Thesis for the Degree of Master of Fisheries Sciences

Application of CYP Bioeconomic Model to the Southern Gulf of Guinea Sardinella Fishery

by

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(CYP 생물경제모형을 이용한 남부 기니만 사디넬라 어업의 자원평가)

Advisor: Prof. Nam Jong-Oh

by

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List of Acronyms

CECAF	Fishery Committee for the Eastern Central Atlantic
CLS	Collecte Localisation Satellites
CPUE	Catch per Unit Effort
CYP	Clarke, Yoshimoto and Pooley
DR Congo	Democratic Republic of Congo
EEU	Environmental Evaluation Unit
EEZ	Exclusive Economic Zone
GCLME	Guinea Current large Marine Ecosystem
GRT	Gross Registered Tonnage.
ICSEAF	International Commission for the Southeast Atlantic Fisheries.
KOICA-PKNU	Korea International Cooperation Agency-Pukyung National University.
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
MT	Metric Ton.
NOAA	National Oceanic and Atmospheric Administration.
SADC	Southern African Development Community.

SPM	Surplus Production Model.
UBC	University of British Columbia
UCP	University of Cape Town
UNCLOS	United Nations Convention on the Law of the Sea.

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the Southern Gulf of Guinea Sardinella Fishery

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Abstract

Application of CYP bioeconomic model to the Southern Gulf of Guinea sardinella fishery is estimated in this study. The results show that the present level of exploitation with the MSY level imply biological overfishing of the sardinella stock. Given the overexploited status of the sardinella resource, great improvement in the fishery can be achieved if fishing effort of 825 vessels can be reduced by 32 per cent from the present MSY level of 46,111 metric tons. But the maximum net revenue can be gradually achieved until

the resource recovers to the steady state biomass associated with MEY. Based on the cost/price structure of the sardienlla fishery, we estimated the effort of 560 vessels that maximises the harvest level associated with MEY of 43,154 metric tons.

Area based catch level approach shows the evidence that Congo is catching three times more sardinella than Angola. An indication of the sensitivity of the area catch rates variation is given by design of four scenarios at 2.5, 5, 7.5 and 10 per cent so as to analyze the economic interation between Congolese and Angolan sardinella fishery industry. The outcomes predicted increasing or decreasing trends of catch, effort, fishing cost, total revenue and subsequently the profit. Zero per cent represents MSY reference point values. Therefore, under substantial effort and catch reductions on Congo side, the economic losses on Angolan side are substantially mitigated by increases in catch and effort, and economic parameters.

In the sub-region level, there should be synchronization between Congolese and Angolan surveys including other nations involved in the sardnella fishery to address the issue of transboundary sardinella resource management. Therefore, stock assessment “output control system” can be adopted in the Southern Gulf of Guinea sardinella fishery among adjacent nations. This implies an urgent need to formulate appropriate effort reduction management policies through cooperation among neibhouring States in order to derive maximum benefits from the sardinella fishery.

I. Introduction

Economical, political, legal and other social arrangements in fisheries should be evaluated according to how they further human and ecological wellbeing, expand people’s capacities and strengthen the basis for the human freedom”. (P. Cardoso, P. Fielding and *coll*., 2011).

The need to manage fisheries resources is well established (Gordon 1954). Fisheries resources are renewable and common property resources. Without management, these resources will be exploited to the extent that the rate of catch will surpass the maximum yields that the resources can sustain, leading rent obtainable from the fisheries resources will be completely dissipated, causing economic losses.

The sardinella resources stocks are distributed throughout the Southern Gulf of Guinea, hence is transboundary resource (fig. 1). The shared sardinella stocks of the Southern Gulf of Guinea is commercially exploitable, it migrates along a maritime boundary between Angola, Congo-Brazzaville, Congo Democratic Republic and Gabon, and can be managed effectively through cooperation between the concerned States (L. Cochrane and M. Tandstad, 1997).

The sardinella fisheries of the sub-region are alleged not being well managed (FAO/CECAF, 2009) while they represent important sources of employment, income and food for many thousands of fishers and their dependents as well as providing sources of fish for many other inhabitants of this sub-region. Important commercial fisheries have developed around the sardinella stocks.

Two distinct species of sardinella are found in the Southern Gulf of Guinea sub-region. The round sardinella (*Sardinella aurita*) and the flat sardinella (*Sardinella maderensis*) (Marchal and Boely, 1977). Although, Troadec and Garcia (1980), postulated that the sardinella resources seem to be only one stock from south of Gabon to south of Angola. Furthermore, some of the countries report catches for sardinella as a whole, without separating the species. For these reasons and for the purpose of this study, the sardinella resources are considered and analyzed as one stock.

The Code of Conduct for Responsible Fisheries (FAO, 1995) makes the following recommendation in connection with shared or transboundary stocks:

1. Paragraph 6.4: In recognizing the transboundary nature of many aquatic ecosystems, States should encourage bilateral and multilateral cooperation in research, as appropriate.

2. Paragraph 7.1.3: For transboundary fish stocks, where these are exploited by two or more States, the States concerned should cooperate to ensure effective conservation and management of the resources.

In keeping with these principles of the Code and with a recognition by the Fisheries Directorates of Angola, Congo-Brazzaville, Congo DR and Gabon, effective management of shared resources could only occur through cooperation and working together.

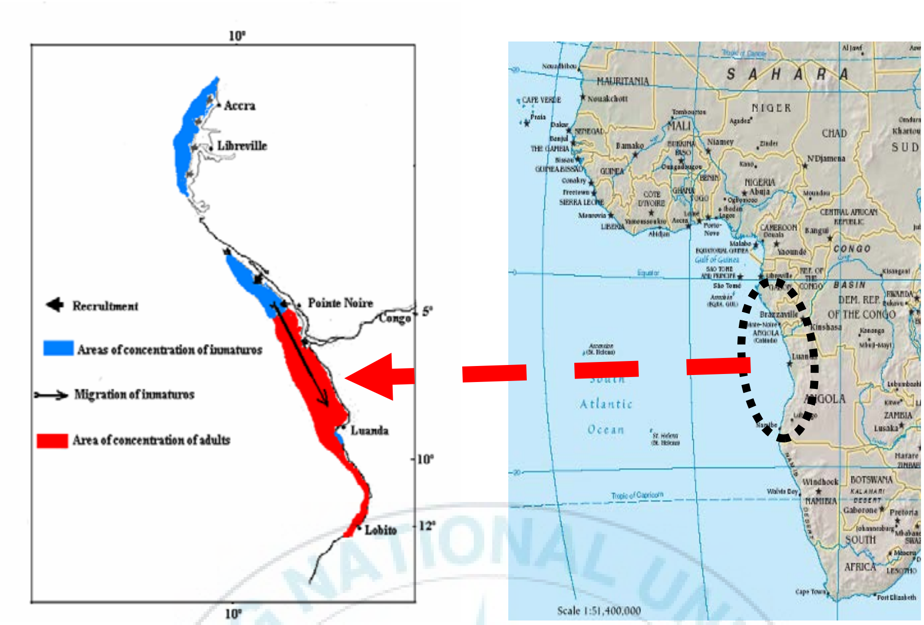

Figure 1. Map of the Southern Gulf of Guinea showing the four countries (Angola, DR Congo, Congo and Gabon) along where the sardinella migrate.

1.1 Research background

The commercial fishing for the transboundary sardinella resource in the southern Gulf of Guinea has been developed strongly in the late 1940s and early 1950s. The objective was to supply food, specifically animal protein to the coastal population, but also the continental producers. In the particular case of Angola, the development of the sector was also intended to contribute to the development of the fish meal industry (L. Cochrane and M. Tandstad, 1997). Since Troadec and Garcia (1980) whose researches on sardinella have given the distribution of the population of these species at different stages of their life cycle due to favorable environmental conditions, Cochrane and Tandstad (1997) used the production modelling approach, especially the dynamic version of the Schaefer (1954) model to estimate the Maximum Sustainable Yield (MSY) for the recommendation of sardinella fisheries management reference point. While others concentrated their efforts towards biological results on the determination of age structures, the diet, etc.

Additionally, Rachid Sumaila in 2006 has studied marine fisheries management of the Guinea Current Large Marine Ecosystem as a whole, using Ecopath and Ecosim model (EwE) on integrated biological and economical parameters. But, bio-economic analysis of sardinella stock of the Southern Gulf of Guinea as transboundary resource has not been yet addressed.

Based on the information highlighted above aggregated, the present research on the stock assessment for single fish species and multiple gear fisheries with an application to the Southern Gulf of Guinea sardinella fishery is carried out. The four sub-region's countries initiated the cooperation for the effective management of this resource since 2006 and want to regulate the fishery in order to maximize production towards sustainable sardinella's fishing activities (FAO/CECAF, 2009). Among them, Angola and Congo progress in monitoring of fishing effort and landings of these important species compare to other countries within the sub-region. Therefore, time-series catch-effort data of the two countries are used in the present study.

The use of the artisanal catch data in the assessment models for the sardinella fish concerns only motorized boats due to problems associated with the collection of the data in the artisanal fishery. In addition, the industrial fisheries concern the ships targeting mainly sardinella species.

1.2 Research objectives

The objectives of this research is firstly, to determine the sustainable fishing effort for the transboundary sardinella resources of the Southern Gulf of Guinea by assessing the available twenty (21) years catch-effort data set, from 1992 up to 2012 by the Clarke, Yoshimoto, and Pooley Exponential

Model. The analysis will lead to the estimation of optimal fishing efforts corresponding to the sustainable and economic exploitation points (MSY and MEY), and characterize the trend of sardinella production and fishing cost against fishing effort. Additionally, the maximization of these sardinella fisheries implies understanding of its stock equilibrium at MEY, which is more biologically conservative than the Maximum Sustainable Yield (MSY).

The reason of using the bio-economics model is simple because, regardless of what happens to prices and costs of sardinella fishing activities, catch and effort at MEY will always ensure that profits are maximized. While with a biological target of MSY alone, as it had been studied previously in the sub-region, however, it is quite possible that profits could be small.

Furthermore, we hypothesized that dramatically increasing of sardinella production over the five last years (from 2008 up to 2012) will push the stock to the overexploitation level.

Secondly, this study seeks to ascertain the main causes of problems related to the sardinella fisheries in Congo and Angola by examining the current fisheries management and addressing policy implications and recommendations for the sustainability of the Southern Gulf of Guinea sardinella fishery.

1.3 Research necessity

Research work is mandatory before graduation at KOICA-PKNU International Graduate Program of Fisheries Science. This study is expected to serve as a contribution to the acquisition of basic scientific skills on the stock assessment for the Southern Gulf of Guinea sardinella fishery. It provides some insight for current state of exploitation of the sardinella fishery as a transboundary resource based on the Clarke, Yoshimoto, and Pooley's (CYP) bio-economic model analysis and the implications for effective cooperative management policies among countries sharing the sardinella stock biomass.

II. Overview of the Southern Gulf of Guinea fishery

2.1. Literature review

The Southern Gulf of Guinea sub-region extends from South of Gabon (0°) to the South of Angola (17°S) throughout Congo-Brazzaville and Congo Democratic Republic, and covers nearly 3,000 kilometers of coastline (fig. 1). The climate along the coast is characterized by sub-tropical upwelling conditions with tropical conditions near the Equator.

Given the nature of the marine resources in the region, there are potential benefits to be derived if efforts are made to manage and develop the resources efficiently. The sardinella fishery of this region offers one such possibility. This fishery is of particular importance because of its potential as a low cost source of protein for millions of people in the four coastal countries.

Large volumes of frozen and processed products are also traded intra-regionally. However, because of the highly migratory nature of the sardinella fish stocks and the different groups that participate in this fishery, coastal states are faced with a number of management problems.

In addition, the sardinella stocks move across four national water territories, during their migrations no one coastal state can claim full jurisdiction over any particular stock. Thus, in the absence of any enforceable regulatory measures between states sharing these stocks, no one has any interest in preserving the sustainable nature of this common property resource. Added to this, are biological and environmental factors that cause significant yearly fluctuations in the abundance of the stocks.

The fisheries are managed through regulatory provisions whose purpose is to manage the effort, seasons and fishing zones, catch limits, mesh, protection of species and the prohibition of destructive fishing practices, etc. Despite the existence of these laws and regulations, instruments, their implementation are either absent or inadequate in all these countries. In 2013 the first management plan of the shared stocks of sardinella of the Southern Gulf of Guinea established for five years were published. The funds have been provided by the ACPFish II project.

The objective of this management plan is to contribute sustainably and equitably to the sardinella fishery management for the reduction of poverty and improvement of food security within the four concerned countries.

Angola has the most elaborate structures for the management of its fisheries with its Fisheries Department, composed of two advisory councils, technical services, administrative and regulatory, the central management and directions of subordinated institutions. The Institute of Marine Research (National Institute of Fisheries Research, INIP) falls into the latter category. In addition, there is a technical consulting (associations and representatives) to review the recommendations and measures. Other countries have much less elaborate structures.

