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BIOECONOMIC ANALYSIS: A CASE STUDY OF THE INDUSTRIAL PELAGIC FISHERIES IN CAPE VERDE

Anisio Fernandes Oliveira Évora
National Institute for Fisheries Development
Cape Verde
anisio.evora@indp.gov.cv

Supervisor:

Daði Már Kristófersson
University of Iceland, Iceland
dmk@hi.is

ABSTRACT

This paper develops a bioeconomic model to identify optimal management of the pelagic fisheries, applied to the industrial pelagic fisheries of Cape Verde. The result of the analysis of the period 2003 to 2012 show very high fluctuation in the net benefits of the fishery. The net benefits were mostly negative due to excessive fishing effort which results in high cost, while the total revenue remains weak. The current (2012) fishery reference situation indicates a slightly excessive fishing effort. Hence, the fisheries exist at a stage that requires care in terms of management with bioeconomic criteria at levels very close the biological equilibrium (BE). Despite this, it is known that adequate fishery management is necessary to achieve sustainable fishing, so this current state represents an opportunity for management. By analysing this scenario, we emphasise biological and economic outcomes. To achieve maximum sustainable profits, around 111,602 thousand CVE annually equal to 22% of the total revenue, the fishing effort must be reduced from 6,264 to 3,752 days at sea in a long-run sustainable option. However, it must only reduce from 6,264 to 5,042 days at sea to achieve the maximum sustainable profits around 32,827 thousand CVE annually, equal to 6% of the total revenue, in a short-run sustainable option. The fundamental problem of economic inefficiency in fisheries, the called common property problem, may be seen to be caused by inadequate property rights in the underlying natural resources. Due to this lack of property rights, trades in the natural resources cannot occur. As a result, markets cannot form and, consequently, there are no market forces to guide behaviour to the common good. All potential economic rents from the fishing activity are fritted away by investment in excessive fishing capital and fishing effort. Moreover, this economic waste is generally accompanied by an unjustifiable reduction in and, sometimes, even decimation of the biological capital, the fish stocks. However, the analysis shows that the main source of improvement of the fishery management in this case of study is linked to the implementation of the ITQs to the harvest sector, to correct this management failure, and reduce the fishing efforts and rebuild the fish

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stock. ITQs have been introduced in numerous fisheries around the world, apparently generally, even consistently with good economic results.

ACRONYMS

ACOPESCA	-	Competent Authority for Fisheries Surveillance
BE	-	Bioeconomic Equilibrium
CPUE	-	Catch Per Unit Effort
CVE	-	Cape Verde Currency
DGP	-	General Directory of Fisheries
EEZ	-	Economic Exclusive Zone
EMEY	-	Effort at Static Maximum Economic Yield
EMSY		Effort at Maximum Sustainable Yield
FAO	-	Food and Agriculture Organization
GDP	-	Gross Domestic Production
INDP	-	National Institute for Fishing Development
INE CV	-	National Institute of Statistics Cape Verde
ITQs	-	Individual Transferable Quota System
MCS	-	Monitoring Control and Surveillance
MEY	-	Maximum Economic Yield
MSOC	-	Maritime Security Operations Center
MSY	-	Maximum Sustainable Yield
NPV	-	Net Present Value
PRBFMs	-	Property Rights Based Fisheries Management System
TAC	-	Total Allowed Catch
TURF	-	Territorial User Rights in Fisheries
VMS	-	Vessel Monitoring Systems

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1 INTRODUCTION

Fisheries management is surrounded by risk and uncertainty. Measuring the biological and economic impacts of management measures adopted in fisheries is important for policy makers to ensure the sustainability of the activity. Maximising fisheries harvest while ensuring a self-sustaining stock is not an easy task. At the same time, it is difficult to regulate fishing effort for several reasons, among which Sumaila (1999) indicates: "(i) renewable resources are often "common property"; (ii) different fishing vessels affect stocks differently; (iii) the catch of juveniles or mature fish can have important consequences for those species which are long-lived; and (iv) the capital embodied in the exploitation is often non-malleable."

Policy makers are confronted with the task of maximizing production and maintaining employment on one hand and avoiding the risk of industry collapse in the near future due to resource depletion on the other. Measures of control are divided in two categories: the input control (including exclusive areas, seasonal closing, effort allocation, etc.) and output control (concerning the catches and their size and includes for instance TACs and individual quota). Management of fisheries requires the integration of resource biology and ecology with the economic factors that determine fisher's behavior in space and time (Anderson and Seijo, 2010).

A fishery is not a static phenomenon, human interventions or natural events that happen in one period can have repercussions in the future. Thus, independent of fishing, stocks can fluctuate in the short and long run because of natural factors. Human actions can have lasting effects on both the stock and fishing fleet that will affect the ability to control harvest in the future. However, the stock will increase if recruitment of new individuals and the growth of existing individuals add more to biomass than is removed by natural and fishing mortality.

The pelagic fisheries in Cape Verde have significant economic and social impacts. They provide an important source of protein in the diet and are important to food security for the people. Additionally, the value of catches and the number of fishermen employed within the industry also play an important role in the economy of Cape Verdian society. The pelagic fishery in Cape Verde are divided in small pelagic and big pelagic. The most abundant species within the small pelagic with best commercial value are black mackerel (*Decapterus macarellus*), scad mackerel (*Decapterus punctatus*), bigeye scad (*Selar crumenophthalmus*), blackspot picarel (*Spicara melanurus*), blue runner (*Caranx crysos*), pompano (*Trachinotus ovatus)*, and the African moonfish (*Selene dorsalis)*. All these small pelagic species can be found at 30-200 m depth and usually form fish schools at the surface (INDP, 2014). The total catch of these small pelagic species has fluctuated over the last 10 years, and in the last two years the total catch of small pelagics has been relatively low in comparison with the previous years, mainly black mackerel, which is economically important in this group. The big pelagics are basically skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), frigate tuna (*Auxis thazard),* sawfish (*Acanthocybium solandri*), Atlantic little tunny (*Euthynnus alleteratus*) and gilthead bream (*Coryphaena hippurus*).

Detailed historical economic data on the fisheries resources in Cape Verde are not readily available. However, there are some scientific papers and statistical reports that briefly explain and give some details, though few of these have focused on the economics of the fishery. As a result, it has been difficult to determine financial profitability and economic viability of the fishery. What is clear is that ship owners are faced with financial and technical problems since most of the fishing vessels are poorly equipped and old-fashioned and their operation is costly (INDP, 2014).

Fisheries policy and management in Cape Verde is mainly based on biological analysis such as stock assessment, mostly ignoring economic aspects of the sector. The biological analysis is quite important because it allows for a discussion of the interaction between effort harvest and stock size. Analysis of the sustainability of the pelagic stocks and how they react to fishing pressure requires a deep understanding of the population dynamics and external human and environmental factors. How will the stock of fish change over time with and without fishing? What is the harvest production function? What is the relationship between the inputs used and the amount of fish that will be harvested from a given stock size? What level of effort will be produced under specific circumstances. Bioeconomic models seek to answer these complex questions. Commercial fishing is an activity that is undertaken for profit. Incorporation of information about sales price, cost of fishing and how the profit level will vary with output, allows for a model that can help predict likely level of effort and outputs (Anderson and Seijo, 2010).

In addition to being both a biological and a food-supply resource, the erosion and subsequent collapse of fisheries pose an immediate economic threat to fishers and others whose livelihoods depend on fishing. In order to avoid this tragedy, establishing biologically and economically sustainable fisheries is clearly desirable and necessary, so, the biological based management options should be coupled with economic management options from the fishery so as to know the interactions between the biology and economics within the fishery (Anderson and Seijo, 2010). Therefore, this study seeks to use bioeconomic modelling to find optimal management solutions for the industrial pelagic fishery in Cape Verde. Ineffective management of fisheries is likely to result in the depletion of the shared resource, meaning unrecoverable ecological and economic losses.

The main objective of this paper is, therefore, to get a biological and economic understanding of the industrial pelagic fisheries in order to determine the most efficient management and to optimize the fisheries policy for such fisheries in Cape Verde.

Specifics objectives of this project are:

a) Assess the fishery management options (biological related) in Cape Verde
b) Assess the potential benefits of the pelagic fishery in Cape Verde
c) Assess and determine the optimal level of effort, in order to obtain the optimal utilization of a fish stocks, and maximize the net present value (NPV) of harvest for the industrial pelagic fishery,
d) Suggest a policy for sustainable fishing

The results of this analysis will hopefully represent a step in the direction of developing the appropriate management for the industrial pelagic fishery, particularly the improvement of property rights, and maximizing the utilization of the stock.

2 OVERVIEW OF FISHING SECTOR IN CAPE VERDE

The Archipelago of Cape Verde (Figure 1) is approximately 500 km off the coast of Senegal, West Africa. It consists of ten islands and eight uninhabited islets with a total population of around 500,000 people (National Institute of Statistics of Cape Verde - INE CV).

Since the islands are of volcanic origin and emerge from an abysmal pit with an average depth of 4,000 km, the continental shelf (of less than 200 m depth) is fairly narrow which may not be suitable as breeding grounds for many marine fish.

