME
Areas (total)	z	Nordext, GC, PC, G, CAS, Sudext
Areas (Sénégal)	$zsen$	GC, PC, CAS, CAS
Species	i	Sr ,sp
Cohorts	c	c1, c2..., c492
Years	a	a1, a2,... ,a40
Months of the year	$nmois$	mois1, mois2,... ,mois12
Origin area of fish migrations	ori	Nordext, GC, PC, G, CAS, Sudext
Destination area for fish migrations	$dest$	Nordext, GC, PC, G, CAS, Sudext

Annex 3

Model parameters and their values

Parameter	Meaning	Subscripts	Unit	Value in the reference simulation
$ParamR$	Initial recruitment of a monthly cohort of species i, in a zone c	i,z,c	individual	Defined in the parameter file
t_r	Date of recruitment of cohort c	c	time	
k	Growth parameter of the von Bertalanffy function	i	time	S. ronde : 0.100833 S. plate : 0.040833
t_0	Fictitious "date of birth" corresponding to the time when the size would be zero.		time	S. ronde : -0.72 S. plate : -7.08
α	Parameter of the weight-length relationship	i		S. ronde : 0.006392 S. plate : 0.0098535
β	Parameter of the weight-length relationship	i		S. ronde : 3.274 S. plate : 3.1676
txi	Investment rate	e	%	0.3
$txi1$	Disinvestment rate	e	%	0.1
$parCV$	Variable cost	e	FCFA/month	ST : 3.449 million FCFA FME : 1.171 million FCFA
$parLIC$	Amount of fishing license (permit)	e	FCFA / year	ST : 25 000 FCFA FME : 25 000 FCFA
$parCF$	Fixed cost	e	FCFA / year	ST : 372 605 FCFA FME : 324 690 FCFA
$parCDEB$	Landing cost		FCFA /t	1000 FCFA
$Ffix$	Fishing mortality in areas outside the Senegalese EEZ	$z \in \{Nordext, G, Sudext\}$		0.08 ; 0..08 ; 0.08
$TxActu$	Discount rate		%	5
PR	Price per species	i	FCFA /t	Sr : 130995 FCFA Sp : 103670 FCFA
$ParCiF$	Fixed intermediate consumption	e	FCFA/month	ST : 126 573 FCFA FME : 153 207 FCFA
$ParCiv$	Variable intermediate consumption	e	FCFA/month	ST : 3 448 629 FCFA FME : 1 170 857 FCFA
$Ferm$	Closure of fishing areas	$zsen$		Defined according to the scenarios
$FinalTime$	Final time of the simulation		month	480

$ParEquip$	Crew size by fleet type	e	person	ST : 20 : FME : 10
Parameter	Meaning	Symbol	Unit	Value in the reference simulation
$TxCaptAccess$	Bycatch rate by value	e	%	ST : 0.24 IND : 0 FME : 0.32
$TxCroisCapt$	Annual growth rate of fishing power	e	%	ST : 0.02. IND : FME : 0.01
$ParCicarbTTC$	Monthly consumption of fuel ATI	e	FCFA	ST : 3150000 FCFA FME : 1013000 FCFA
$ParCicarbHT$	Monthly consumption of fuel ET	e	FCFA	ST : 3706000 FCFA FME : 1191000 FCFA
$ParDetaxMot$	Annual engine tax exemption, per fishing unit	e	FCFA	ST : 415666 FCFA FME : 268333 FCFA
$ParDetaxEng$	Annual exemption of fishing gear taxes, by fishing unit	e	FCFA	ST : 360000 FCFA FME : 97200 FCFA

Annex 4

Catchability of both sardinella

Fish Age (month)	Catchability *Sardienlla aurita*
4 - 6	4.2247E-06
7 - 9	1.1574E-05
10 - 12	2.7162E-05
11 - 15	1.5477E-05
16 - 18	6.4401E-05
19 - 21	5.9776E-05
22 - 24	6.6904E-05
25 - 27	6.1756E-05
28 - 30	6.7922E-05
31 - 33	4.677E-06
34 - 36	1.9845E-06
37 - 39	1.7133E-06
>39	1.6992E-05

Fish Age (month)	Catchability *Sardinella maderensis*
7 - 9	1.1362E-07
10 - 12	9.9849E-07
11 - 15	3.3935E-06
16 - 18	1.4198E-06
19 - 21	9.4787E-06
22 - 24	1.1746E-05
25 - 27	1.3759E-05
28 - 30	7.5257E-06
31 - 33	7.1591E-06
34 - 36	1.4042E-05
37 - 39	7.6991E-06
40 - 42	7.1011E-06
43 - 45	3.2785E-06
46 - 48	5.1656E-06
49 - 51	3.4174E-06
>51	2.2283E-06

Annex 5

Monthly migration matrices for *Sardinella aurita*. Share of the number of fish migrating from a origin area to other areas. The diagonal of each matrix must remain equal to 0. ORI (origin), DEST (destination), GC (Grande Côte), PC (Petite Côte), CAS (Casamance), G (Gambia), sudex (Guinea Bissau) and nordex (Mauritania).

S. aurita

January		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0.7	0	0	0	0
	GC	0	0	0.1	0	0	0
	PC	0	0	0	0.1	0	0
	G	0	0	0	0	0.07	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
February		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0.3	0	0	0	0
	GC	0	0	0.05	0	0	0
	PC	0	0	0	0.1	0	0
	G	0	0	0	0	0.07	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
March		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0	0	0.05	0	0	0
	PC	0	0	0	0.005	0	0
	G	0	0	0	0	0.7	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
April		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0	0	0.05	0	0	0
	PC	0	0	0	0.05	0	0
	G	0	0	0	0	0	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
May		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0.4	0	0	0	0	0
	PC	0	0.2	0	0	0	0
	G	0	0	0.2	0	0	0
	Cas	0	0	0	0.2	0	0
	Sudext	0	0	0	0	0	0
June		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0.7	0	0	0	0	0
	PC	0	0.2	0	0	0	0
	G	0	0	0.5	0	0	0
	Cas	0	0	0	0.5	0	0
	Sudext	0	0	0	0	0	0

July		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0.5	0	0	0	0	0
	PC	0	0.3	0	0	0	0
	G	0	0	0.5	0	0	0
	Cas	0	0	0	0.1	0	0
	Sudext	0	0	0	0	0	0
August		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0	0	0	0	0	0
	PC	0	0.1	0	0	0	0
	G	0	0	0.2	0	0	0
	Cas	0	0	0	0.1	0	0
	Sudext	0	0	0	0	0	0
September		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0	0	0	0	0
	GC	0	0	0	0	0	0
	PC	0	0.1	0	0	0	0
	G	0	0	0.2	0	0	0
	Cas	0	0	0	0.1	0	0
	Sudext	0	0	0	0	0	0
October		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0.6	0	0	0	0
	GC	0	0	0	0	0	0
	PC	0	0	0	0	0	0
	G	0	0	0	0	0	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
November		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0.6	0	0	0	0
	GC	0	0	0.05	0	0	0
	PC	0	0	0	0	0	0
	G	0	0	0	0	0	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0
Décember		DEST					
		Next	GC	PC	G	Cas	Sudext
ORI	Next	0	0.7	0	0	0	0
	GC	0	0	0.1	0	0	0
	PC	0	0	0	0.005	0	0
	G	0	0	0	0	0.07	0
	Cas	0	0	0	0	0	0
	Sudext	0	0	0	0	0	0