The sardinella resources of Angola, Congo, Congo DR. and Gabon are as defined by Hayashi (1993), “group of commercially exploitable organisms spread across or along a migrant maritime boundary between two or more national water jurisdictions, which can be operated effectively through cooperation between the relevant states and where emigration and immigration to other jurisdictions should be considered” (ACPFish II, 2013).

Baptista (1976) stated that the migration of sardinella starts offshore from north to south at the end of the cold season or beginning of the hot season and appears off central and southern Angola during September or October. After February, they start moving north but this time in inshore waters. This could explain the seasonal variation in catches in the area. These stocks are influenced by a tropical hydroclimate characterized by the Guinea and Benguela current systems which affect the oceanographic conditions of the sardinella and other pelagic fisheries (fig. 2).

The abundance of sardinellas is linked to the upwelling periods. They are exploited by both the artisanal and industrial fleets. Artisanal fleets form the main fishing fleet for the sardinellas in this region. Surface gillnets operated from motorized canoes are employed in the artisanal fishery while the industrial fleet uses pelagic trawl and purse seine.

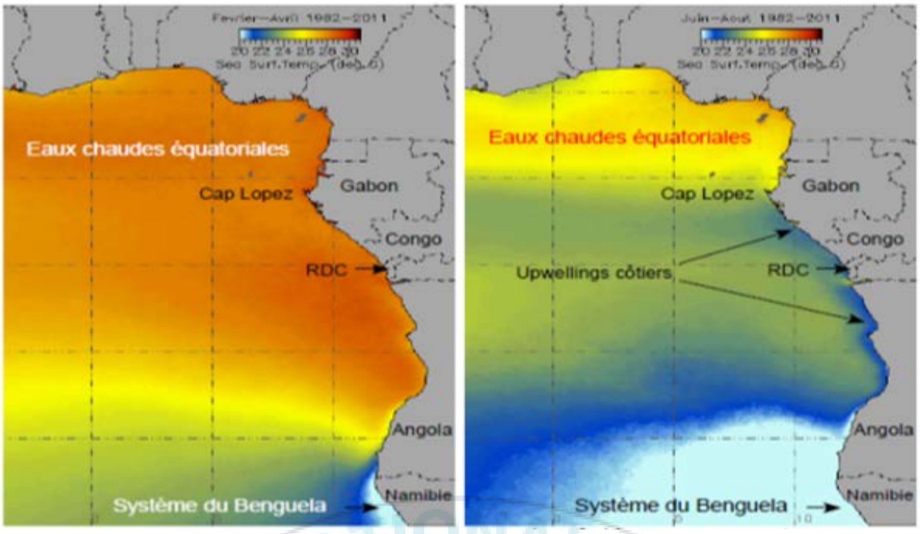

Figure 2. Maps of sea surface temperatures of Southern Gulf of Guinea from NOAA satellites (a: warm season & b: cold season).

A main feature of the hydrography of Southern Gulf of Guinea is the upwelling process with a maximum in June-August. This results in intensified primary production, and the existence of a thermal front. Seasonal variations of the hydrographical conditions cause temporal and spatial variables of the distribution of sardinella (Luyeye N., 2002). Catches and surveys show that seasonal changes cause north-south movement of sardinella along the coast, with a southward displacement of the adults during the warm season. The displacement north and south for both sardinella species is also linked to the feeding area as well as reproduction.

It is known that the sardinella species feed on both phyto- and zooplankton. In warm and cold seasons, the Guinea and Benguela currents influence the movement of the phyto- and zooplankton (Luyeye N., 2002).

2.1.1. Angolan fisheries

Angola has a coastline of 1,650 Km. Its exclusive economic zone (EEZ) is defined to 200 nautical miles, an area of over 510,000 Km^2. At present the fisheries sector is the third main economic sector following the oil and mining industries (diamonds). Fish is the main source of animal protein available nowadays. The consumption per capita is an average of 19 kg per person per year with nearly 30 kg in the coastal zones (Alberts et *al.*, 1990).

The fishing fleet in Angola is usually classified into artisanal, semi–industrial and industrial on the basis of vessel size. The industrial sector dominates effort directed on fish using mostly purse seine and pelagic trawl vessels from about 25 m length overall. The artisanal sector is probably the most important Angolan fishery with respect to employment and well–being of Angolans and for this reason a separate Artisanal Fisheries Institute

(Instituto para o Desenvolvimento de Pesca Artesanal–IDPA) was established 1996. The artisanal sector dominates effort on the stocks fish using mainly small boats of various types up to about 10 m in length, although there is an increasing trend towards motorization. The semi–industrial sector uses vessels that range between 12 and 25 m.

Pelagic stocks are a major fish resource of Angola and represent approximately 80 % of the total catches landed in the country (Anon, 1991). The most important pelagic fish stocks are sardinella and mackerels.

The sardinella stocks in the area from the Congo to the southern border of Angola for many years supported fisheries of substantial importance. Commercial exploitation of small pelagic fish started for the purpose of the fish meal industry in the early fifties. During the fifties and sixties catch dynamics seemed to be dependent on stock fluctuations rather than on fishing effort (Campos Rosado, 1974).

Surveys carried out by the vessel *"Dr. Fridtjof Nansen"* indicate the intensive fishing, even when allowing for some under-estimations of biomass with the acoustic method. Observed trends of roughly constant biomass from 1985 to 1989 support the impression of the stock affected by the fishery. However, there are several sources of errors in acoustic abundance estimates of fish. These are usually classified as technical, methodological and behavioral (Luyeye N., 2002).

Since May 1996, the Artisanal Fisheries Institute, in cooperation with FAO and the French Ministry for Cooperation, has been implementing a control programme for the catch/effort along the coast.

Following Angola's independence (1976-1977), a significant increase of the Soviet purse seine fleet was observed, mostly in tonnage classes 5 and 6 (150-1,000 GRT). The Soviet factory ships that processed fish onboard entered the fishery. There was a decline trend of sardinella from 350,000 tonnes (in 1977) to 180,000 tonnes in 1983 due mainly to the removal of the Soviet purse–seine fleet in 1990. The pre 1998 average catch (FAO and ICSEAF statistics) approximates 123,130 tons. It is stressed however that historical catch statistics are unreliable and only provide approximations of the estimated landings (Luyeye, 2005). De Campos (1974) reported that sardinella stocks in the area from the Congo to the southern border of

Angola for many years supported fisheries of substantial importance with total landings in the period 1961–1974 varying between 60,000 t and 250,000 tons. Since 1992 up to 2007, reported catches have been much lower than 68,000 tons.

During the 1990s, a significant decrease in the foreign fleet was observed and catches. The decrease in the foreign fleet was not completely compensated by an increase in the national fleet due to insufficient national capacity. In the period after 1992 up to 2007, the catch productions fluctuated mostly in the range of 10,000 and 50,000 tons. After that the fishery started to increase again and reached 75,000 and 77,000 tons in 2008 and 2009 respectively (fig. 3). Baptista (1976) stated that the migration of sardinella starts offshore from north to south at the end of the cold season or beginning of the hot season and appears of central and Southern Angola during September or October. After February, they start moving north but this time in inshore waters. This could explain the seasonal variation in catches.

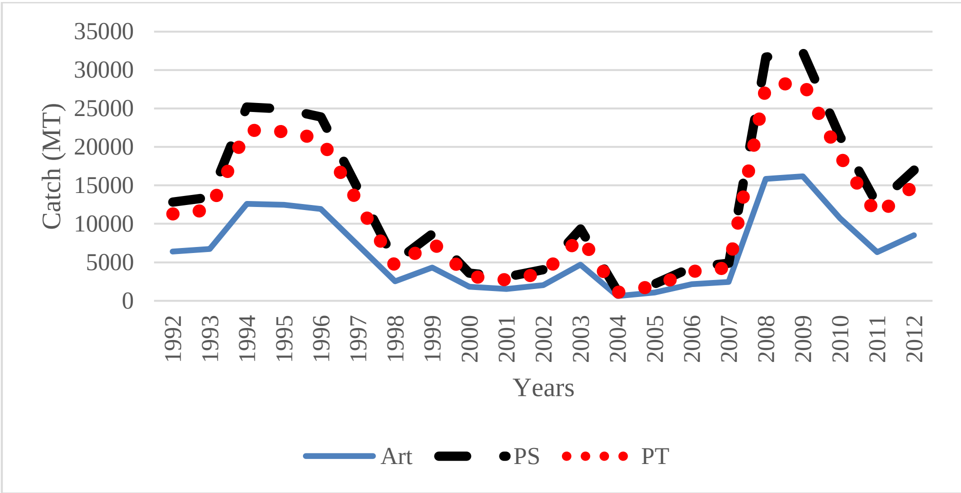

Figure 3. Trend of sardinella catch for artisanal, purse seine and pelagic trawl from 1992 to 2012.

The catch per unit of effort for the artisanal and industrial fisheries was calculated separately. Due to data collection bottlenecks, sardinella species is not reported separately, they are reported as *Sardinella spp.* (fig. 4). The CPUE from the artisanal and industrial fleet indicated two annual trends. Firstly an increasing trend from 1993 to 1995 and then trend has started decreasing since 1996 partly as a result of management measures and fluctuate up to 2006 before it has started to increase again in 2007. CPUE shows clear upward or downward trend, but both show large year-to-year fluctuations.

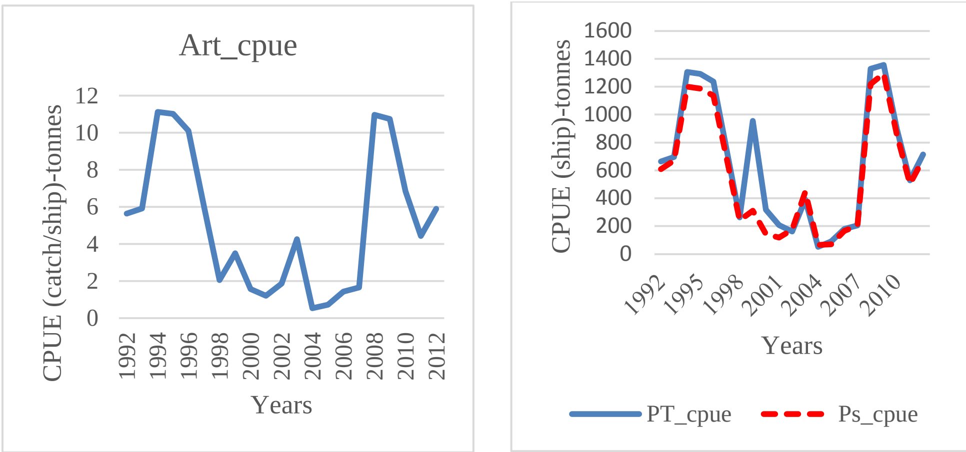

Figure 4. Trend of CPUE for artisanal (a), purse seine and pelagic trawl (b) from 1992 to 2012.

i. Fisheries legislation

Law of Aquatic Biological Resources (*Lei dos Recursos Biológicos Aquático*- the 'new law'*):* this is the main law that governs the management of Angolan aquatic resources. It replaced the Fisheries Law of 1992 (*Lei das Pesca* - LP) as it was outdated, and did not reflect international and regional developments in the fisheries sector. The 'new law' was drafted in 2003 and promulgated in 2004. It established new principles and provisions regarding the sustainable management of marine resources. This 'new law' incorporates provisions and objectives established under international and regional agreements such as: UNCLOS (regarding conservation and optimum utilization of living resources in Angola's Exclusive Economic Zone – EEZ), the SADC Fisheries Protocol and the (voluntary) FAO's Code of Conduct and Protocol on Responsible Fishing, including promoting the contribution of fisheries towards food security and livelihoods. To enforce the new legal regime other regulations were promulgated (e.g. with regard to surveillance, research, recreational fisheries and licensing).

Angolan law defines the following types of fisheries: commercial (artisanal, semi-industrial and industrial) and non-commercial fisheries (subsistence, recreational and research). Marine artisanal fisheries are differentiated from other commercial fisheries on the basis of the size of the fishing vessels (up to 14 metres) and operate in the inshore 4 nautical mile (nm) zone (extended to 8 nm in the north), which has been declared as an exclusive artisanal fishing zone.

i.1 Fishing license and quotas

The practice of fishing is conditional on the acquisition:

- A property registration certificate and a navigation license (Kz 25500 (~ $US 250)/ year);
- A fishing license and a navigation license. Validation annual periodicity.