Figure 1: The approximate area of Cape Verde Exclusive Economic Zone (EEZ)

The sea around Cape Verde is thermally stratified with a thermocline between 40 and 70 m. The average annual temperature is about 24°C. The total surface of the Economic Exclusive Zone (EEZ) is 734,265 km^2, the potential for fishing is around 36,000-44,000 tons, and the main fishing resources are small pelagic (mackerels), tunas (big eye, skipjack) demersal species (grouper, etc) and lobsters (Seijo *et al.*, 1998; INDP, 2014).

2.1 The importance of the fisheries and its governance

As in many developing countries, the sector of Cape Verde is not only a vital part of the country's goal to engage in world trade but serves a vital cultural and societal role in the communities. Though the fisheries sector contributes only about 1% for the national GDP, it is considered an important source of income still playing a decisive role in the diet of the population as main source of protein and important to food security for the people and contributing to the generation of wealth through exports. The per capita consumption of fish is around 26 kg and the fisheries sector are seen as an important factor to strengthen the national economy.

The governance of the fishery sector in Cape Verde is by the Minister of Infrastructure and Maritime Economy, National Council of Fisheries and Marine Resources, Marine Resources Directorate-General, INDP, and ACOPESCA. Each element of this structure is responsible for maintaining a good institutional framework for management and enforcement. The Director-General of Marine Resources is responsible for formulating fisheries policy, issuing laws and licensing of fishing activities. The National Institute for Fishing Development is responsible for fisheries research and issuing recommendations for fisheries management. ACOPESCA is the competent authority for fisheries surveillance, recently created for monitoring and ensuring compliance with the rules on health, legality and quality of fisheries and fishery products. Finally, the National Council of Fisheries and Marine Resources holds biennial meetings for discussing the future of the fisheries management. An illustration of the fisheries management structure in Cape Verde is pictured in Figure 2.

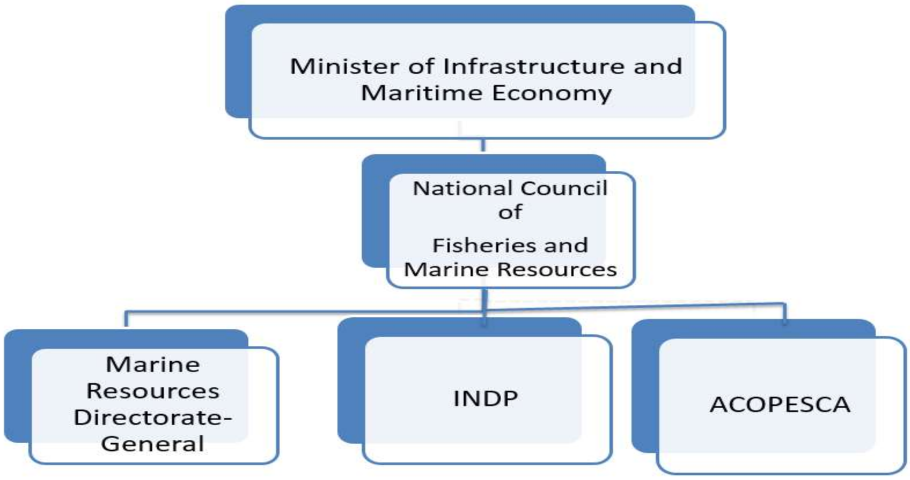

Figure 2: Organic structure of fishery sector in Cape Verde

There are also other institutions, for instance, the Maritime and Port Agency, which are responsible for inspection and registration of fishing vessels and coastal surveillance. The Coast Guard is responsible for supervision of the Economic Exclusive Zone.

Fisheries activities are regulated through property rights and a licensing system. The licenses are issued by the General Directory of Fisheries (DGP). For instance, in order for semi-industrial and industrial vessels to get a license, they need to have onboard navigational aid and depth sounders devices, in addition to the electronic VMS (Vessel Monitoring Systems) and logbooks, property title of fishing vessel, and a sanitary certificate issued by the competent authority. For artisanal fishing, only a property title of the fishing boat is required for licensure.

In 2011, the Maritime Security Operations Center (MSOC) was established and a new vessel with more capacity and speed was acquired to patrol the EEZ. In 2013 the Fishing Inspector was created. The Fishing Inspector works with the Coast Guard and Maritime and Port Agency to protect the Economic Exclusive Zone against illegal fishing and minimize the difficulty of surveillance of the EEZ. The enforcement activity include inspection offshore, inshore and on landings ports to ensure the compliance the fishery management and enforcement rules.

The fishing in offshore areas is still a challenge and there is a lack of strong law enforcement measures against the illegal fishing from foreign countries. The fishing sector continues to have problems, such as lack of communication between institutions of the sector, evidence of overfishing of some species, lack of a social security system for fishing operators and difficult access to banking credit for fishing, etc.

According to an INDP Census (2011), the fishery sector is divided into two parts: artisanal and industrial/semi-industrial (Figure 3), and overall employs in the producing and marketing around 5,784 fishermen and fishmongers. The artisanal sub-sector consists of a multi-species and multi-gear fleet numbering approximately 3,717 registered fishers operating over 1,239 registered boats, mainly open boats of wood and fiberglass ranging from 4-8 m in length, with 8-25 HP outboard engines. It employs around 987 fishmongers. The artisanal fishing takes place close to the coast and the main fishing gear is hand lines for demersal fish and tuna, and purse seine for small pelagic. Some of artisanal fleet boats also use beach seines mainly for catching juvenile mackerel or bigeye scad for bait, which are then used to catch tuna. It is usually the wives of fishermen who market the fish. At the areas where the fishing communities are dispersed, cars are used to transport the fish to the customers. There are also local sales made walking from door to door.

The semi-industrial/industrial fishing fleet consists of 111 vessels varying in size from 8 to 25 m with 40-510 HP engines, and employs around 1,080 fishermen. The technological facilities available vary according to the type of vessel. Most of these vessels are minimally equipped with navigational aid and echo sounders devices and in some cases sonar to detect fish schools.

Industrial vessels often go out ten times per month on fishing trips lasting roughly two days, usually operate 11 months per year, with one month reserved for maintenance of the ship. The production is mainly for processing and export. The main species caught are tunas, small pelagic, demersal fish and lobsters. Purse seine, hand line, and long line fishing are the most important gear used by these fishing vessels.

Labor remuneration for fishermen is based on a catch share system, not on fixed wage, both in the artisanal and industrial sectors. The crew receives a share in the harvest value, after deduction of the operational costs (Variable Cost per fishing day) of the vessel on this harvest. Boat types are pictured in Figure 3.

Figure 3: Artisanal fishing fleet (upper and lower right panel) and Industrial fishing fleet (upper and lower left panel) in Cape Verde

The total landings from the artisanal and semi-industrial/industrial fleet in the last years increased from around 8,000 tons in 1994 to up to around 14,000 tons 14,000 tons in 2014 (INDP, 2014). The estimated marine harvest from the industrial fleet is large relative to the artisanal fleet (Figure 4) in the last years. The main reason for this growth is related to an increased interest after 2012 in the processing of small tuna (*Auxis thazard*) for canning. Before this, the fishing fleet did not fish this species in great quantity. Thus, the industrial fleet's contribution is arguably more valuable to the country's economy as it earns valuable foreign exchange for the country each year.

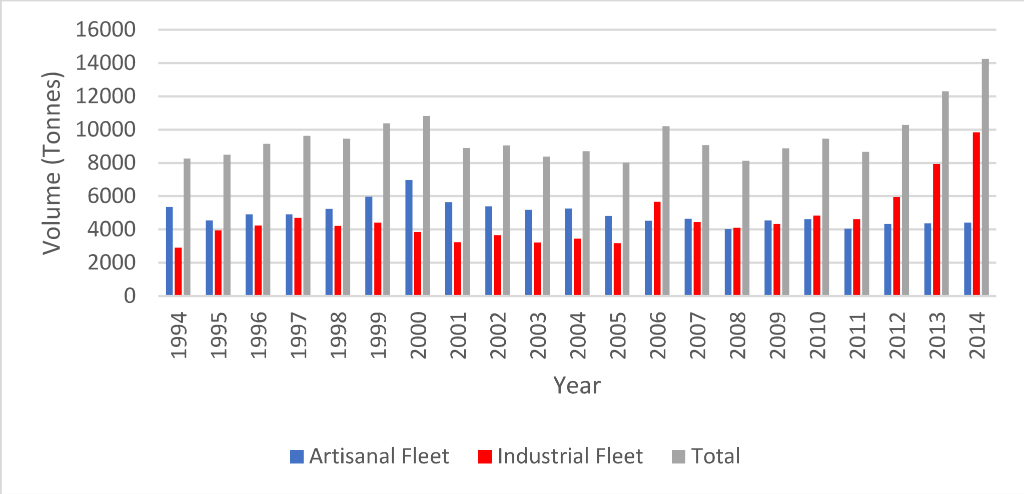

Figure 4: Volume of caught marine species in Cape Verde from 1994-2014

2.2 Flow of fisheries value chain

As stated above, the pelagic resources can be exploited by the industrial or artisanal fleet in Cape Verde. However, the flow of pelagic value chain depends on method of harvest (Figure 5). The pelagic fish from the industrial fleet is either sold directly to the fish processing factory to be canned and sold to the retailers or export or sold directly in the fish markets to the final consumers. For instance, the mackerels, skipjack tuna, yellowfin tuna, bigeye tuna and frigate tuna is either sold fresh, salted, or canned as one of the main raw-material, in the local market. It is also exported by the canning industry, to the European Union markets mainly, Spain, Portugal, Italy, etc. The others pelagic species are exclusively sold in the local fish markets to restaurants or directly to the final consumers.