Fishing licenses are obtained through associations or fishing communities. These licenses (and prices) depend on the:

- type of boat (canoe, chata e catronga);
- overall dimensions of the boat;
- requested quota.

i.2 Agreements and conventions

There are fisheries agreements with neighbouring countries, especially Congo and Namibia. The country has ratified some regional and international Conventions such as:

- SEAFO (South East Atlantic Fisheries Organization Convention) (April 2003);

- SADC: SADC Fisheries Protocol. CECAF (Fisheries Committee for the Eastern Central Atlantic Region);
- INFOPECHE Intergovernmental Organisation for Marketing and advisory Services for fish product in Africa);
- COMHAFAT (Ministerial conference of fisheries Cooperation Among African states bordering the Atlantic Ocean);
- ICCAT (International Commission for Conservation of Atlantic Tuna).

i.3 Actors of the artisanal fishing sector

i.3.1 Cooperatives and fishers

The first cooperative was founded in 1978 in Cacuaco district, Luanda province. The managers deal with and to whom it is addressed to its measures for development support. The Cooperative statutes are declared to the Ministry of Justice. Different communities are located along the coastline and are managed by fisheries agencies, these communities represent and defend the fishermen interests and rights. Angola fishermen belong and work for the development of coastal communities.

i.3.2 Artisanal processors

The artisanal processor groups are mostly represented by women. Sardinella fish are preferred salted and dried for long conservation during the transportation. Sale is prior to women and some agreement between women and vessel owners for access to the product is concluded.

i.3.3 Technical and organizational implementation of production tools

In Angola, artisanal fishing is done on moonless nights and there is no fishing during the rainy season (May to November). Fishing costs including food, oil and 60 liters of fuel, are amounted on average of 20,000 Kz (~ $US 200). The sharing of production is 60% for the owner and 40% for 7 crew. In other provinces, the share is 50% of total production for the crew (2 times 6 men) and 50% for the owner after deducting the reimbursement of fishing costs.

i.4 Industrial fishing

Angola has large fishing boats distributed in major provinces (Zaire, Bengo, Cabinda, Luanda, Kwanza Sul, Benguela and Namibe) originated from Spain and China. Semi-industrial fishing are composed by wooden trawlers and purse seiners. (ACPFish II, 2013).

i.4.1 Industrial fish processing companies

Angola is the only country where there is an industry producing fishmeal among the Southern Gulf of Guinea countries. It takes about 8 kg of fresh fish to 1 kg of fish meal. Fishmeal is intended for export. There would be 12,000 tons of fish for fishmeal. Similarly Angola still has national enterprises that allow for a better economic incentive to boost the sector. Thus in Porto Ambo province, a national enterprise is to rehabilitate or rather replace old facilities to new frozen capable of 45 tons daily.

For the processing purposes, industrial processors have an arrangement with the artisanal one, to sell the surplus. Consequently, the artisanal fishers receive the technical assistance to modernize the artisanal fleet and their landing grounds.

2.1.2. Congolese fisheries

Congo Atlantic Ocean's coastline is about 170 Km. Its exclusive economic zone (EEZ) is defined to 200 nautical miles, an area of over 60,000 Km². It is largely situated between latitudes 4° and 5° south and longitudes 11° and 12°2' East. The coastal zone is found in Kouilou province located in south west Congo and is about 13,650 kilometres, about 4% of the national territory (ACPFish II, 2013).

Congolese fisheries are categorized in three distinct types. First, the traditional canoe fishery, carried out for a very long time by the local fishermen (Vilis) using small canoes propelled with oars (pagaies), and fishing with driftnets, presently made of nylon. This fishery has been increasing in recent years. There were about 500 canoes participating in the fishery in 1977, with a total catch estimated at about 1,500 tonnes/year.

From 2000 to 2012, the number of canoes has been reduced and fluctuated between 336 and 457 canoes.

Second, the so-called “popo” fishery, which was initiated with about ten boats in 1963, remained fairly constant in the first years but suddenly developed from 1972 onwards. After a decline in the number of boats in 1978, this number seems to have returned towards its earlier level in 1979. The fishery is carried out by expatriates from West Africa who have introduced a fishing technique new for Congo using motorized canoes bought in Ghana and employing nylon encircling gillnets which are industrially produced in Benin. The sardinella landings of this fleet may attain about 5,000 tons/year. In 2000, the number of those canoes was seriously reduced to 182 due to Congolese management system to rebuild the deplete stock of pelagic fishes and estimated to 218 canoes in 2012. The total amount of marine fishes produced was estimated to be 13,352 and 16,505 tons in 2000 and 2012 respectively.

Third, the industrial fishery, carried out by purse seiners. From 1964 to 1969, there was one seiner of 25 tons hold capacity only. In 1970 and 1971, two boats participated in this fishery, and the number increased to three in 1972 and four in 1977. During this period, there was a progressive replacement of the first small seiners, preserving the fish on ice, by larger units (40-120 tonnes hold capacity), most of which preserve the fish in cooled sea water. The total amount of marine fishes produced was estimated to be 22,433 and 43,184 tons in 2000 and 2012 respectively (fig.5).

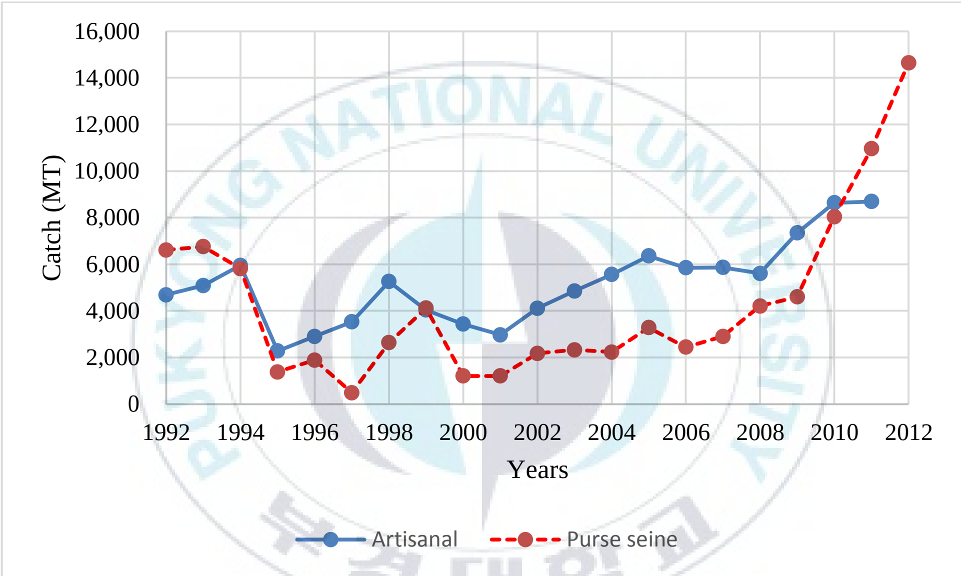

Figure 5. Trend of sardinella catch for artisanal and purse seine in Congo from 1992 to 2012.

Fishing is considered to be a major activity by the government as a source for food as well as a sector with great potential for investment. Annual capture is estimated at 70,000 – 80,000 tons for continental fishing and 20,000 - 30,000 tons for maritime fishing. Currently, the total number of industrial ships in Congo is about thirty ships. Artisanal fishing contributes to about 40% of the national sea fish catch.

Industrial exploitation of sardinella began at Pointe Noire in 1956 with a single ship that made the first fishing trials between Pointe Noire and Libreville, reaching 5 and 8 vessels in 2000 and 2012 respectively.

It should be mentioned that the Congolese fishery statistic's department has a good data collection system of total catch for the industrial fisheries (ACPFish II, 2013).

Figure 6. Trend of CPUE for artisanal (a) and purse seine (b) in Congo from 1992 to 2012.

The catch per unit of effort (CPUE) compares to Angolan one and shows same upward-downward trend with fluctuations year-to-year (fig. 6). The CPUE of the sardinella increases spectacularly during the “long cold season”, and also during the “short cold season”, and decreases drastically during the “long” and “short warm season”. These facts have led to the hypothesis that adults arrive in the Point Noire area at the beginning of the cold seasons and disappear at the beginning of the warm seasons (Bouchereau, 1976 cited in ACP Fish II, 2013).

i. Fisheries legislation

The National fisheries and aquaculture Policy is being adopted by the Government (ACP Fish II, 2013). Marine fishery is currently governed by Law No. 02-2000 of 1 February 2000 related to the organization of sea fishing in the Republic of Congo. The exercise of industrial marine fishery is subject to obtaining a quota. This annual catch quota is not renewable. The fishing license is an administrative document evidencing the allocation of a quota to a ship and is available upon request with an information sheet concerning:

- the name of the owner, his nationality and of its members;

- the number and place of registration;
- the date of ship’s construction;
- the characteristics of the vessel, the type of fishery , the characteristics of fishing gear;
- the mode of treatment and conservation edge.

Professional marine artisanal fishing is done for economic purposes, on board small-scale boats, motorized or not. The exercise of this fishery is subject to obtaining a fishing license issued by the Fisheries Administration. The management system provides a conditioned access to the resource such as quotas, fishing licenses and fishing permits.

The development of maritime service ensures monitoring fisheries, control and surveillance of marine fishing. The observation’s center of fishing boats is tasked with monitoring, control and positioning of vessels operating in waters under Congolese jurisdiction, through the VMS tags.

In addition, Congolese authorities have taken steps to curb illegal fishing in their territorial waters to ensure the survival of fishery resources and boost food security. The latest measure is a satellite surveillance system that monitors all the fishing boats operating in the country's maritime waters. It is a measure designed to combat illegal fishing, since we have to ensure sound management of the fish, which are the inheritance of all Congolese. We must safeguard them for future generations who will also turn to them for food.”

The authorities put the VMS system in place with help from the international satellite data group “Collecte Localisation Satellites” (CLS), based in Toulouse, France. The two signed an agreement in 2006, but the system became operational in February 2011. Most of the boats plying Congolese waters come from China. Others are from the Netherlands and France.

Furthermore, the government of Congo-Brazzaville has banned shark fishing of its Atlantic coast to prevent depletion of stocks caused by massive demand in Asia for shark fins, and "catching dogfish sharks has become large-scale because senegalese traders do big business exporting fins to Asian countries."

i.1 Actors of the artisanal fishing sector

i.1.1 Fishermen

There are no available updated count distinguishing between categories of fishermen. According to ACPFish II (2013), the total number of artisanal fishers exploiting marine fish resources in Congo is estimated at 3,500 fishermen.

i.1.2 Processors

Artisanal landings are not equipped with cold storage and ice maker. Thus, despite some products that can be sold fresh to the local market very quickly after landing, the rest of the products, the vast majority of them, is transformed. The two most commonly used processing techniques remain the smoking and salting drying. Congolese women are represented by 80 % of total number of marine processors. Recently, the number of women processing landing fishes have been estimated at 800 women.

i.1.3 Technical and organizational implementation of production tools

The motorized boats used for the artisanal fishing have an average length of 14 meters to 1.5 meters wide and a depth of 0.80 cm. The engine is made using Yamaha outboard motor enduro Ch 40. The total number of boats registered in industrial fisheries has increased from 16 in 1987 to 13 in 1990 to increase again to 18 in 1992. From 2005 to 2012 the industrial fleet was multiplied "by 3. This is mainly due to the arrival of Asian ship-owners, particularly China in 2008.

In early 2012, 95 vessels were distributed as follows:

• 8 purse seiners

• 12 freezer trawlers

• 74 wet trawlers

• 4 carriers

Chinese type vessels are built in the Congo by Chinese carpenters two shipyards located at the mouth of Kouilou and belong to the Chinese arms that operate in the waters of the Congo; Shipyards Jinri fishing and Rong Chang. Currently, the construction of new vessels is prohibited.

i.2 Industrial fishing

i.2.1 Industrial fishing gear used to catch sardinella

The purse seines are used in Congolese marine water to catch sardinella. The reason is that only the purse seine can be used to regulate fishing, if catches are too great, it is possible to release the fish without destroying the surplus, which the trawl does not allow. The fishing gear and equipment operating in the industrial fishery are exported from Europe and China.

i.2.2 Industrial fish processing companies

There are two companies, Agimex and Ets Guenin which buy fish for freeze. However, the ship equipped with freezer also has ground freezing rooms. Processing conditions have improved since there is electricity available at port before the plant treated with a generator.

The statistical quantities of sardines processed by freezing plants do not exist but it is known that Agimex and Ets Guenin processed 10,000 to 12,000 tonnes of product in 2012; which also imported the product from Mauritania, Angola, Namibia and South Africa.

The evacuation of fishery products to major markets depends on the accessibility of rail and roads. Marketing is handled by domestic and foreign private operators with limited financial means with inappropriate transportation. There are no data available and updated information on this activity.

III. Theoretical approaches of single species and multiple fishing gears

3.1 Data collected

Available data on the shared sardinella fisheries of the Southern Gulf of Guinea have been provided by National Department of Fisheries of Congo and Angola. The data used for estimating standardized effort and the surplus production models are obtained from the Annual Fisheries Statistics Department. These data were m
ainly gathered in the “Report of the FAO/CECAF (2009) and the Fisheries Management Plan for shared sardinella stocks of the Southern Gulf of Guinea (ACPFish II, 2013).

Data on cost per standard ship number are not available in the Annual Fisheries Statistic, but they can be obtained and adapted from studies by various authors such as socio-economic report (2013) of Africa Caribbean Pacific Fish II Project (ACPFish II), Fish Book of the Guinea Current Large Ecosystem Marine (GCLME), etc.

Fishing costs comprise operating, fixed labor and opportunity costs. Opportunity costs include expenses on fuel, ice, food and maintenance of ships and gears. Items such as license fees include in the fixed costs. Producer price of sardinella fish is used in this study since it is the price directly received by fishers. The abundance of sardinella in the area is linked to the upwelling periods and they are exploited by both the artisanal and industrial fleets in Angola and Congo.