The fish from the artisanal fleet is sold to the fish markets, restaurants, or directly to the final consumers. Occasionally the fish is sold salted. The processing factories never buy fish from the artisanal fleet, because of European Union rules on quality of fish that is going to be exported to the European market. Frequently the fish from the artisanal fleet does not have the required quality (Econstor, 2012).

Nowadays, only lobsters from industrial fleet can be exported directly to the European market. It must, however, be landed in a landing ports certified for the European Union. Lobsters caught from the artisanal fleet are also sold in the fish markets, at restaurants or directly to the final consumers.

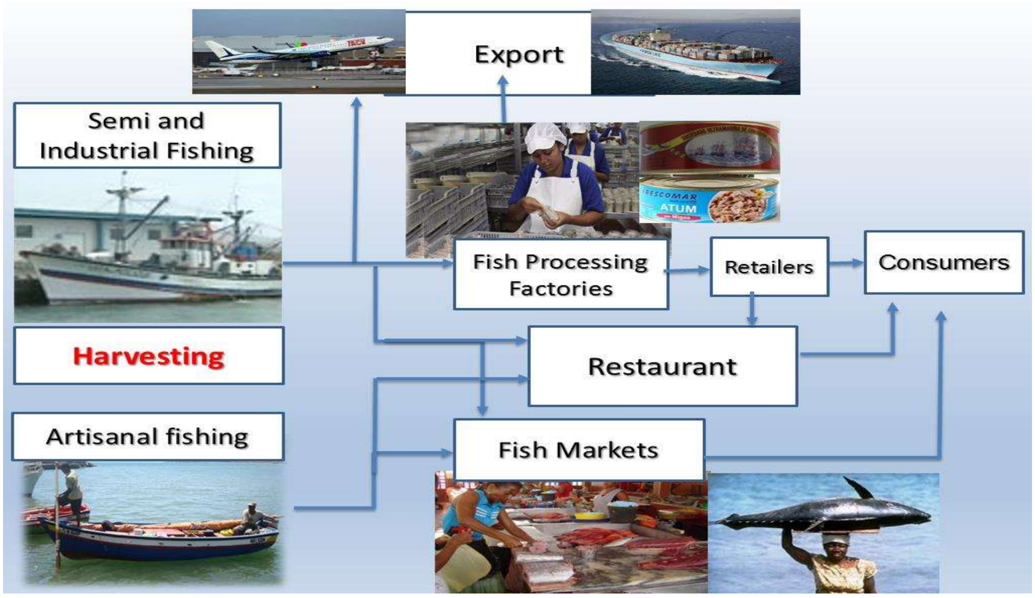

Figure 5: Flow of fisheries value chain in Cape Verde

2.3 Current pelagic fishery management

The management of pelagic fishery in Cape Verde is based on biological theories, which seem to be quite effective (INDP, 2014). There is a temporary closure for black mackerel which is from August 1 until September 30. There are also minimum sizes for catch and selling i.e., black mackerel 18 cm fork length, blackspot picarel 17 cm fork length, chicharro 16 cm fork length. The small pelagics are reserved to the national fleet, and foreign vessels are not allowed to catch those species. It is prohibited to catch, land and market yellowfin or bigeye tuna weighing less than 3.2 kg.

The 12-nautical mile territorial waters are reserved exclusively for the national fishing fleet, and area within three nautical miles is reserved exclusively to artisanal fishing. The maximum sustainable yield for some pelagic species was defined in 2013 and is as shown in Table 1.

Table 1: Maximum sustainable yield for some pelagics species with better commercial value in Cape Verde (INDP, 2014)

RESOURCES	MAXIMUM SUSTAINABLE YIELD (MSY-Tons)
Black Macharels (*Decapterus macarellus*)	2,500 – 2,700
Bigeye Scad (*Selar crumenophthalmus*)	1,000
Blackspot Picarel (*Spicara melanurus*)	300
Tunas (all species)	25,000

There are also some fishing gear and techniques restrictions such as, fishing with dynamite, use of autonomous means of artificial respiration (bottles and compressors) and the use dredgers is prohibited. A minimum mesh size of in 30 mm is set for gillnets.

2.4 Pelagic fishery production

The pelagic fish represents the most important export marine product from Cape Verde. Its economic and social impact has already been mentioned. The highest total annual landings of small pelagic was 5 thousand tonnes contributing 50% to all marine fish landed in 2006. However, the landings decreased suddenly in 2014, the total catch was around 3,092 tonnes representing only 22% of the all marine fish landed in 2014. On the other hand, the highest total annual landings record for tunas, (mainly a small tuna called frigate tuna) was around 8 thousand tonnes in 2014, as shown in Figure 6.

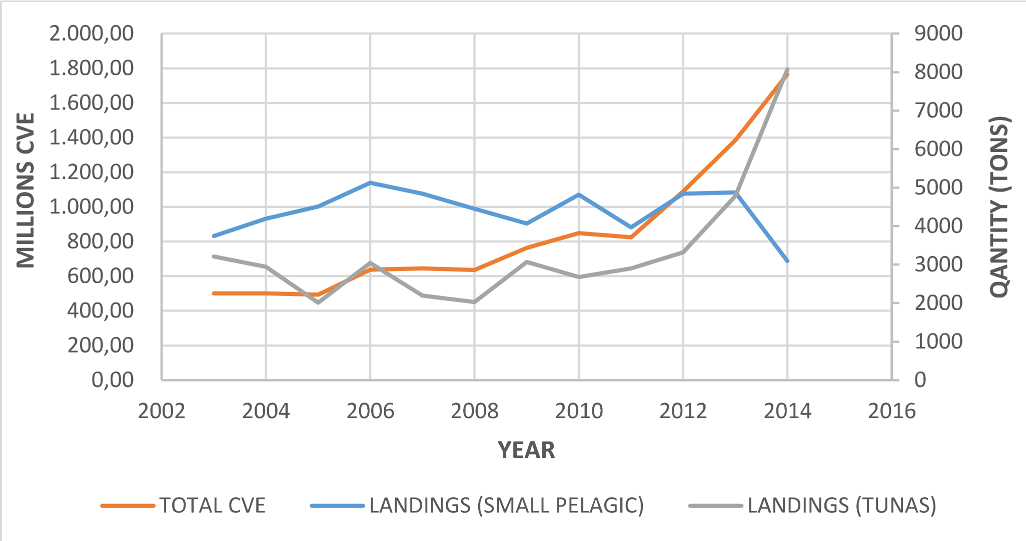

Figure 6: Pelagic fish value and quantity caught in Cape Verde from 2003-2014

As shown in Figure 7 below, the price of pelagic fishery has varied significantly from 2002-2014. The price in the fish markets depending on the catch amount. The small pelagic may be sold with a varying overall price over time between 50 CVE to 130 CVE. Today the canning industry buys mackerels for a fixed price of 35 CVE. The tunas are usually sold per kilo with an overall price varying over time between 80 CVE to 170 CVE. The canning industry have also, a fixed price for small tuna (frigate tuna) of 50 CVE. Fluctuations in catch as related to fishing effort in Cape Verde between 2002-2014 are shown in Figure 8.

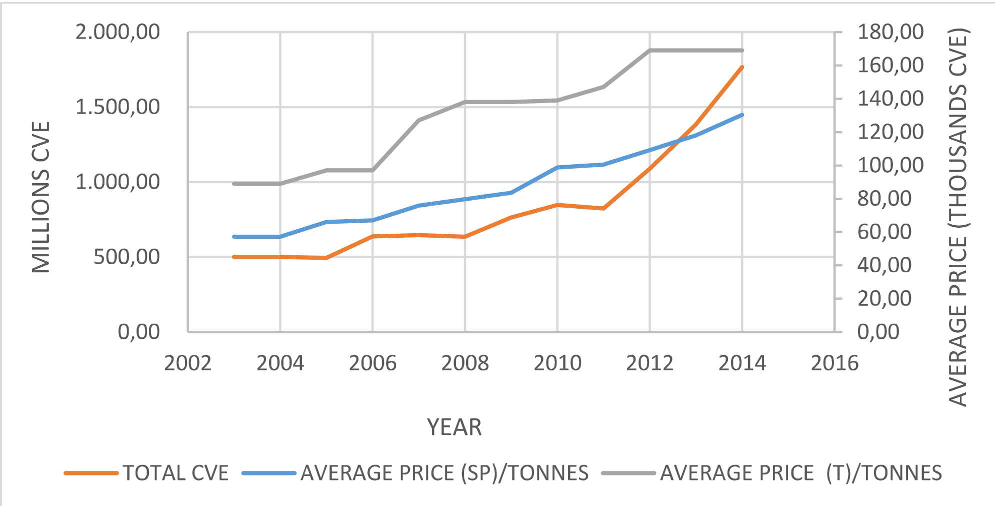

Figure 7: Pelagic fishery value and average price (Cape Verde currency) from 2003-2014 (FRESCOMAR, 2014; INDP, 2014)