In order to analyze the bio-economics model for sardinella species, twenty one (21) years catch-effort data from 1992 up to 2012 were used. Fishing effort used in this analysis is number of fishing ships (Tab. 1).

Table 1. Trend of sardinella catch (MT) and fishing effort (number of vessel) from 1992 to 2012. Art: Artisanal, PS: Purse seine and PT: Pelagic trawl.

Year	Angola						Congo			
	Production, MT			Effort, vessel			Production, MT		Effort, vessel	
	Art	PS	PT	Art	PS	PT	Art	PS	Art	PS
1992	6,405	12,810	11,285	1,136	21	17	4,687	6,610	147	5
1993	6,720	13,440	11,840	1,138	20	17	5,087	6,754	141	5
1994	12,600	25,200	22,200	1,134	21	17	5,952	5,814	152	4
1995	12,470	24,941	21,972	1,132	21	17	2,279	1,378	158	5
1996	11,942	23,884	21,041	1,183	21	17	2,903	1,888	178	5
1997	7,238	14,477	12,753	1,209	21	17	3,533	485	175	4
1998	2,534	5,069	4,465	1,234	21	17	5,258	2,636	181	5
1999	4,340	8,680	7,647	1,242	28	8	4,035	4,119	194	6
2000	1,802	3,605	3,176	1,149	25	10	3,431	1,209	227	5
2001	1,541	3,082	2,715	1,271	26	13	2,973	1,212	248	3
2002	2,033	4,067	3,583	1,088	23	22	4,115	2,179	256	4
2003	4,674	9,348	8,235	1,099	21	21	4,852	2,330	180	4
2004	632	1,264	1,114	1,192	19	21	5,559	2,235	180	3
2005	1,089	2,179	1,919	1,503	31	21	6,357	3,283	180	2
2006	2,161	4,323	3,808	1,510	26	21	5,853	2,447	217	2
2007	2,447	4,894	4,312	1,479	24	21	5,863	2,907	254	3
2008	15,841	31,682	27,910	1,445	26	21	5,608	4,206	360	3
2009	16,170	32,340	28,490	1,506	25	21	7,345	4,602	264	4
2010	10,710	21,420	18,870	1,565	25	21	8,641	8,042	264	7
2011	6,300	12,600	11,100	1,424	25	21	8,695	10,958	253	6
2012	8,505	17,010	14,985	1,444	25	21	8,752	14,636	218	8

3.2 Methodology

Fisheries bio-economists are largely concerned with relationship between the level of fishing effort expended in the fishery and the resultant level of catch. These determine the costs and benefits of fishing respectively and hence the level of economic rent for fishers. As fisheries are dynamic systems, changes in catch levels can affect the population size of the stock. This in turn affects subsequent catch rates. Therefore, fisheries managers are often interested in determining sustainable catch levels. The catch is sustainable only if it is equal to the natural growth in the fish population. By removing the natural growth through fishing, the population remains at the same level, and is said to be in equilibrium. Hence, the same level of catch can be taken year after year without any effect on the stock.

The Surplus Production Models (SPMs) provide an indication of the long run sustainable yield at given levels of fishing effort in the common fish stock assessment. By surplus production, it is meant that the growth in the fish stock is surplus to that required to keep the population at the same level. That is, the difference between the level of recruitment to the fishery and the level of natural mortality. In the absence of fishing, it would be expected that the rate of growth in a population would be zero, as the population would be limited by the natural carrying capacity of the environment. Above this level, there would be insufficient food to support the population.

Hence, it would return to the size that could be supported by its habitat through increased mortality. As the population size is decreased, the relative abundance of food enables the population to grow at a greater rate than natural mortality. In the absence of fishing, the population would grow until the carrying capacity was again reached (Pascoe, 1995).

3.2.1 Standardization of fishing effort

Sardinella fish species of Southern Gulf of Guinea are caught by artisanal, purse seine and pelagic trawl (FAO/CECAF, 2009). Since units of fishing effort for these gear types differ, the units need to be standardized. The general model of catch per unit effort (CPUE) is:

$$C\hat{P}UE = CPUE_r \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon} \quad (1)$$

where $CPUE_r$ is the reference $CPUE$ at one level of each of the factors. Subscript I refers to the factors, and subscript j refers to the levels of each factor. P_{ij} represents the relative fishing power for the j^{th} level of the i^{th} factor. For the reference level of each factor, P_{ij} is set to 1. A superscript dummy variable X_{ij} is equal to 1 when a datum refers to the j^{th} level of the i^{th} factor and 0 otherwise. ε is a normal random variable with mean 0 and constant variance σ^2. A natural logarithmic transformation of equation (1) results in a GLM [1]

$$\ln \hat{CPUE} = \ln CPUE_r + \sum_i \sum_j X_{ij} \ln P_{ij} + \varepsilon \quad (2)$$

or

$$Y = \beta_0 + \sum_k \beta_k X_k + \varepsilon, \quad \{k\} = \{i\} \cup \{j\} \quad (3)$$

[1] GLM considers consistency in trends over various combinations of factors. Another use of the GLM is in forecasting missing values of CPUE for some combination of factors. The missing data can be estimated from the predictive equation. For the GLM model, see Gavaris (1980) and Quinn & Deriso (1999) cited in Jongoh Nam (2009).

where the subscript k subsumes i and j. The Y- intercept β_0 is the reference natural log CPUE, and the parameters { β_k } are natural logarithms of the power coefficients (Lee 1991, Quinn and Deriso 1999, Seo and Zhang 2001).

The standardized natural log CPUE ($\ln \hat{CPUE}$) can be estimated by explanatory variables:

ln $CPUE$ *and* X_{ij}. The standardized $\hat{CPUE}$ can be estimated by exponentiating the $\ln \hat{CPUE}$.

A standardized fishing effort ($\hat{E}_{art}$ or $\hat{E}_{ps}$ or $\hat{E}_{pt}$) of sardinella caught by each gear can be calculated by the equation (4):

$$C_{T_t} = C_{art} + C_{ps} + C_{pt}, \quad \hat{E}_{T_t} = \hat{E}_{art_t} + \hat{E}_{ps_t} + \hat{E}_{pt_t}$$

$$\hat{CPUE}_{T_t} = \hat{CPUE}_{art_t} + \hat{CPUE}_{ps_t} + \hat{CPUE}_{pt_t};$$

$$\hat{E}_{art_t} = \frac{C_{art_t}}{\hat{CPUE}_{art_t}}, \hat{E}_{ps_t} = \frac{C_{ps_t}}{\hat{CPUE}_{ps_t}} \; and \; \hat{E}_{pt_t} = \frac{C_{pt_t}}{\hat{CPUE}_{pt_t}} \qquad (4)$$

where C_{Tt} is total annual catch of sardinella caught by artisanal, purse seine and pelagic trawl. C_{art_t} , C_{ps_t} and C_{pt_t} are annual catch of sardinella by artisanal, purse seine and pelagic trawl respectively. $\hat{E}_{T_t}$ is total annual standardized fishing effort summed across annual standardized fishing effort ($\hat{E}_{art_t}$, $\hat{E}_{ps_t}$ and $\hat{E}_{pt_t}$) of the three gears. $\hat{E}_{art_t}$, $\hat{E}_{ps_t}$ and $\hat{E}_{pt_t}$ are annual standardized fishing effort of sardinella caught by artisanal, purse seine and pelagic trawl respectively. $C\hat{PUE}_{T_t}$ is total annual standardized *CPUE* of sardinella caught by the three gear types. $C\hat{PUE}_{art_t}$, $C\hat{PUE}_{ps_t}$ and $C\hat{PUE}_{pt_t}$ are the annual standardized *CPUE* for sardinella caught by artisanal, purse seine and pelagic trawl respectively. For all variables, the subscript *t* refers to the annual single data. Given C_{Tt} and $\hat{E}_{T_t}$, the *MSY* level of sardinella yield curve can be estimated by a surplus production model. Here, whether we use the Fox, Schaefer or CYP model, the results are determined by the empirical relationship between $\hat{E}_{T_t}$ and $C\hat{PUE}_{T_t}$. The *MSY* of the single species and three fishing gears case can be allocated as MSY_{art}, MSY_{ps} and MSY_{pt} by equation (5).

$$MSY_{art} = C_{MSY_{art}} = C_{MSY}\left(\frac{\hat{E}_{art}}{\hat{E}_{ps} + \hat{E}_{pt} + \hat{E}_{art}}\right),$$

$$MSY_{ps} = C_{MSY_{ps}} = C_{MSY}\left(\frac{\hat{E}_{ps}}{\hat{E}_{art} + \hat{E}_{pt} + \hat{E}_{ps}}\right) \text{ and}$$

$$MSY_{pt} = C_{MSY_{pt}} = C_{MSY}\left(\frac{\hat{E}_{pt}}{\hat{E}_{art} + \hat{E}_{ps} + \hat{E}_{pt}}\right) \tag{5}$$

where $\frac{\hat{E}_{art}}{\hat{E}_{ps} + \hat{E}_{pt} + \hat{E}_{art}}$, $\frac{\hat{E}_{ps}}{\hat{E}_{art} + \hat{E}_{pt} + \hat{E}_{ps}}$, $\frac{\hat{E}_{pt}}{\hat{E}_{art} + \hat{E}_{ps} + \hat{E}_{pt}}$ are the rates of standardized fishing efforts for each gear type. C_{MSYart}, C_{MSYps}, C_{MSYpt} represent the harvest at *MSY level* of sardinella caught by each gear type when aggregate MSY is partitioned based on past effort and catch data (Lee 1991, Seo and Zhang 2001).

3.2.2 Clarke, Yoshimoto, and Pooley Model (CYP) (1992): MSY Estimation

1. CYP yield curve induced by Gompertz growth function

The Clarke, Yoshimoto, and Pooley (1992) developed an integrated version of the Fox model along similar lines as employed by Schnute (1977) when developing the integrated version of the logistic model. The CYP yield (asymmetric) curve based on the Gompertz growth function has been used as an alternative to the Schaefer (symmetric) curve based on the logistic growth function (Fox 1970). The CYP yield curve can be expressed by the Gompertz growth function:

$$C_t = qkE_t e^{-(q/r)E_t} \tag{6}$$

where C_t is the annual sustainable yield of sardinella caught by the three gear types at year t. $CPUE_\infty$ is the initial CPUE that would occur if the stock were at an unexploited level ($CPUE_\infty = q \cdot k$). *k* is the carrying capacity of the environment. *q* is the catchability coefficient and *r* is the intrinsic growth rate.

2. *Clarke, Yoshimoto, and Pooley (CYP) Method*

The CYP equation is given as follows:

$$\frac{1}{U}\frac{dU}{dt} = r\ln(qk) - r\ln(U) - qE \tag{7}$$

Which can be integrated over a year to produce

$$\ln\left[\frac{U_{t+1}}{U_t}\right] = r\ln(qk) - r\ln(\overline{U}) - q\overline{E} \tag{8}$$

Following the same procedure as used by Schnute, an approximation for equation (8) is derived by adding equation (8) for time t to itself for time t+1. Assuming the approximation given in equation

$$\overline{U_t} \cong \sqrt{U_t U_{t+1}} \tag{9}$$

the resulting equation can be specified as follows:

$$\ln\left(\overline{U}_{t+1}\right) - \ln\left(\overline{U_t}\right) = 2r\ln\left(qk\right) - r\left(\ln\left(\overline{U}_t\right) + \ln\left(\overline{U}_{t+1}\right)\right) - q\left(\overline{E}_t + \overline{E}_{t+1}\right)$$

(10)

Solving this algebraically for $\ln\left(\overline{U}_{t+1}\right)$ gives

$$\ln(\overline{U}_{t+1}) = \frac{2r}{2+r}\ln\left(qk\right) + \frac{2-r}{2+r}\ln\left(\overline{U}_t\right) - \frac{q}{2+r}\left(\overline{E}_t + \overline{E}_{t+1}\right) \tag{11}$$

3. MSY Estimation

The E_{MSY} that maximizes yield in equation (6) can be given by the first order condition:

$$\begin{aligned}\frac{\partial C_t}{\partial \hat{E}_t} &= \frac{\partial\left(qkE_t e^{-(q/r)E_t}\right)}{\partial \hat{E}_t} = 0 \\ &= -\frac{q}{r} qke^{-(q/r)E_t} E_t + qke^{-(q/r)E_t}\end{aligned} \tag{12}$$

Dividing both sides of equation (12) by $\frac{q}{r} CPUE_{\infty} \exp(-\frac{q}{r} \hat{E}_{T_t})$ and solving the resulting equation for $\hat{E}_{T_t}$ gives:

$$\hat{E}_{T_t} = E_{MSY} = \frac{r}{q}. \tag{13}$$

By substituting E_{MSY} for $\hat{E}_{T_t}$ in equation (6), *MSY* can be estimated by equation (10):

$$C_e = MSY = C_{MSY} = qkE_{MSY} e^{-(q/r)E_{MSY}} \tag{14}$$

3.2.3 CYP Bioeconomic Model: Maximum Economic Yield (MEY)

1. MEY Estimation

To estimate MEY, we firstly need to generate net revenue (NR). The NR can be estimated by subtracting total cost (TC) from total revenue (TR). NR is:

$$NR \;\; (or \quad \pi) = TR - TC = pC - TC = pqke^{-(q/r)E} - amE \tag{15}$$

where *NR* is the annual net revenue, *p* is the weighted average producer price of sardinella harvested by the three gear types for six recent years ($/kg) and *C* is the annual sustainable yield. *TC* is estimated by weighted unit cost multiplied by number of vessel. a is the weighted average unit cost ($/vessel) of the three gear types.[2] *m* is the annual average rate of sardinella