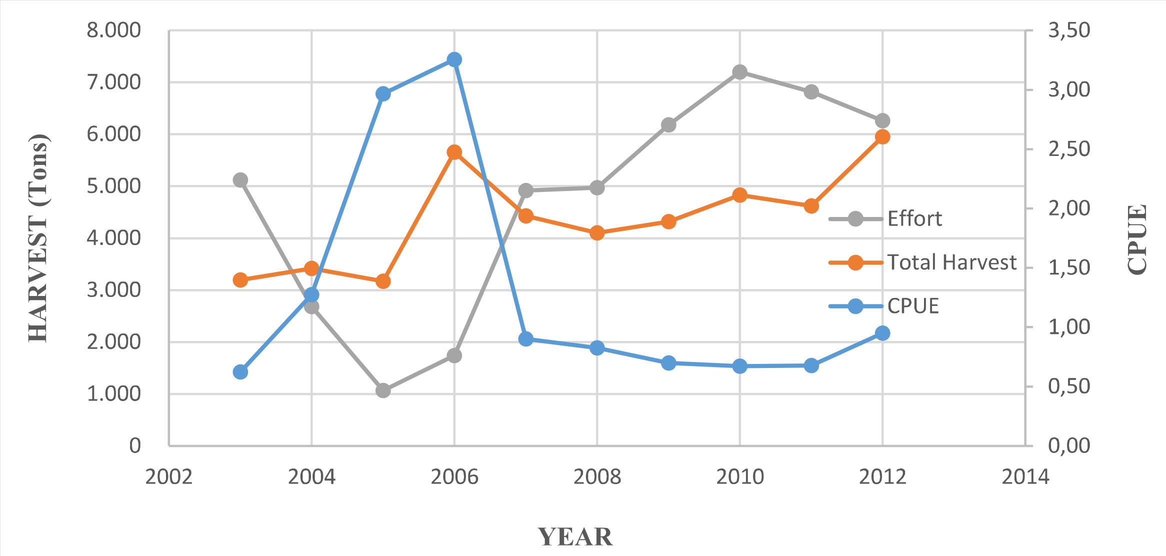

Figure 8: Relationship between catch per unit of effort, effort and total harvest of industrial fleet in Cape Verde

3 FISHERIES AND BIOECONOMIC MODELS

Successful fisheries management must take into account both biological and economic aspects. For this reason, bioeconomic models are employed to provide directions for fishery management (Defeo and Seijo, 1999; Ulrich *et al*., 2002; Lleonart *et al*., 2003; Maynou *et al*., 2006; Mattos *et al.*, 2006; Anderson and Seijo, 2010). Biological analysis allows for a discussion of the interactions between effort, harvest, and stock size. But in order to understand the operation of a commercial fishery, it is necessary to understand what level of effort will actually be produced under specified circumstances. Commercial fishing is an activity that is for the most part undertaken for profit. If you introduce information about price, cost and how the profit level will vary with output, it is possible to build a model that can help predict likely level of effort and outputs.

A fishery can be thought of as a stock or stocks of fish and the enterprises that have the potential to exploit them. It can be a very simple system where a fleet of similar vessels from a single port exploits a single stock of fish. Or it can be more complicated where fleets from different ports using differing technologies harvest fish from several stocks that are ecologically related. This chapter has been adapted from the lectures by Prof. Ragnar Arnason in the specialization course in Fisheries Policy and Planning. However, the fisheries model used in this analysis of the Cape Verde industrial pelagic fishery is based on the work of Gordon (1954) and Schaefer (1957) (Anderson and Seijo, 2010) who developed a basic bio-economic model for fisheries management. This model has been found to be adequate for many fisheries around the world.

The main elements of this model are (i) a biomass growth function which represents the biology of the model, (ii) a harvest function which constitutes the link between the biological and economic part of the model, and (iii) a fisheries profit function which represents the economic part. However, for prediction of the maximum sustainable yield (MSY) of the industrial pelagic fishery, we apply the "surplus production models" (Graham, 1935; Anderson 1979; Anderson and Seijo, 2010).

This approach was selected for the following reasons: (i) the pelagic resources data in Cape Verde is very limited and do not support an advanced bio-economic model, (ii) the model developed here can later be extended and refined when more and better data becomes available. Particularly, we apply the Gordon-Schaefer model to maximize the long run profits from the resource.

More precisely the model is as follow:

$$\dot{x} = G(x) - Y \text{ (Net Biomass growth)} \qquad (1)$$

Where x represents biomass, $\dot{x}$ is biomass growth and Y is harvest. The function G(x) is natural biomass growth.

$$Y = y(e, x) \text{ (Harvesting function)} \qquad (2)$$

The volume of harvest is taken to depend positively on fishing effort as well as the size of the biomass to which the fishing is applied.

$$\pi = py(e, x) - C(e) \text{ (Net Benefits or Profit function)} \qquad (3)$$

Where p represents the price of fish landing and $C(e)$ is the cost function of fishing effort. The profit function depends on the fish price, the sustainable fish yield and the fishing operation costs. The fishing costs depend on the use of economic inputs, which is the fishing effort can represent the profit function equation.

Thus, the above model comprises three elementary functions: the natural growth function *G(x)*, the harvesting function $y(e, x)$ and the cost function $C(e)$. And those models can be explained as follows.

3.1 The biomass growth function

The fish stock measured in terms of biomass is the natural capital of the system. The focus of interest is its ability to reproduce and provide new recruits, the growth rate of individuals, the natural mortality rate, and the rate of fishing mortality. Thus, the stock will increase if recruitment of new individuals and the growth of existing individuals add more to biomass than is removed by natural and fishing mortality. Populations of organisms cannot grow infinitely; the growth of organisms is constrained by environmental conditions and food availability. It has been shown that populations of organisms strive to stabilize at the highest possible population size for a given set of conditions (Anderson and Seijo, 2010). Marginal growth of a population increases when the size of the population decreases, and marginal growth decreases when the size of the population increases, this may be called density dependent growth. Biological growth functions of such populations may be expressed as follows:

$$G(X) = rX - sX^2 \qquad (4)$$

Where X is population size, r is the intrinsic growth rate of the population and s is the ratio of the growth rate to carrying capacity, which is a measure of density dependent mortality. This is the parabolic equation also referred to as "Verhults equation" or the logistic growth equation (Anderson and Seijo, 2010).

Specifically the parameter, s, can be expressed in terms of environmental carrying capacity, k the largest size that can be achieved given food supplies, habitat, etc. and intrinsic growth, as:

$$s = -\frac{r}{k} \qquad (5)$$

From equation (5) substitute s in equation (4), we get the most commonly used expression of the logistic growth equation and equation (4) can be rewritten as:

$$G\ (X) = rX\left(1 - \frac{X}{k}\right) \qquad (6)$$

Where the parameter r represents the intrinsic growth rate, the rate at which the stock would typically grow with no external effects, X is population biomass, the parameter k represents the carrying capacity of the environment, the largest size that can be achieved given food supplies, habitat, etc.

The first term in the equation, rX, shows that growth is proportional to stock size, but the second term, $\left(1 - \frac{X}{k}\right)$ adds the complexity that growth decreases with stock density, $\frac{X}{k}$, and when the stock size equals the carrying capacity, growth will fall to zero. The combined effect is an inverted U-shaped growth curve where growth initially increases with stock size but ultimately falls to zero. The maximum growth rate can be found by taking the first derivative of Equation 6, setting it equal to zero, and solving for X. Ignoring the time subscripts, we have:

$$r - \frac{2rX}{k} = 0 \qquad (7)$$

Solving for X results in:

$$X_{MSY} = \frac{k}{2} \qquad (8)$$

This shows that at lower stock sizes growth varies directly with stock size because recruitment increases, and the more individuals there are in the stock, the greater will be the effect on individual growth. After a certain point, however, the stock will begin pushing against the environmental carrying capacity, which will reduce recruitment and individual growth and increase natural mortality. In this range, net growth is inversely proportional to stock size and eventually falls to zero.

3.2 The harvest function

Harvest is the result of deliberative actions by participants in the fishery. Consider now how harvest will affect the population dynamics of fish stock. Thus, the periodic change in stock size with harvest can be represented as follows:

$$X_{t+1} = X_t + G\ (X_t) - Harvest_t \qquad (9)$$

Meaning that the stock size next year will be equal to stock size this year plus growth this year minus catch this year. In this case, the stock will reach an equilibrium where $G\ (X_t) = Harvest_t$.

To understand fisheries utilization, it is necessary to understand what goes into decisions to fish or not to fish. Assuming that each unit of effort harvest equals the amount from the targeted stock and an equilibrium situation where catch equals natural growth, the equilibrium stock size (x) may be expressed in terms of carrying capacity (k), catchability coefficient (q) and fishing effort (e). For the harvesting model in accordance to the generalized (Schaefer 1954) (Anderson and Seijo, 2010) version, may represent short-run yield:

$$Y_t = qE_t X_t \qquad (10)$$

Where q is the catchability coefficient and E_t is fishing effort. The catchability coefficient is the embodiment of the technology that is used to harvest fish. The catchability coefficient changes over time due to technological and management changes.

Generalized Schaefer:

$$Y(x, e) = qE^{\alpha} X^{\beta} \qquad (11)$$

Where the coefficient β indicates the degree of schooling behavior by the fish, which β Є [0,1]. And 0 <α ≤ 1.

3.3 The cost and net benefits function

Consequently, the costs of fishing effort will be a linear function of the amount of effort –index of economic input in the form of labor, investment, fuel, maintenance and supplies, fixed costs and overhead that is devoted to the fishery on an annual basis. The annual cost of fishing $C(e)$ is proportional to effort (e). For this report, it was assumed that the fishing boats are homogeneous. The cost function is expressed as:

Specific form: $$C(e) = ce + fk \qquad (12)$$

Where c represents marginal costs, and fk represents fixed costs.

The net benefits function assumes a constant price p, which when multiplied by harvests will give the revenues (R) from the fishery. Profits (π) are therefore obtained by subtracting total costs ($C(e)$) which include; (i) costs associated with fishing effort and harvest and (ii) costs independent of fishing effort and harvest or fixed costs fk, from the marginal revenues (R), thus obtaining the following:

$$R = py(e, x) \qquad (13)$$

$$C(e) = ce + fk \qquad (14)$$

$$c = \frac{\sum(c_1 e + c_2 e + c_3 e + c_4 e + \cdots)}{e_{No.of\ fishing\ day\ per\ vessel}}$$

Where c_1 is the cost of fuels and lubricants, c_2 is the cost of ice for fish conservation on board, c_3 is the cost of food and supplies, c_4 is the cost miscellaneous.

$$fk = \sum (fk_1 + fk_2 + fk_3 + fk_4 + fk_5 + \cdots)E$$

Where fk_1 is the value of depreciation of the vessel, fk_2 is the value of the vessel and fishing gear insurance, fk_3 the value of the fishery license, fk_4 is the captain and machinist wage, fk_5 is the cost of vessel and fishing gear maintenance, and E represent the number of boats in the fishery.

The short-run total cost C_s may be represented:

$$C_s(e, y) = c_s e + \delta(pye - c_s e) + fk \qquad (15)$$

Where $\delta(pye - c_s e)$ represents the share of the crew, and $1 > \delta \geq 0$, and $c_s e$ represents the variable cost per fishing day in a short-run option, represents as following:

The long-run total cost C_l may be represented:

$$C_l(e, y) = c_l e + \delta(pye - c_l e) + fk_l e \qquad (16)$$

Where $c_l e$ represents the variable cost per fishing day in a long-run option, and the fk_l represents the fixed cost in a long run option that can be expressed:

$$fk_l = \frac{fk}{E} \frac{1}{DAS}$$

DAS represents the day at sea per year per vessel, it is an assumption around 110 day at sea per vessel per year estimated according to fishing effort data available.

The profits from the fishery are defined as the total revenues $R = py(e)$ less total costs $C(e)$ defined above, and therefore the profits function are:

$$\pi(e, x) = py(e, x) - C(e, y) \qquad (17)$$

Or, the profits at Short-run (π_s) can be expressed:

$$\pi_s(e, x) = p\big(y(e, x)\big) - (1 - \delta).\,(py(e, x) - c_s e) - c_s e - fk \qquad (18)$$

The profits at long-run (π_l) can be expressed:

$$\pi_l(e, x) = p\big(y(e, x)\big) - (1 - \delta).\,(py(e, x) - c_l e) - c_l e - fk_l e$$

3.4 Fishery reference points and optimisation

3.4.1 Static reference points

The static analysis is sufficient to explain the basic concept and to demonstrate why an open access system with no or incomplete property rights will provide incentives that will often lead to an inefficient combination of effort and stock size (Anderson and Seijo, 2010). Though static reference points are useful, their static nature diminishes their utility as fisheries management tools. This is especially true since it is unlikely that any fishery is in complete equilibrium at any given time (Seijo *et al*., 1998).

3.5 Static reference points for the maximum sustainable yield (MSY), maximum economic yield

(MEY) and the bionomic equilibrium (BE) will be examined using the biological and economic model described above. Reference points are included for the stock biomass, harvest and effort levels as well as for revenues, costs and profits within the fishery (see Appendix). The biological components of these reference points will be determined in accordance to the generalized Schaefer (1954), Anderson and Seijo (2010), Whitmarsh (2011) and Bjørndal *et al.*, (2012).

Biomass at MSY may be obtained using the formula:

$$X_{MSY} = \frac{\alpha}{2\beta} \qquad (19)$$

And,

$$k = X_{max} = \frac{\alpha}{\beta} \qquad (20)$$

While the associated harvest is obtained as follows:

$$Y_{MSY} = \frac{\alpha^2}{4\beta} = \frac{r}{4} k \qquad (21)$$

Or,

$$Y_{MSY} = \alpha E_{MSY} + \beta E_{MSY}^2$$

3.5.1 The Static model for long run and short run sustainable fisheries

Fisheries management is typically a complex problem, from both an environmental and political perspective. The main source of conflict occurs between the need for stock conservation and the need for fishing community well-being, which is typically measured by employment and income levels. For most fisheries, overexploitation of the stock requires a reduction in the level of fishing activity. While this may lead to long-term benefits (both conservation and economic), it also leads to a short-term reduction in employment and regional incomes. In regions which are heavily dependent on fisheries, short-term consequences of conservation efforts may be considerable (Mardle *et al*., 2001).

The long run is the conceptual time period in which there are no fixed factors of production, so that there are no constraints preventing changing the output level by changing the capital stock or by entering or leaving an industry. The long run contrasts with the short run, in which some factors are variable, and others are fixed, constraining entry or exit from an industry. In macroeconomics, the long run is the period when the general price level, contractual wage rates, and expectations adjust fully to the state of the economy, in contrast to the short run when these variables may not fully adjust (Keynes, 1936).

In static model for long run, change production levels in response to (expected) economic profits or losses, and the land, labor, capital goods and entrepreneurship vary to reach associated long-run average cost. In the simplified case of plant capacity as the only fixed factor, a generic firm can make these changes in the long run (i) enter an industry in response to (expected) profits (ii) leave an industry in response to losses (iii) increase its plant in response to profits (iv) decrease its plant in response to losses.

3.6 Sensitivity Analysis

A sensitivity analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input. The sensitivity analysis can be helpful in overcoming, at least partly, the difficulties arising in the parameter determination and validation of complex fisheries models or procedures. Sensitivity analysis can be used for (i) the so-called internal model validation (i.e., determination whether the levels of uncertainties in the estimated input parameters are acceptable for modelling purposes or not), (ii) estimating the relative contribution of uncertainty in each input parameter to the model output uncertainty, and (iii) determining the levels of input parameter uncertainties which would lead to acceptable model results (Majkowski, 1982). Global sensitivity analysis is normally conducted by varying the values of model parameters around their reference value with a given amplitude, traditionally ±20% (De Castro *et al*., 2001; Elkalay *et al*., 2003). The impact of these variations on one or several response variables is then assessed. Performing a sensitivity analysis requires (i) definition of input "factors" and their modalities (values), (ii) choice of response variables to be considered, (iii) use of an appropriate simulation design, and (iv) definition of the statistical model to be applied to analyses the response variables (Lehuta *et al*., 2010). Sensitivity indices (SIs) were assessed by the fit of a meta-model to response variables.

4 DATA SOURCES

The data for this report was collected from different sources. The data required was classified into two categories: biological and economic data.

4.1 Biological data

The data for the biological production of the pelagic fishery, including biomass, harvest quantities for the period 2003 to 2012 are based on statistical reports from INDP Statistics Division. In the Statistics Division, the harvest data from industrial fleet are based on statistic system with a sampling plan (Shimura, 1984). However, the total harvest data from industrial fleet is the sum of the collected data in industrial fishing ports in the islands of Santiago, S. Vicente, S. Nicolau and Sal. Thus, only for the artisanal fleet data, this sampling plan has a spatial stratification where each island is sampled every month resulting in a temporal stratification based on months. So, the nine islands are treated as a nine (spatial) strata with the twelve months of the year. The overall coverage rate is 18% of the 97 landings ports in Cape Vert. According to Shimura (1984), those sampling ports were selected considering the number of boats and fishing gear available and the accessibility. Six random samplings are made each month for collection of data. Those data are used for harvest monthly estimation for each landing port through the extrapolation factor between the number of working days of the month and the number of sampled days, further, the island boats number and the sampled port boats number.

These data show that the total harvest of the industrial fleet is greater than artisanal fleet. Further, the harvest from industrial fleet is geared toward export, while the artisanal fleet has targeted the small local market only.

4.2 Effort data

The associated effort are based on statistical reports from INDP Statistics Division. And, the associated effort is split depending on category of fleet, thus, for industrial fleet the associated effort are days at sea, and for artisanal fleet the associated effort is the number of trips. The associated effort was developed by obtaining the number of licensed industrial boats per year from the Statistic Division database.

4.3 Economic data

The economics of the pelagic fishery was analysed from estimates of marginal costs, revenues and profits, and included were also harvest effort and fish price from 2003 to 2012. The data were based on information from the Statistic Division of INDP. However, the cost data was estimated according to the INDP research vessel which is used as both a research and industrial vessel. The costs incurred by the vessel was used to calculate the total costs incurred by other vessels because the vessel has similar technical features (length, gross tonnes, engine horse power, etc.) found in the semi-industrial and industrial fleet as defined in the previous chapters. Then, assuming research fishing vessel is adequately similar and often go out ten times per month on fishing trips lasting roughly two days, usually operating 11 months per year, with one month reserved for maintenance of the ship and fishing gear we obtain the total number of fishing day per year, and per boats.