[2] The *a* is the weighted average unit cost for the recent 6 years of sadinella caught by each fishing gear when the base year 2010 is normalized to be 100. Also, to estimate the weighted *a*, we use several data such as the total cost per ship, effort ratio of sadinella caught by each gear, and the producer price index. The weighted average unit cost (*a*) = annual total cost per ship ($/ship) × effort ratio of sadinella caught by each gear × producer price index. The producer price index is based on the Food Production Index of Angola and Congo estimatd by the World Bank over 21 years (1992-2012).

landed value caught by each gear type.[3] TR is estimated by p multiplied by catch in equation (6). Weighted price and weighted unit cost are obtained by multiplying their original values with catch and fishing effort rates respectively. The level of effort (E_{MEY}) that produces MEY can be both found by using the first order condition for profit maximization:

$$\frac{\partial NR_t}{\partial \hat{E}_T} = \frac{\partial\left(pqke^{-(q/r)E_t} - amE_t\right)}{\partial \hat{E}_T} = 0$$

$$= -\left(\frac{q}{r}\right)E_t\, pqke^{-(q/r)E_t} + pqke^{-(q/r)E_t} - am. \qquad (16)$$

Unlike the E_{MEY} equation of the Gordon-Schaefer model and E_{MEY} of the Fox model cannot be easily expressed in closed form. At best, the relation can be expressed as follows:

$$E_{MEY} = \frac{r}{q}\left[1 - \frac{am}{pqk}e^{-(q/r)E_{MEY}}\right] \qquad (17)$$

[3] m can be estimated by dividing total landed values of all species caught by a chosen gear type to total landed values of sardinella caught by the gear type. The reason for using sardinella production is so that one needs only the fishing cost of sardinella caught by the chosen gear type. In particular, since the production has a positive relationship between landed value and fishing labor charge, the rate of sardinella landed value was used as an alternative measure of fishing cost.

$$C_{MEY} = qkE_{MEY}e^{-(q/r)E_{MEY}} \ . \tag{18}$$

2. *NR estimation at the level of MSY*

The Net revenue ($\pi = NR$) at the level of MSY by nation can be estimated by the following equations.

$$\pi_A = NR_A = NR_{Art.A} + NR_{Ps.A} + NR_{Pt.A}$$

$$\pi_C = NR_C = NR_{Art.C} + NR_{Ps.C}$$

Where NR_A (π_A) and NR_C (π_C) are net revenue of Angola and Congo respectively.

$NR_{Art.A}, NR_{Pt.A}$ and $NR_{Pt.A}$ represent net revenue of artisanal, purse seine and pelagic trawl for Angola, and $NR_{Art.C}$ and $NR_{Ps.C}$ represent net revenue of artisanal and purse seine for Congo.

TR at the level of MSY can be estimated by equation

$$TR_A = TR_{Art.A} + TR_{Ps.A} + TR_{Pt.A} \text{ and } TR_C = TR_{Art.C} + TR_{Ps.C} \qquad (19.1\ \&\ 19.2)$$

where TR_A and TR_C are the total revenue of sardinella caught in Angola and Congo by gear types at the level of MSY. p_A and p_C are the annual average producer prices of sardinella caught in both countries and C_{AMSY} and C_{CMSY} are the harvest of sardinella caught by gear types in Angola and Congo. TC is the annual total cost at MSY level of sardinella caught by each gear in Angola and Congo respectively. Total cost (TC_A & TC_C) can be estimated by a , m and the annual number of vessels E_t at MSY.

$$TC_A = TC_{Art.A} + TC_{Ps.A} + TC_{Pt.A} \text{ and } TC_C = TC_{Art.C} + TC_{Ps.C} \qquad (20.1\ \&\ 20.2)$$

Therefore, based on equation (15), the net revenue of each gear type by nation is calculated as follows :

$$NR_{Art.A} = TR_{Art.A} - TC_{Art.A} = p_{Art.A} C_{AMSY} \left[\frac{E_{Art.A}}{\sum_{i=1}^{3} E_i} \right] - a_{Art.A} m_{Art.A} E_{Art.A}$$

$$NR_{Ps.A} = TR_{Ps.A} - TC_{Ps.A} = p_{Ps.A} C_{AMSY} \left[\frac{E_{Ps.A}}{\sum_{i=1}^{3} E_i} \right] - a_{Ps.A} m_{Ps.A} E_{Ps.A}$$

$$NR_{Pt.A} = TR_{Pt.A} - TC_{Pt.A} = p_{Pt.A} C_{AMSY} \left[\frac{E_{Pt.A}}{\sum_{i=1}^{3} E_i} \right] - a_{Pt.A} m_{Pt.A} E_{Pt.A}$$

$$NR_{Art.C} = TR_{Art.C} - TC_{Art.C} = p_{Art.C} C_{CMSY} \left[\frac{E_{Art.C}}{\sum_{i=1}^{2} E_i} \right] - a_{Art.C} m_{Art.C} E_{Art.C}$$

$$NR_{Ps.C} = TR_{Ps.C} - TC_{Ps.C} = p_{Ps.C} C_{CMSY} \left[\frac{E_{Ps.C}}{\sum_{i=1}^{2} E_i} \right] - a_{Ps.C} m_{Ps.C} E_{Ps.C}$$

3.2.4 Allocation rule

1. *Catch rate by nation*

Catch and fishing effort time-series data of Angola and Congo were used to compute total catch and total fishing effort of artisanal, purse seine and pelagic trawl. Therefore, catch rate of each nation is produced by dividing sardinella catch of nation with total sardinella catches of both nations based on average of recent six years.

Thus, Catch rate = sardinella catch of one nation / total sardinella catches of both nations.

2. *Effort rate by fishery*

Number of vessel is used in this study as effort to assess trends in fishing effort against which variations in catches can be compared. Sum of three different gear effort's values gives the total fishing effort. Effort rate of each sardinella fishery is producing by dividing efforts of one gear with total fishing efforts of all gears based on average of recent six years.

3. *Area based catch level*

The sardinella stock being transboundary, it is assumed to be homogeneously distributed in the Southern Gulf of Guinea that straddles the EEZ's borders of Angola and Congo. That is, sufficient mixing occurs such that fishing mortality on one side of the border affects the stock size on both sides of the borders. In addition, catch and effort rates are assumed to be constant over time. In this case, let the total catch (C) summed by fishing gear in a period be represented by:

$$C = \sum_{i=1}^{n} c_i \qquad n = 1, 2, 3 \tag{22}$$

where c_i is catch or harvest by the fishing gears used in Angola and Congo, n is fishing gear types. Furthermore, fish stock depends on the species population density within a specific area, and the catch rate (*Cr*) by area can be obtained as follows:

$$C_{rA} = \frac{\sum_{i=1}^{3} c_{iA}}{EEZ_A} \quad \text{and} \quad C_{rC} = \frac{\sum_{i=1}^{2} c_{ic}}{EEZ_C} \tag{23.1 \& 23.2}$$

where c_i and $EEZ_{A\&C}$ are catches or harvests and area of Angola and Congo respectively. The reason for using area based catch level is that we need to consider appropriate catch allocation by nation depending on catch level per area such as hectare to protect transboundary sardinella species across both nations.

IV. Results and discussions

4.1 Data analysis

Sardinella is selected as a target species because it has a commercial value and is heavily exploited. It is caught by artisanal using generally gillnet, purse seine, and pelagic trawl gear types. The main fishing zones of the artisanal, purse seine, and pelagic trawl gears associated with sardinella are the Southern area of the Gulf of Guinea (Troadec and Garcia, 1980).

4.1.1 Catches and catch rate of sardinella and target gear types

Catches and catch rate of sardinella by gear type for the 21-year period (1992~2012) are based on Congolese (DPM) and Angolan (INIP) fisheries statistic Department. It is important to note that the average catch rate of artisanal in Angola (57.9 %) is higher than that of artisanal in Congo (42.1 %). Same trends has been observed for purse seine in Angola (71.2 %) and (28.8 %) in Congo as shown in Table 2. The catch rate values of sardinella are averages of six recent years. Catch rate of sardinella by pelagic trawl gear type is not taken into consideration for comparison for our study, because Congo does not report about sardinella pelagic trawl's catch. From 1992 to 1997, the Angolan artisanal fishery had very high catch rates than Congolese one. After that period, reversed trend occurred (decreasing) ; where congolese catch rates were continuously higher up to 2007. Angolan catch rates restarted to increase in year-range of 2008-2012.

Angolan purse seine fishery showed high catch rates year-range than Congolese one during all the period of study (1992-2012) except in years 2008 and 2009 where lower values had been observed. An argument for that high catch rates either in Angola or in Congo would have been due to very good recruitment. Fontana and Pianet (1973) in their study on 'Biology of sardinella of Congo and Gabon found that the high gonadosomatic index may have given rise to exceptional recruitment of sardinella species during year-range of 1968-1972).

Table 2. Catch and catch rate of sardinella caught by each gear type (1992~2012) (Unit: MT and %)

Year	Artisanal				Purse seine			
	Catch	Catch rate	Catch	Catch rate	Catch	Catch rate	Catch	Catch rate
1992	6405	0.577	4687	0.423	12810	0.66	6610	0.34
1993	6720	0.569	5087	0.431	13440	0.67	6754	0.33
1994	12600	0.679	5952	0.321	25200	0.81	5814	0.19
1995	12470	0.845	2279	0.155	24941	0.95	1378	0.05
1996	11942	0.804	2903	0.196	23884	0.93	1888	0.07
1997	7238	0.672	3533	0.328	14477	0.97	485	0.03
1998	2534	0.325	5258	0.675	5069	0.66	2636	0.34
1999	4340	0.518	4035	0.482	8680	0.68	4119	0.32
2000	1802	0.344	3431	0.656	3605	0.75	1209	0.25
2001	1541	0.341	2973	0.659	3082	0.72	1212	0.28
2002	2033	0.331	4115	0.669	4067	0.65	2179	0.35
2003	4674	0.491	4852	0.509	9348	0.8	2330	0.2
2004	632	0.102	5559	0.898	1264	0.36	2235	0.64
2005	1089	0.146	6357	0.854	2179	0.4	3283	0.6
2006	2161	0.27	5853	0.73	4323	0.64	2447	0.36
2007	2447	0.294	5863	0.706	4894	0.63	2907	0.37
2008	15841	0.739	5608	0.261	31682	0.88	4206	0.12
2009	16170	0.688	7345	0.312	32340	0.88	4602	0.13
2010	10710	0.553	8641	0.447	21420	0.73	8042	0.27
2011	6300	0.42	8695	0.58	12600	0.54	10958	0.47
2012	8505	0.493	8752	0.507	17010	0.54	14636	0.46
	Average	0.579		0.421		0.71		0.29

Source: Congo: Directorate of Marine Fisheries, 2013.

Angola: National Institute of Fisheries Investigation.

4.1.2 Economic parameters estimates for sardinella

The necessary data information to estimate economic parameters are shown in Table 3a &b. As economic parameters, we consider the fishing cost per vessel, producer sale price of sardinella, the unit cost and the rate of sardinella landed values of each gear type. Fishing cost per vessel and unit cost are six recent years average values expressed in terms of year 2010 value[4] (Tab. 4).

[4] The annual fishing cost per ship represents the weighted average fishing cost per ship. It is expressed as the year 2010 value of the annual fishing cost per ship when the base year 2010 is normalized to be 100.

Table 3a. Angola total vessels (TV), fishing cost, producer price for target species and gear types, and R(landed value rate in %).

Year	Angola														
	Artisanal					Purse seine					Pelagic trawl				
	TV	Fishing cost per ship (10^6 \$)	Price (\$)	Unit cost (10^3\$)	R (%)	TV	Fishing cost per ship (10^6 \$)	Price (\$)	Unit cost (10^3\$)	R (%)	TV	Fishing cost per ship (10^6 \$)	Price (\$)	Unit cost (10^3\$)	R (%)
1992	1,136	15.3	0.05	13.5	0.03	21	0.92	0.07	43.7	0.04	17	0.74	0.07	43.7	0.051
1993	1,138	15.4	0.05	13.5	0.03	20	0.88	0.08	43.8	0.04	17	0.74	0.08	43.8	0.053
1994	1,134	17.4	0.07	15.3	0.08	21	1.04	0.1	49.6	0.08	17	0.84	0.1	49.6	0.113
1995	1,132	16.8	0.07	14.9	0.08	21	1.01	0.1	48.1	0.09	17	0.82	0.1	48.1	0.118
1996	1,183	18.7	0.08	15.8	0.08	21	1.08	0.11	51.3	0.09	17	0.87	0.11	51.3	0.12
1997	1,209	19.2	0.1	15.9	0.06	21	1.08	0.11	51.6	0.05	17	0.88	0.11	51.6	0.073
1998	1,234	22.6	0.13	18.3	0.02	21	1.25	0.15	59.4	0.02	17	1.01	0.15	59.4	0.03
1999	1,242	21.6	0.11	17.4	0.04	28	1.58	0.14	56.4	0.04	8	0.45	0.14	56.4	0.048
2000	1,149	23.2	0.15	20.2	0.02	25	1.64	0.18	65.4	0.02	10	0.65	0.18	65.4	0.023
2001	1,271	29.3	0.2	23.1	0.02	26	1.95	0.27	74.8	0.02	13	0.97	0.27	74.8	0.026
2002	1,088	28.6	0.26	26.3	0.03	23	1.96	0.36	85.2	0.03	22	1.87	0.36	85.2	0.039
2003	1,099	31.2	0.33	28.4	0.07	21	1.93	0.41	91.9	0.07	21	1.93	0.41	91.9	0.097
2004	1,192	36.3	0.38	30.4	0.01	19	1.87	0.48	98.6	0.01	21	2.04	0.48	97.2	0.014
2005	1,503	50.1	0.46	33.4	0.02	31	3.35	0.61	108.1	0.02	21	2.21	0.61	105	0.028
2006	1,510	51.2	0.47	33.9	0.04	26	2.86	0.63	109.8	0.04	21	2.24	0.63	106.7	0.057
2007	1,479	56.5	0.6	38.2	0.05	24	2.97	0.8	123.8	0.05	21	2.6	0.8	123.8	0.073
2008	1,445	58.5	0.67	40.5	0.34	26	3.41	0.9	131.1	0.37	21	2.56	0.9	121.7	0.501
2009	1,506	77.2	1.08	51.3	0.45	25	4.16	1.44	166.2	0.48	21	3.29	1.44	156.7	0.649
2010	1,565	84.5	1.2	54	0.31	25	4.38	1.6	175	0.33	21	3.52	1.6	167.5	0.453
2011	1,424	84.5	1.45	59.4	0.2	25	4.81	1.93	192.4	0.22	21	3.92	1.93	186.9	0.293
2012	1,444	70.6	0.98	48.9	0.22	25	3.96	1.31	158.4	0.24	21	3.28	1.31	156.2	0.325

Source: ACPFish II, 2013 and GCLME (Fish Book), 2013.

Table 3b. Congo total vessels (TV), fishing cost, producer price for target species and gear types, and R(%) (landed value rate).

Year	Congo									
	Artisanal					Purse seine				
	TV	Fishing cost per ship (103 $)	Price ($)	Unit cost ($)	R (%)	TV	Fishing cost per ship (103 $)	Price ($)	Unit cost ($)	R (%)
1992	147	6,878	0.196	46787	0.108	5	557	0.32	111400	0.23
1993	141	6,738	0.205	47789	0.12	5	569	0.33	113780	0.24
1994	152	7,713	0.231	50747	0.149	4	483	0.38	120825	0.22
1995	158	8,670	0.27	54876	0.062	5	653	0.44	130660	0.06
1996	178	10,130	0.399	56908	0.112	5	677	0.47	135500	0.08
1997	175	10,038	0.405	57362	0.138	4	546	0.37	136575	0.02
1998	181	10,358	0.403	57229	0.204	5	681	0.51	136260	0.12
1999	194	11,878	0.462	61227	0.168	6	875	0.59	145783	0.2
2000	227	14,145	0.478	62313	0.145	5	742	0.65	148360	0.06
2001	248	15,620	0.489	62984	0.127	3	450	0.67	149967	0.07
2002	256	16,668	0.522	65111	0.182	4	620	0.71	155025	0.12
2003	180	11,880	0.585	65999	0.237	4	629	0.78	157150	0.14
2004	180	12,747	0.674	70818	0.291	3	506	0.9	168600	0.14
2005	180	13,615	0.769	75638	0.356	2	360	1.03	180100	0.23
2006	217	17,307	0.855	79758	0.346	2	380	1.14	189900	0.18
2007	254	21,063	0.924	82924	0.36	3	592	1.23	197433	0.22
2008	360	31,567	1.033	87687	0.364	3	626	1.46	208767	0.36
2009	264	24,080	1.118	91211	0.496	4	869	1.58	217175	0.4
2010	264	24,948	1.2	94500	0.605	7	1575	1.7	225000	0.73
2011	253	24,384	1.248	96381	0.62	6	1377	1.77	229483	1.02
2012	218	21,761	1.339	99820	0.647	8	1901	1.9	237663	1.41

Source: ACPFish II, Socio-economic Report, 2013.

GCLME, Fish Book, 2012.

Table 4. Economic parameters' estimates of sardinella caught by artisanal, purse seine and pelagic trawl.

Gears	Effort (ship)	p Producer price($/kg)	a Unit cost ($/ship)	Weighted p Producer price($/kg)	Weighted a Unit cost ($/ship)
Artisanal	1,746	1.07	30,092	0.35	29,018
Purse seine	30	1.47	97,865	0.61	2,119
Pelagic trawler	21	1.33	58,118	0.35	816
Average (recent 6 years)		1.29	62,025	0.43	10,651

4.2 Analysis of results

4.2.1 Standardized fishing effort

This analysis is undertaken only with respect to two factors (year and gear) with 21 levels (1992~2012) of the year factor and three levels (artisanal, purse seine and pelagic trawl) of the gear factor. The year variable is a qualitative one and indicates that all years are not the same. This may be indicative of the many other determinants that are omitted from a lumped parameter model. From a scientific perspective, their omission and replacement with qualitative variables is undesirable but reflects the status quo of data availability. For convenience, the reference CPUE is based on year 1992 data and the pelagic trawl gear type.

The General Linear Method (GLM) run by the equation (3) fits the data well, with an R^2 of 0.983 and an F-statistic of 110.738 with 21 observations and 20 degrees of freedom ($p<0.05$). Table 5 provides estimates of β coefficients, statistics, p-value and estimates of the relative fishing power coefficients associated with the GLM regression (Tab. 5). Eleven years are highly significant. Years 1995, 1996, 2003 and 2008 are significants within ($p<0.1$). Estimates of years 1993, 1997, 1999, 2010, 2011 and 2012 are not significant within both ($p<0.05$ and $p<0.1$).

Estimates of the relative fishing power coefficients can be calculated by exponentiating the estimates of β coefficients. The reference CPUE of the pelagic trawl obtained from the intercept is 639,198.29. The CPUE differs somewhat from that of the reference year 1992 in all years. This difference could be due to unequal catchability using each of the three gear types. This implies that fishing effort of the three gear types needs to be standardized in the GLM (Quinn and Deriso, 1999).

Table 5. Coefficients' estimates and statistic outputs

Factor level	Coefficient	Est.	Std. Error	t-Statistic	Prob.	Pij
ln (U)	β_0	13.36797	0.203105	65.81803	0.000	639,198
1993	β_1	0.063966	0.274461	0.23306	0.817	1.07
1994	β_2	0.565341	0.274461	2.059821	0.046	1.76
1995	β_3	0.416625	0.274461	1.517971	0.137	1.52
1996	β_4	0.379467	0.274461	1.382589	0.175	1.46
1997	β_5	-0.06811	0.274461	-0.24816	0.805	0.93
1998	β_6	-0.76754	0.274461	-2.79654	0.008	0.46
1999	β_7	-0.23808	0.274461	-0.86743	0.391	0.79
2000	β_8	-1.03214	0.274461	-3.76059	0.001	0.36
2001	β_9	-1.28089	0.274461	-4.66693	0.000	0.28
2002	β_{10}	-1.07123	0.274461	-3.90302	0.000	0.34
2003	β_{11}	-0.38157	0.274461	-1.39026	0.172	0.68
2004	β_{12}	-1.57469	0.274461	-5.73736	0.000	0.21
2005	β_{13}	-1.3866	0.274461	-5.05208	0.000	0.25
2006	β_{14}	-1.0159	0.274461	-3.70141	0.001	0.36
2007	β_{15}	-0.90421	0.274461	-3.2945	0.002	0.40
2008	β_{16}	0.505744	0.274461	1.842678	0.073	1.66
2009	β_{17}	0.559423	0.274461	2.038258	0.048	1.75
2010	β_{18}	0.237977	0.274461	0.86707	0.391	1.27
2011	β_{19}	-0.05893	0.274461	-0.21471	0.831	0.94
2012	β_{20}	0.16845	0.274461	0.613749	0.543	1.18
d1	β_{21}	-4.16116	0.103737	-40.1127	0.000	0.02
d2	β_{22}	0.051466	0.103737	0.496118	0.623	1.05

Note: factors considered are year (1992~2012) and gear (1, 2, 3). p-value: 95% significant level ($p<0.05$).

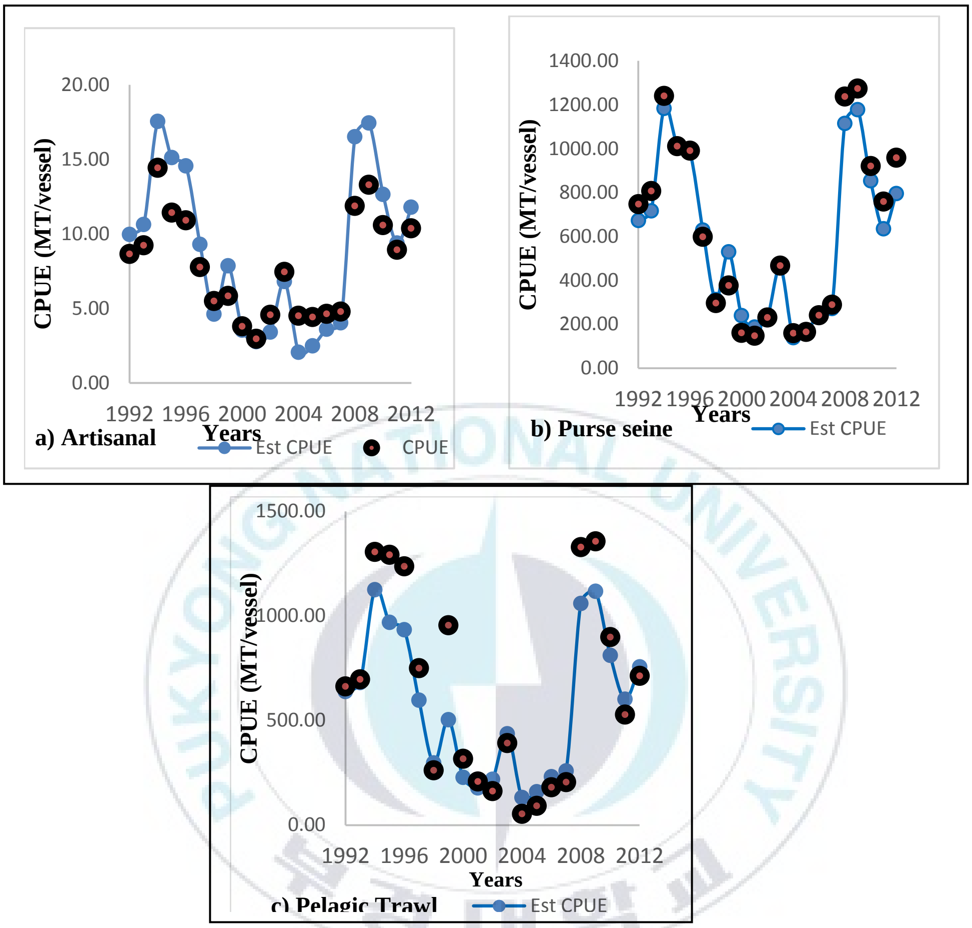

Figure 7. Observed and estimated CPUE of sardinella as function of year and gear type (1992~2012).

The good fit of the model between both the observed actual CPUE and the standardized CPUE over 21 years, with the exception of actual CPUE in 1994, 1995, 1996, 1998, 2008 and 2009 for the pelagic trawl (Fig. 7). A reason for the relatively high increase in CPUE for the pelagic trawl during the above mentioned years could be the rate or the proportion for artisanal fishing effort being 96.4%, much greater than purse seine and pelagic trawl fishing efforts, 2.16% and 1.40% could affect estimated standard CPUE of purse seine and pelagic trawl fishing gears. However, the trend of estimated standard CPUE is almost similar or close to real CPUE based on very high R^2 of 0.983.

From the observed actual catch and standardized $CP\hat{U}E_{T_t}$ yielded by the GLM, we obtain the standardized $\hat{E}_{T_t}$ of sardinella caught by the three gear types as shown in Table 6a & b.