Additional input and comparative information were obtained through interviews with persons involved in the fisheries sector, including ship-owners and fishers, and from public data sources such as the Statistics Division database (INDP, 2014).

4.4 Estimation of parameters

4.4.1 Biological parameters

The biological parameters for the industrial fisheries like intrinsic growth rate alpha (α) and the mortality rate beta (β) were estimated using linear regression of CPUE (catch per unit of effort) versus effort taking into account the available data on harvests and effort each year (2003-2012) (see Appendix). As explained previously in the biomass growth function, it is possible to get the Xmax or the carrying capacity (K) from the expression $K = \frac{\alpha}{\beta}$. The effort at maximum sustainable yield was obtained from the expression $E_{MSY} = \frac{\alpha}{2\beta}$ and the sustainable yield as a function of effort was obtained from the equation $Y_{MSY} = \alpha E_{MSY} + \beta E_{MSY}^2$ Then, the value obtained for the biological parameter are given below in Tables 2, 3, and 4.

Table 2: Biological parameters estimated for the Small pelagic fishery in Cape Verde

Biological parameters	Estimate	Lower	Upper	R square
Alpha	0.921668	0.55111	1.292222	0.98587
Beta	-0.000066			
Xmax (K)	13,990.9	8,365.9	19,615.8	
E_MSY	6,995.4	4,182.9	9,807.9	
Y_MSY	3,223.7	1,152.6	6,337.0	

Table 3: Biological parameters estimated for the tuna fishery in Cape Verde

Biological parameters	Estimate	Lower	Upper	R square
Alpha	0.506510	0.19455	0.818468	0.90222
Beta	-0.000049			
Xmax	10,410.9	3,998.9	16,822.9	
E_MSY	5,205.5	1,999.4	8,411.5	
Y_MSY	1,318.3	194.5	3,442.3	

Table 4: Biological parameters estimated for the other fish category in Cape Verde

Biological parameters	Estimate	Lower	Upper	R square
Alpha	0.044324	0.00741	0.09606	0.98436
Beta	- 0.000002			
E_MSY	9,626.6	1,609.2		
Y_MSY	213.3		1,002.0	

4.4.2 Economic parameters

The total costs (TC) are defined as the sum of the fixed costs (fk) and variable costs as explained above. The fixed costs are those incurred independent of fishing activity and will include: (i) depreciation of vessel value and equipment (ii) vessel and fishing gear insurance (iii) fishery license (iv) captain and machinist annual wage (v) vessel and fishing gear maintenance (vi) management and overhead costs. Annual fixed costs are shown in Table 5. The estimate for the value of vessel and equipment is based on information given in interviews which produces a collective estimated value of 14,000,000 CVE (Cape Verde currency), with an annual depreciation rate of 4%. Thus, total annual depreciation costs are obtained from the value of the vessel and equipment estimated divided by 25 years (annual depreciation) which is equal to 560,000 CVE per year, with the average annual maintenance cost around 54,000 CVE. The licensing fee is equal to 26,356 CVE per year, and the vessel and fishing gear insurance are estimated to be 298,653 CVE. Cost associated with the fixed wage (captain & machinist) were estimated around 864,000 CVE. Thus, total fixed costs (fk) are estimated to be 2,291,009 CVE, per year per vessel.

Then, the fixed cost can be expressed in the equation:

$$fk = \sum(fk_{depreciation} + fk_{insurance} + fk_{licence} + fk_{wage} + fk_{maintenance}).E_{No.of\ boats}$$

Table 5: Annual fixed cost estimates associated with each industrial vessel

Item	Fixed costs, value (CVE)
Depreciation	560,000.00
Vessel and fishing gear insurance	298,653.00
Fisheries License	26,356.00
Captain & machinist wage	864,000.00
Vessel and fishing gear maintenance	542,000.00
Total (fk)	**2,249,009.00**

Whereas, the variable costs are those which depend on fishing activity and will include (i) fuels & lubricants, (ii) ice for fish conservation on board, (iii) foods and supplies (iv) miscellaneous. The fuel cost estimated are based on trip data for cost of travel up to the main fishing grounds and back to the landings ports, calculated at the average price in 2012 which placed this value at 91,500 CVE per ton. According to the research fishing vessel data, the fuel consumption per year is around 32 tonnes, multiplying that value by per average price in 2012, the total fuel annual cost is placed in 2,928,000 CVE. The average amount of ice used per year is around 75 tonnes and the average ice price is around 12,500 CVE per ton, so the total cost is around 937,500 CVE. Foods and supplies are estimated at 439,600 CVE. And miscellaneous items totaled approximately 220,000 CVE. Thus, the total variable cost is estimated to be 4,525,100 CVE per year per vessel, as shown in Table 6. With the assumption that each vessel goes out 130 days per year, the variable cost per fishing day (c) are estimated around 34,808 CVE per vessel.

Then, the variable cost per fishing day can be expressed in the equation:

$$ce = \frac{\sum(c_{fuel} + c_{ice} + c_{foods} + c_{miscellaneous})}{No.of\ fishing\ day\ per\ vessel} * e_{Total\ day\ at\ sea}$$

Table 6: Variable cost per year and per fishing day estimated, associated with each fishing vessel

Item	Variable costs, Value (CVE)
Fuels & lubricants	2,928,000.00
Ice for fish conservation on board	937,500.00
Foods	400,000.00
Fresh Water	39,600.00
Others supplies	220,000.00
Total (ce)	**4,525,100.00**
Variable Cost per fishing day	**34,808.46**

Then, the total cost function was be expressed as:

$C_s(e,y) = c_s e + \delta(pye - c_s e) + fk$, representing the short-run total cost C_s,

And,

$C_l(e,y) = c_l e + \delta(pye - c_l e) + fk_l e$, representing a long-run total cost C_l .

Where δ is the share of the crew. The share of crew is estimate as 50% of total revenue minus variable cost that may be expressed as:

$$\delta = (py - ce)\,(0.5)$$

The parameter p was estimated based on overall fish price for the period 2003 to 2012 (see appendix).

Within this context, and based on the economic parameters and the harvest function the profit function may be expressed as:

$$\pi = py - (ce + \delta + fk)$$

5 RESULTS

5.1 The static model of the fishery

Sustainability can be reached at many levels of biomass. According to Gorgon (1954) the particular interests are the bionomic equilibrium, the maximum sustainable yield biomass and the maximum economic yield biomass, where the $TR_E = TC_E$. Hence, the fishery would expand up to E_{BE}, in that case the resource would then be in equilibrium, since harvesting is being undertaken on a sustainable yield basis, and the perfectly competitive fishing industry would also be in equilibrium, since true economic profits would be equal zero.

Thus, sustainability or equilibrium biomass solutions are quite important as they imply long-run stability in biological and economic point of view.

5.1.1 The short-run sustainable fishery policy

Figure 9 is basically a summary of the short-run sustainable fishery model for Cape Verde (industrial pelagic fisheries) based on modified Gordon-Schaefer specifications in which have associated revenue, cost and profits, in fishing effort.

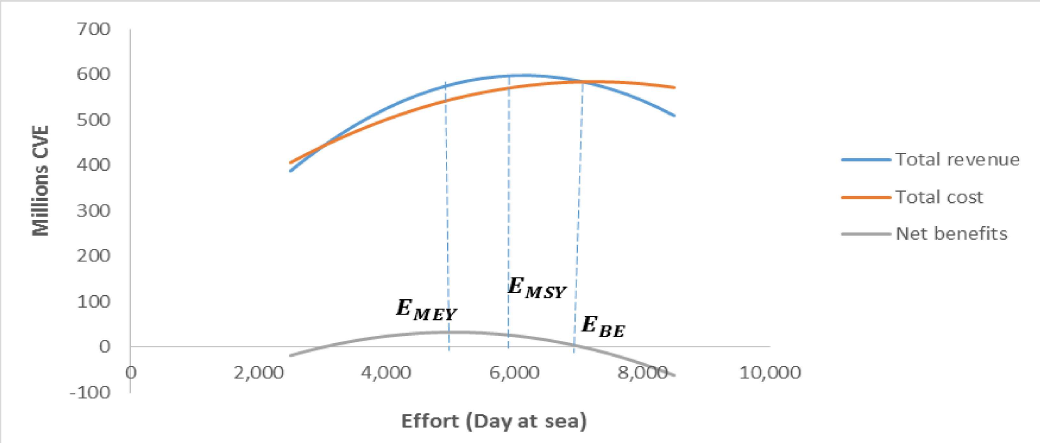

Figure 9: Short-run sustainable fishery model for Cape Verde (industrial pelagic fisheries) based on modified Gordon-Schaefer specifications

Note that the net benefits curve represents the profits, after having subtracted the variable cost from the total revenue and then, 50% crew share, and the fixed cost.

Equilibrium fisheries management reference points were calculated based on the modified Schaefer-Gordon bioeconomic model showed above. The reference point includes the current condition (2012), in order to calculate the bioeconomic equilibrium (BE), maximum sustainable yield (MSY) and maximum economic yield (MEY). Thus, Table 7 below presents an economic outcome corresponding, according to these reference point.

Table 7: Short-run sustainable equilibrium and current (2012) reference point for industrial pelagic fisheries.