Table 6a: The observed actual data and estimates of GLM (1992~2012)

Year	Observed data								
	Production, MT			Effort, ship			CPUE (ship)-Kg		
	Art	PS	PT	Art	PS	PT	Art	PS	PT
1992	11,092	19,420	11,285	1,283	26	17	8,645	746,923	663,823
1993	11,807	20,194	11,840	1,279	25	17	9,231	807,760	696,470
1994	18,552	31,014	22,200	1,286	25	17	14,426	1,240,560	1,305,882
1995	14,749	26,318	21,971	1,290	26	17	11,433	1,012,263	1,292,453
1996	14,845	25,772	21,040	1,361	26	17	10,907	991,236	1,237,693
1997	10,771	14,961	12,753	1,384	25	17	7,782	598,462	750,185
1998	7,792	7,704	4,465	1,415	26	17	5,506	296,329	262,656
1999	8,375	12,799	7,646	1,436	34	8	5,832	376,445	955,848
2000	5,233	4,813	3,175	1,376	30	10	3,803	160,462	317,571
2001	4,513	4,293	2,714	1,519	29	13	2,971	148,053	208,822
2002	6,148	6,245	3,582	1,344	27	22	4,574	231,328	162,850
2003	9,526	11,678	8,235	1,279	25	21	7,448	467,134	392,164
2004	6,191	3,499	1,113	1,372	22	21	4,512	159,054	53,033
2005	7,446	5,461	1,919	1,683	33	21	4,424	165,501	91,390
2006	8,014	6,769	38,084	1,727	28	21	4,640	241,772	181,335
2007	8,310	7,801	4,311	1,733	27	21	4,795	288,935	205,314
2008	21,448	35,887	27,910	1,805	29	21	11,883	1,237,512	1,329,057
2009	23,515	36,942	28,490	1,770	29	21	13,285	1,273,862	1,356,666
2010	19,351	29,462	18,870	1,829	32	21	10,580	920,687	898,571
2011	14,995	23,558	11,100	1,677	31	21	8,941	759,935	528,571
2012	17,257	31,646	14,985	1,662	33	21	10,383	958,969	713,571

Note: Art (artisanal), PS (purse seine) and PT (pelagic trawl).

Table 6b: The observed actual data and estimates of GLM (1992~2012)

Year	GLM							
	ESt. St. CPUE (catch/ship)-kg			Est. St. Effort (ship)			ln Est. St. CPUE	Est. St. CPUE summed
	Art	PS	PT	Art	PS	PT		
1992	9964.83	672958	639199	1113	29	18	10	36043
1993	10623.1	717411	681423	1111	28	17	11	37893
1994	17538.6	1184438	1125022	1058	26	20	11	65023
1995	15115	1020764	969559	976	26	23	11	61549
1996	14563.7	983532	934194	1019	26	23	11	57730
1997	9308.71	628648	597112	1157	24	21	10	32012
1998	4625.2	312355	296686	1685	25	15	9	11576
1999	7853.7	530387	503780	1066	24	15	10	26066
2000	3549.92	239738	227711	1474	20	14	9	8768
2001	2768.13	186941	177563	1631	23	15	9	6904
2002	3413.82	230547	218982	1801	27	16	9	8663
2003	6803.86	459487	436437	1400	25	19	10	20382
2004	2063.44	139351	132361	3000	25	8	8	3561
2005	2490.44	168188	159751	2990	32	12	8	4886
2006	3608.05	243663	231440	2221	28	16	9	8207
2007	4034.37	272454	258787	2060	29	17	9	9702
2008	16523.9	1115911	1059933	1298	32	26	11	62841
2009	17435.1	1177449	1118384	1349	31	25	11	63282
2010	12642.2	853768	810940	1531	35	23	11	42610
2011	9394.56	634446	602620	1596	37	18	10	30062
2012	11793.1	796425	756473	1463	40	20	11	41953

In addition, from equation (4), we can calculate the rate of standardized fishing effort of each gear distributed between the three gears. The average rate over 21 years (1992~2012) is 0.961, 0.023 and 0.015, for each gear type, respectively (Tab. 7a & b).

Table 7a. Average rate of fishing efforts of the three gears for sardinella (1992~2012) (Unit: %).

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Effort rate ART	0.96	0.96	0.96	0.95	0.95	0.96	0.98	0.96	0.98	0.98	0.98
Effort rate PS	0.02	0.02	0.02	0.03	0.03	0.02	0.01	0.02	0.01	0.01	0.01
Effort rate PT	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01

Table 7b. Average rate of fishing efforts of the three gears for sardinella (1992~2012) (Unit: %).

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Avg
Effort rate ART	0.969	0.99	0.985	0.98	0.978	0.96	0.96	0.964	0.97	0.96	0.96
Effort rate PS	0.018	0.01	0.011	0.012	0.014	0.02	0.02	0.022	0.02	0.03	0.02
Effort rate PT	0.013	0.01	0.004	0.007	0.008	0.02	0.02	0.015	0.01	0.01	0.02

Avg.: Average.

Furthermore, we evaluate the relationship between the standardized $\hat{E}_{T_t}$ and the standardized $\widehat{CPUE}_{T_t}$ (Schaefer, 1954; Fox, 1970). The exponential trendline or model gives great R^2 of 0.678 compare to the linear one with R^2 of 0.476 (Fig. 8). Consequently, the analysis shows that the relationship is closer to being exponential than linear.

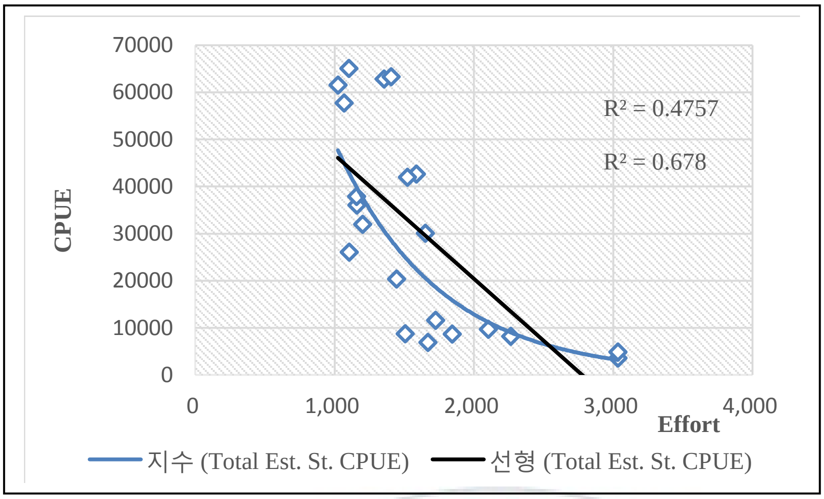

Figure 8. Relationship of estimated fishing effort (E) and estimated sardinella CPUE standardized for three gear types.

4.2.2 CYP Model: estimations of CPUE∞ and q/r

The CYP model in equation (6) estimates coefficients q, k and r. The coefficients of the three parameters are 0.001311; 115,868,265.609 and 1.08175, respectively. Therefore, *CPUE∞* = *q*k* = 151,903 and *q/r* = 0.001418. The CYP regression shows that R^2 is 0.52 and p-value is 0.021 ($p<0.05$), respectively (Tab. 8).

Table 8. Statistic results of CYP model.

Model summary							
Equation	R-Squared (Adj. R-Squared)	C	X1	X2	F. stat (Prob.)	D-W stat	LM Stat. (Prob.)
		t stat. Std. Error (Prob.)	t stat. Std. Error (Prob.)	t stat. Std. Error (Prob.)			
Linear	0.5321 (0.4734)	8.6608 2.5794 3.3576 (0.0202)	0.2716 0.9993 0.2718 (0.3325)	-0.0004 -1.8164 0.0002 0.0881	9.10074 0.0022	2.05287	2.3142 0.1282

Note : C is $\frac{2r}{2+r}$, X1 is $\frac{2-r}{2+r}$, and X2 is $\frac{q}{2+r}$

The positive R^2 values of CYP model shows that the model fits the data better compared to the Schnute, Schaefer, WHI and Fox models. Thus the estimates of the CYP model is used in this study. The biological parameters r, q and k for the sardinella fishery in the Southern Gulf of Guinea are estimated from the CYP model.

4.2.3 Estimates of MSY (C_{MSY}) and E_{MSY}

The yield-effort curve for the CYP model together with the actual catch and effort data (1992 - 2012) for the sardinella fishery in the Southern Gulf of Guinea are depicted in figure 9. It can be observed from figure that actual catches and effort for the fishery lie at the depletable zone of the yield-effort curve, indicating biological overexploitation of the fishery.

MSY (C_{MSY}) and E_{MSY} estimated are 46,111 metric tons (MT) and 825 vessels, respectively. From the average rate of standardized fishing effort (the artisanal fishery = 0.961, the purse seine = 0.023 and the pelagic trawl = 0.015) of each gear type, MSY (C_{MSY}) and E_{MSY} of sardinella for each gear was estimated. MSY (C_{MSY}) and E_{MSY} of sardinella caught by the artisanal are 44,312 MT and 793 vessels. MSY and E_{MSY} of the purse seine are 1,061 MT and 19 vessels. MSY and E_{MSY} of the pelagic trawl are 692 MT and 12 vessels. Furthermore, the results of the regression fixed between the observed catches and the CYP yield curve with the same horizontal line of standardized fishing effort show that R^2 is 0.53. The p-value of the independent variable (observed catches) is 0.021 ($p<0.05$).

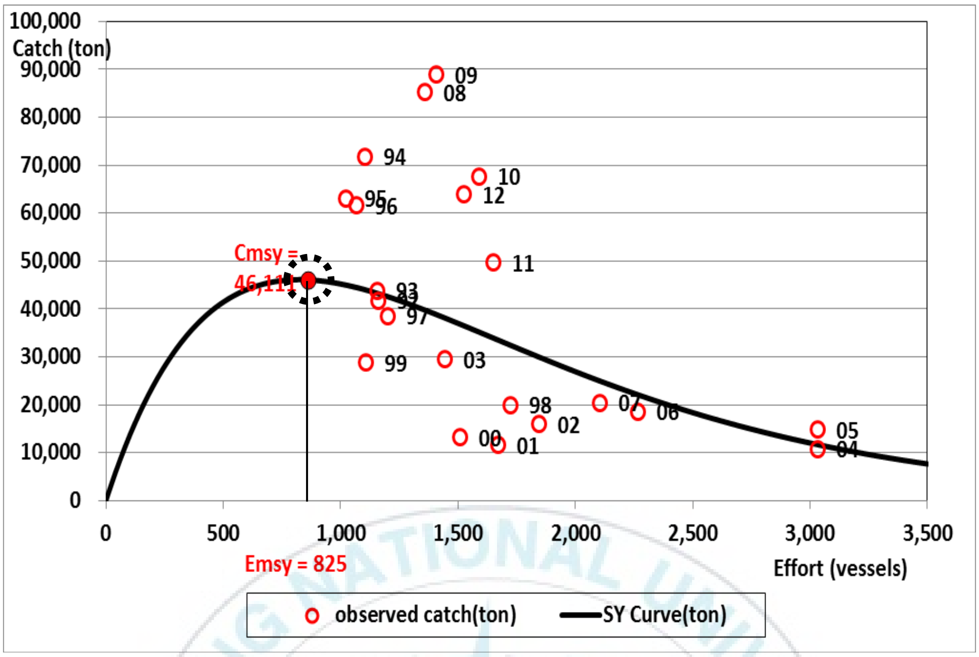

Figure 9. Sustainable yield curve, MSY and EMSY for sardinella in the Gulf of Guinea

artisanal, purse seine and pelagic trawl based on the CYP model.

The present level of exploitation with the MSY level confirm that biological overfishing of the sardinella stock in the Southern Gulf of Guinea has occurred. Great improvement in the fishery can be achieved if fishing effort can be reduced to the MSY level of exploitation. That is, if fishing effort can be reduced by 825 from the present level of total estimated effort equal to 1,605 fishing vessels, this situation will consequently lead to the increase of yield and stock biomass.

The same trend of overexploitation of sardinella stock of Angola was observed in 1989 by Albeits (1990) because the artisanal fishery was becoming a major concern to the Angolan government, as the catch was used for food security by the coastal population. He reported that the artisanal fleet along the Angolan coast consists of approximately 3,835 vessels and led to increasing of fishing activities.

The Report of the FAO/CECAF (2009) Working Group on the Assessment of Small Pelagic Fish–Sub group, concluded that sardinella stock of Angola, Congo, DR Congo and Gabon is considered “moderately exploited”. However, they warned that care should be taken when analysing the results for this species, because their results indicate that total catch level may be temporarily increased.

4.2.4 Estimates of MEY and E_{MEY}

The MEY and E_{MEY} of sardinella caught by the three gear types are estimated by equations (17) and (18) and the economic parameters of table 4. The estimated MEY is about 43,153.8 MT and standardized fishing effort at the level of MEY is about 560 vessels. Net Profit (NP) at the level of MEY is approximately 12,587.7 million US dollars.

The estimated MEY of sardinella caught by the three gear types is about 93.6% of the estimated MSY; the estimated E_{MEY} is about 67.9% of E_{MSY}. This means that, when E_{MSY} is reduced by 32.1% to reach E_{MEY}, MEY which is also a sustainable yield, falls by 6.4%. In short, current fishing effort of the three gear types for sardinella is excessive.

Since the sardinella stock has recently been crossed the limit reference point of MSY as shown in figure 9, it is not possible for fishing effort at the level of MSY to achieve maximum net revenue due to the current state of the sardinella stocks. In other words, given the overexploited status of the resource, the fishing effort at the level of MSY can gradually recover the resource, but cannot achieve the maximum net revenue until the resource recovers to the steady state biomass associated with MEY. In addition, since artisanal, purse seine and pelagic trawl have been used for catching other species, the revenues of vessels of the three gear types that harvest species other than sardinella should also be taken into account. The net revenue at

MEY is higher than at MSY when the resource recovers. Hence, if the sardinella resource is allowed to recover, operating at MEY can be much more efficient than operating at the level of MSY in terms of fishing effort and net revenues (fig. 10).

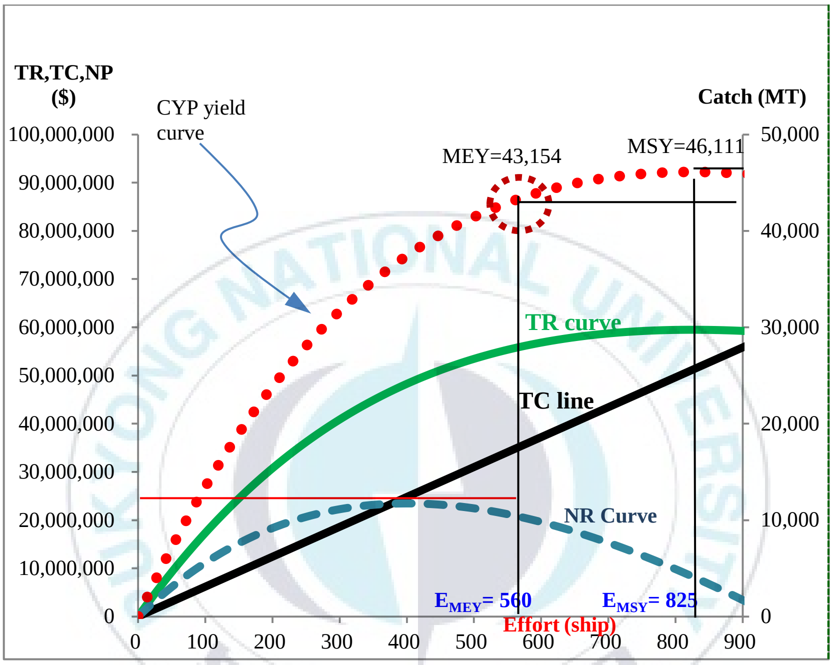

Figure 10. Total revenue, total cost and net revenue of the Gulf of Guinea artisanal, purse seine and pelagic trawl harvesting sardinella: estimates based on the CYP bioeconomic model.

4.2.5 Estimates of NR at the level of MSY

Sardinella net revenues of the three gears can be estimated by equations (21.1) for Angola and (21.2) for Congo. At the current proportional levels (Art =0.96; Ps=0.26 and Pt=0.14) of fishing efforts between the three gears, NR of Angola is about \$12.5 million and NR of Congo is about \$10.9 million. Also, total NR of the two nations is about \$23.5 million (Tab.9).

This result implies that at MSY level, Angola inputs much more fishing effort than does Congo. As a result, Angola has earned much more in net revenue terms than Congo. This result may be due to a lower unit operating cost and higher fishing effort of sardinella caught by Angola.

Table 9. TR, TC and NR of Angola and Congo at MSY.

Nations	TR	TC	NR
Angola	27,153,475	14,645,046	12,508,429
Congo	22,758,501	11,763,742	10,994,759
Total	49,911,976	26,408,789	23,503,188

4.2.6 Scenario of NR allocation between nations based on area catch level

The outcomes of area based catch level are generated for each country by converting the EEZ in hectare expressed in kilometer square. There is evidence that Congo is catching three times more sardinella than Angola. The area catch rates (C_r) computed under EEZ values are 3.11 and 0.93 for both countries respectively (Tab. 10).

Table 10. Area catch rates of Congo and Angola for the period 1992-2012. C_{Art}, C_{Ps} and C_{Pt} represent catch in metric tons for artisanal, purse seine and pelagic trawl fisheries respectively.

Angola					Congo			
Hectare (EZZ) Km^2	C_{Art}	C_{Ps}	C_{Pt}	C_r	Hectare (EZZ) Km^2	C_{Art}	C_{Ps}	C_r
51,000,000	9995.51	19991	17611	0.93	6,000,000	7484	7559	3.11
	0.16659	0.333	0.294			0.1247	1.866	

Given above results (Tab. 10) and sardinella being transboundary, the resource is assumed to be homogeneously distributed in the Southern Gulf of Guinea that straddles the EEZ's borders of Angola and Congo. That is, sufficient mixing occurs such that fishing mortality on Congolese side could affect the stock size on Angolan side. Therefore, economic interaction between Congolese and Angolan sardinella fishery industry can be empirically analyzed.

To obtain an indication of the sensitivity of the area catch rates variation, four scenarios are designed at 2.5, 5, 7.5 and 10 per cent to predict increasing or decreasing trends of catch, effort, fishing cost, total revenue and subsequently the profit to balance the exploitation of sardinella as a transboundary resource within cooperative countries. Zero per cent represents MSY reference point values. The results are presented in Table 11. As it can be seen while scenario's percentage at different level changes, catch and effort change as well and influence negatively fishing cost, total revenue and profit in Congo while in Angola, all those parameters are influenced positively.

Given this, it is predicted that under substantial effort and catch reductions on Congo side, the economic losses on Angolan side are substantially mitigated by increases in catch and effort on one hand, and economic parameters on the other hand. Effort estimation is related to the catch in Angola and Congo based on catch level at different proposed scenarios.

Table 11. A comparison change in four scenarios (2.5, 5, 7.5 and 10 per cent) based on area catch rate. Zero per cent represents MSY reference point

Scenarios	Angola (MSY)					Congo (MSY)				
	catch (10^3 kg)	effort (ship)	total revenue (10^3 $)	total cost (10^3 $)	profit (10^3 $)	catch (10^3 kg)	effort (ship)	total revenue (10^3 $)	total cost (10^3 $)	profit (10^3 $)
0%	24,956	447	27,153	14,645	12,508	21,155	378	22,759	11,715	11,044
2.5%	26,109	468	28,408	15,321	13,087	20,002	357	21,518	11,076	10,443
5%	27,261	488	29,662	15,997	13,666	18,849	337	20,278	10,436	9,842
7.5%	28,414	509	30,916	16,672	14,244	17,696	316	19,038	9,797	9,241
10%	29,567	530	32,171	17,348	14,823	16,544	296	17,798	9,158	8,640

The result obtained implies that the sardinella resources have a higher economic value in Angola as compared to Congo. This is because whereas Congo is catching more than Angola based on area catch level, the profits at MSY are lower than those of Angola.

Nonetheless, there is need to manage the resources based on area catch level because if the statu quo changes, either of the countries start to loose or gain economically from the fishery.

5 Policy Implications and Conclusions

5.1 Consideration of transboundary spaces

The legal regime published on 1982 by United Nations Convention contains one provision pertaining to the management of transboundary fish stock, namely Article 63 (1), which reads as follows : « Where the same stock or stock of associated species occur within the Exclusive Economic Zones of two or more coastal States, these shall seek, either directly or through appropriate subregional or regional organizations, to agree upon the measures necessary to coordinate and ensure the conservation and development of such stocks without to the other provisions of this part (V) (UN, 1982, Article 63 (1)). »

Based on the legal regime of United Nations Convention and the area catch level results, there is need to use the above proposed scenarios to conserve the sardinella resources so as to provide reasonable allocation rule's strategy. In the mean time, each country should consider fish population dynamique to have balanced catch allocation. Therefore, Angolan side should cooperate with Congo side by considering area based catch level in order to gain fairly their profits on transboundary species.

5.2 Implications of bioeconomic analysis

5.2.1 Sardinella fisheries evaluation

Sardinella fisheries play a significant role in sustaining the livelihood of riparian people of the Gulf of Guinea (ACP Fish II, 2013). The present level of exploitation with the MSY level confirm that overexploitation of sardinella resource and created adverse biological impact on sardinella stock and economic impacts on people. Beside, the study outcomes support the hypothesis that overfishing of sardinella stock is due to the increasing of total catch production over the years 2008-2012 and fishing effort of both artisanal and industrial fisheries somehow. Sardinella being a source of income and protein for the people, the reduction in this fish stock is a critical issue which requires implementation of proper cooperative management strategies and policies to recover the sardinella stock at a sustainable level.

Therefore, scenario implications are highlighted based on the outcomes of area based catch level approach and bio-economic modelling in order to improve the current management.

5.2.2 The MEY of the Southern Gulf of Guinea sardinella fishery.

The maximum economic yield (MEY) is done within a sustainable catch framework. That is, it compares economic yields from a sardinella fishery's sustainable catch under various effort levels, where effort is defined as the number of vessels.

The MEY occurs when the sustainable catch or effort level for the fishery as a whole maximises profits, or creates the largest difference between total revenues and the total costs of fishing. For profits to be maximised, it must also be the case that the fishery applies a level of vessel capital and other resources in combinations that minimise the costs of harvest at the MEY catch level. The fishery, in other words, cannot be overcapitalized and vessels must use the right combinations of such inputs as gear, engine power, fuel, and crew to minimise the cost of a given harvest (Kompass, 2005).

The total revenue curve is showing the relationship between effort and yield in dollar amounts. The larger is effort the smaller is stock size. Every point along this curve represents an effort and yield combination that is sustainable, with effort of 825 vessels at MSY. The total cost curve is taken as the total cost of fishing assumed to be increasing and linear in effort, for convenience. MEY in figure 10, occurs at the effort level E_{MEY} of 560 vessels and corresponding value of catch of 43,154 tons that creates the largest difference between the total revenue (TR) of $18,556,159 and total cost of fishing (TC) of $5,968,480, thus maximising profits (*p*) of $12,587,679 given by the difference between TR and TC.

The value of E_{MEY} will change given a change in the price of sardinella, which shifts the total revenue curve up or down, or the cost of fishing, which rotates the total cost curve. Given prices and costs, MEY graph illustrates a highest point, namely that targeting MSY which generates very small profits. With a small increase in the cost of fishing, these could easily go to zero. If so, this would replicate a common property or open access equilibrium even though a management regime is operating. Note as well that a profit maximising movement away from effort at MSY toward effort at MEY implies a smaller value of harvest. Maximising profits requires less effort and smaller catches. The reason of course is that decreases in effort, will correspond to the increases of sardinella stock in the future.

Furthermore, since fishing is one of the main sources of income for the people, consideration of profit maximisation is necessary to ensure that fishing consistently provides sufficient economic benefit to the fishermen. It is important that before implementing such reform, reform objectives have to be clearly defined and shared among various stakeholders (Schmidt, 2012). Sardinellas alone make up a large share of catches and generate significant revenues on all levels of the industry including tax benefits for states.

Sardinella resources are overexploiting for lack of proper management, monitoring and control of the catches. It is therefore of great urgency not only to implement a management plan of sardinella formulated with the financial support of ACP Fish II in 2013, but to organize by improving the scientific socio-economic, monitoring and biological fishing activities.

5.3 Recommendations for sardinella fisheries management system.

In keeping with these principles of the Code and with a recognition by the Fisheries Directorates of Angola, Congo-Brazzaville, Congo DR and Gabon that effective management of shared resources could only occur through cooperation and working together.

In the sub-region level, there should be synchronization between Congolese and Angolan surveys including two Congo countries to address the issue of transboundary sardinella resource management. Because sardinella resource is overexploited, stock assessment “output control system” can be adopted in the Southern Gulf of Guinea sardinella fishery among adjacent nations.

In national level, the survey data are not sufficient for giving all the information needed in the population analysis. It is therefore important to implement a sampling programme on landings for all components of the fishery each year including both catch and effort data, and equally reliable information should be collected on the spatial and temporal distribution, the areas in which fishing is taking place, and when it is taking place. This will allow determination of whether changes in CPUE are due primarily to changes in abundance of the stocks, or they are due to changes in catchability or in the area or time of fishing.

Also, it is necessary to integrate both customary with modern management systems in the fisheries legislation. The reason is that, integration of the two systems will strengthen fisheries co-management between government agencies, communities as well as NGOs. Co-management could be strengthen by adopting a Community-Based Fisheries Resource Management (CBFRM), which is regarded as a fisheries management system initiated by fishers. Cinner and Aswani (2007) supported the use of community by the government due to failure of command and control fisheries management instructions.

Recently the lack of success in implementing Marine Protected Areas in developing contries. CBFRM as government and communities management tool, will facilitate establishment of fisheries regulations, fish stock assessment, set catch limit and monitor the fishing ground and have autority to fine or exclude violators.

The advantages of the CBFRM are high commitment of fishermen, employing traditional fisheries management and retain community-based bottom up approach to resource management. This system requires low cost approach to data collection, assessment of stock-size and low enforcement.

There are some limitations on the analysis of this study. First, there is an unsufficient biological and technical information necessary to the analysis. Due to data limitations, the surplus production model was used. Furthermore, there is lack of information or data on precised sardinella fishing ground area. For this reason, informations on given EEZ of Congo and Angola were used to estimate the area (hectare) based catch level.

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