Reference points	No. Vessel	Effort (Day at sea)	Total Revenues	Variable Cost	Wages	Fixed	Total Costs	Net benefits (1000 CVE)
CURRENT SITUATION	96	6,264	597,366	218,040.20	189,663	168,675.68	576,378.98	20,987
BE	96	7,077	583,687	246,335.34	168,675	168,675.68	583,686.69	0
MSY	96	6,140	597,611	213,713.03	191,949	168,675.68	574,337.89	23,274
MEY	96	5,042	578,505	175,499.85	201,502	168,675.68	545,678.01	32,827

The current (2012) fishery reference situation indicates that fishing effort is slightly excessive compared to the optimal levels (MSY and MEY), despite this the total revenue improves slightly compared with short-run optimal levels. Nevertheless, the variable cost associated with the excessive effort, decreases the share of the crew, and the net benefits from the fishery. It is assumed that in the short-run sustainable option the the number of vessel remaind constant like the current (2012) fishery reference situation in order to reach E_{BE} ; E_{MSY} ; E_{MEY} option, changing only the total day at sea per year.

However, the most efficient outcome in the short run is reached at the MEY option. In the MEY option, the net benefits could increase 56% compared to the current net benefits level, and 36% compared to the MSY profits level. Hence, whether this MEY option have been chosen, means that the fishing effort would need to be adjusted including an initial reducing to the E_{MEY} level.

Note that based on the total cost estimated for the pelagic fishery, the values are also affected by the fishing effort level, on the sustainable BE, MSY and MEY equilibrium options. However, these are fairly close to each other with slight differences, most notable is the fact that there is small overall profits to be made using MSY static short-run option. Thus, the fact that the MSY option to be close the BE may call for caution as a MSY-policy would represent an economic risk, showing that again the MEY option is better. The effect of such risk could be easy realized based on historical effort levels data which show the implications in the net benefits from the fishery on each BE, MSY and MEY option.

Those outcomes are very important and will have significant implications for any management strategy developed. Levels of fishing effort based on historic data are shown in Table 8.

Table 8: Different levels of fishing effort based in historical data (2003-2012) comparing with net benefits (1000 CVE) each year.

Years	Effort (Days at Sea)	Harvest (tons)	Revenue	Variable Cost	Wage	Fixe Cost	Total Cost	Net Benefits
2003	5,123	3,196	229,062	90,242	69,410	121,574	281,225	-52,163
2004	2,682	3,415	248,036	53,616	97,210	134,839	285,664	-37,629
2005	1,068	3,168	245,410	26,541	109,434	130,618	266,593	-21,183
2006	1,738	5,657	481,934	42,363	219,786	138,139	400,287	81,647
2007	4,916	4,432	405,205	110,963	147,121	127,674	385,758	19,447
2008	4,971	4,102	386,869	110,510	138,179	130,890	379,579	7,290
2009	6,184	4,320	450,956	171,900	139,528	193,378	504,806	-53,850
2010	7,197	4,831	541,424	232,321	154,551	244,705	631,577	-90,153
2011	6,818	4,620	549,625	253,289	148,168	251,425	652,882	-103,257
2012	6,264	5,951	775,980	218,040	278,970	215,905	712,915	63,065

As can be seen on Table 8, the fishing effort levels, have been highly variable, in some case very close or even overtaking the bioeconomic equilibrium, thus affecting negatively the net benefits from the fishery.

5.1.2 The long-run sustainable fishery

In the previous chapter a short-run option for the sustainable fishery was shown, however, in order to provide an understanding of the long-run sustainable fishery model, a long-run sustainable option for the industrial pelagic fishery was simulated to explain how the revenue, cost and profits will behave, according to the fishing effort levels. The outcomes were shown according to each option E_{BE} ; E_{MSY} ; E_{MEY} . Thus, Figure 10, shows the long-run sustainable fishery model for pelagic fisheries. Table 9 outlines the long-term sustainable equilibrium for pelagic fisheries in Cape Verde.

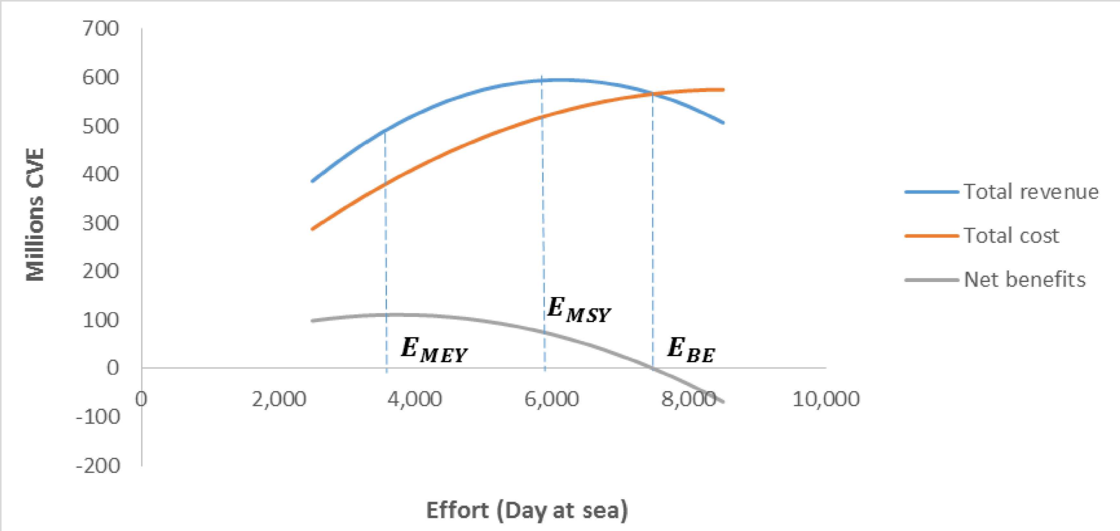

Figure 10: Long-run sustainable fishery model for Cape Verde (industrial pelagic fisheries) based on modified Gordon-Schaefer specifications

Table 9: Long-run sustainable equilibrium and current (2012) reference point for industrial pelagic fisheries

Reference points	No. of Vessel	Effort (Day at Sea)	Total Revenues	Variable Cost	Wages	Fixed Cost	Total Costs	Net benefits (1000 CVE)
CURRENT SITUATION	96	6,264	597,366	218,040	189,663	128,071	535,774	61,592
BE	68	7,504	568,083	261,218	153,432	153,432	568,083	0
MSY	56	6,140	597,611	213,713	191,949	125,529	531,191	66,420
MEY	34	3,752	507,246	130,609	188,319	76,716	395,644	111,602

The simulations above (Figure 10 and Table 9), show that this long-run sustainable option is better in order to get a sustainable and profitable fishery compared with the short-run sustainable option. It is therefore more important to reduce the number of vessels participating in the fishery then cut down on the number of days at sea. As can be seen, the current (2012) fishery reference situation indicates a fishing effort and investment strongly excessive, compared with the long-run sustainable option, hence, the cost associated with excessive effort, reduces the net benefits of the fishery. However, in the long-run sustainable option is assumed that the the number of vessel can change in order to reach E_{BE} ; E_{MSY} ; E_{MEY} option, so the overall fixed cost can change as well.

The MEY option presents the best and most efficient sustainable outcome for the fishery. Here the net benefits can reach almost 2 times more then the current profits, and almost 0.5 times more then the MSY profits level, however suggests that there be largest investment in reduction of fishing effort to allow this efficient sustainable outcome. Although this approach shows an extreme path to the optimal sustainability the fundamental principle of this approach can still be appreciated from a management point of view.

5.2 Sensitivity analysis

The sensitivity analysis consists of varying both the model and the management measure parameters and measuring the effect it has on model outcome. The model used to calculate the short-run and long-run sustainable fishery discussed above is subject to considerable uncertainty. Among other things the parameters used in the model may well be erroneous. In order to check the robustness of the calculated short-run and long run sustainable fisheries parameter misspecification, a sensitivity analysis of short run and long run sustainable fisheries to parameters values was conducted. The sensitivity analysis was run under scenarios to assess the impact of each parameter separately on the response variables (maximizing net benefits) so, the levels of factors were defined by variations between -30% to 30% around the reference value of the key parameters, variable costs and fish price.

5.2.1 Sensitivity analysis of the Short-run sustainable fisheries

The sensitivity analysis was carried out and the results in this context based on changed assumptions of the base year (2012) indicated that the net benefits of the pelagic fishery are ranging between -52,721 thousand CVE and 120,264 thousand CVE when the fish price is assumed to change between -30% to 30% from the current fish price, and remaining the costs, according to the short-run sustainable fishery model for Cape Verde industrial pelagic fishery based on modified Gordon-Schaefer. The analysis shows that the model is very sensitive in relation to changing fish price, keeping the costs like the current (2012) situations, as shown in Figure 11 and Table 10.

The sensitivity analysis further indicates that changes in variable costs remaining current fish price, have slightly changes in net benefits (Figure 11 and Table 11), between 7,362 thousand CVE and 60,012 thousand CVE. The E_{MEY} in this situation remains almost the same as the E_{MEY} got from the model.

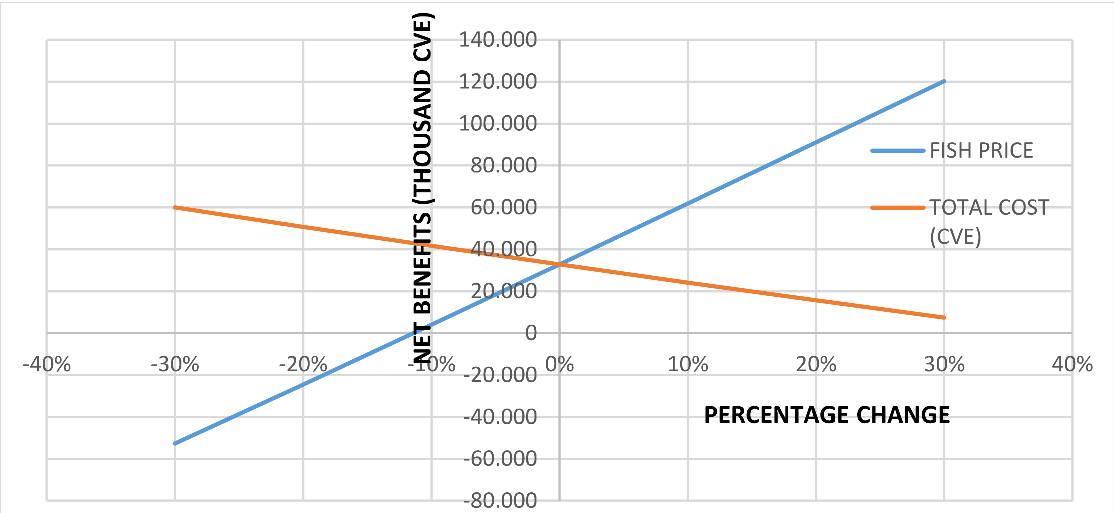

Figure 11: Sensitivity analysis, short-run sustainable fisheries

Table 10: Sensitivity analysis: changing fish price of the current (2012) fishery reference situation, keeping the costs in a short-run sustainable relationship

Fish price		Short Run Sustainable Relationships (Sensitivity analysis - change in fish price)										
% Change	No Vessel	E MEY	Revenue			Total Revenue	Variable costs	Wages	Fixed costs	Total Costs	π (Short-run)
-30%	75	4,571	216,841	153,642	20,550	391,033	159,123	115,955	168,676	443,753	-52,721
-20%	75	4,767	253,067	176,973	24,166	454,206	165,947	144,130	168,676	478,752	-24,546
-10%	75	4,920	288,948	199,911	27,761	516,621	171,254	172,683	168,676	512,613	4,008
0%	75	5,042	324,589	222,574	31,341	578,505	175,500	201,502	168,676	545,678	32,827
10%	75	5,142	360,055	245,037	34,911	640,003	178,974	230,515	168,676	578,164	61,839
20%	75	5,225	395,390	267,349	38,473	701,212	181,869	259,671	168,676	610,216	90,996
30%	75	5,295	430,623	289,546	42,028	762,197	184,318	288,940	168,676	641,934	120,264

Table 11: Sensitivity analysis: changing variable costs of the current (2012) fishery reference situation, keeping the fish price in a short-run sustainable relationship

Costs		Short Run Sustainable Relationships (Sensitivity analysis - change in costs)									
% change	No Vessel	E MEY	Revenue			Total Revenue	Variable costs	Wages	Fixed costs	Total Costs	π (Short-run)
-30%	75	5,371	333,066	222,568	32,615	588,249	130,875	228,687	168,676	528,238	60,012
-20%	75	5,261	330,414	222,768	32,201	585,383	146,514	219,435	168,676	534,624	50,759
-10%	75	5,152	327,588	222,770	31,777	582,135	161,389	210,373	168,676	540,438	41,697
0%	75	5,042	324,589	222,574	31,341	578,505	175,500	201,502	168,676	545,678	32,827
10%	75	4,932	321,417	222,180	30,896	574,492	188,846	192,823	168,676	550,345	24,147
20%	75	4,822	318,071	221,587	30,440	570,098	201,429	184,335	168,676	554,439	15,659
30%	75	4,713	314,552	220,796	29,973	565,321	213,247	176,037	168,676	557,960	7,362

5.2.2 Sensitivity analysis of the long-run sustainable fisheries

The sensitivity analysis results in this context based on changed assumptions of the base year (2012) indicated that even the fish price change in a range of -30% to 30% keeping the total cost, the fishery also have potential for profitability between 41,325 thousand CVE to 190,817 thousand CVE, as shown in Figure 12 and Table 12.

On the other hand, if the total cost change in the same range, however, keeping the fish price, like the current (2012) fishery situations, the fishery also has potential profitability between 158,275 thousand CVE to 74,937 thousand CVE as shown in Figure 12 and Table 13.

And the E_{MEY} in a both situations remains almost the same as the E_{MEY} got from the model.

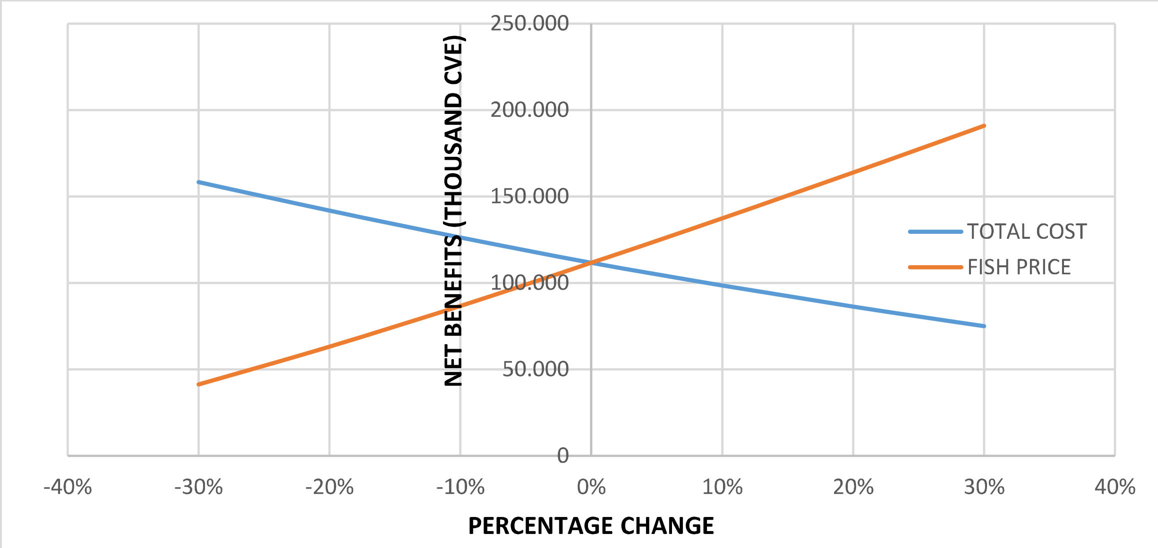

Figure 12: Sensitivity analysis, long-run sustainable fisheries

Table 12: Sensitivity analysis: changing fish price of the current (2012) fishery reference situation, keeping the costs in a long-run sustainable relationship

Day at sea per year per vessel	110

Fish price	Long -run Sustainable Relationships (Sensitivity analysis - change in fish price)										
% Change	No Vessel	E MEY		Revenue		Total Revenue	Variable	Wages	Fixed	Total Costs	π (Long-run)
-30%	25	2,729	154,769	120,659	13,808	289,235	94,993	97,121	55,796	247,911	41,325
-20%	29	3,155	196,769	150,590	17,775	365,133	109,833	127,650	64,513	301,996	63,137
-10%	32	3,487	237,142	178,661	21,643	437,445	121,375	158,035	71,293	350,703	86,742
0%	34	3,752	276,375	205,430	25,441	507,246	130,609	188,319	76,716	395,644	111,602
10%	36	3,969	314,781	231,252	29,190	575,223	138,164	218,529	81,154	437,847	137,376
20%	38	4,150	352,565	256,364	32,900	641,830	144,460	248,685	84,852	477,996	163,833
30%	39	4,303	389,871	280,930	36,582	707,383	149,787	278,798	87,981	516,566	190,817

Table 13: Sensitivity analysis: changing total costs of the current (2012) fishery reference situation, keeping the fish price in a long-run sustainable relationship

Costs	Long run Sustainable Relationships (Sensitivity analysis - change in costs)										
% Change	No Vessel	E MEY		Revenue		Total Revenue	Variable Costs	Wages	Fixed Costs	Total Costs	π (Long-run)
-30%	41	4,468	306,107	218,328	28,898	553,333	108,878	222,227	63,952	395,057	158,275
-20%	38	4,230	297,016	214,966	27,796	539,778	117,784	210,997	69,183	397,964	141,814
-10%	36	3,991	287,106	210,667	26,643	524,416	125,028	199,694	73,438	398,159	126,256
0%	34	3,752	276,375	205,430	25,441	507,246	130,609	188,319	76,716	395,644	111,602
10%	32	3,526	265,469	199,613	24,258	489,341	135,022	177,159	78,587	390,769	98,572
20%	30	3,301	253,830	192,958	23,031	469,818	137,863	165,978	79,628	383,468	86,350
30%	28	3,075	241,456	185,464	21,759	448,678	139,132	154,773	79,836	373,742	74,937

6 DISCUSSION

6.1 Sustainable fishery

The model used in this paper is a static model based on modified Gordon-Schaefer specifications that seeks to provide an estimate for optimal management of the pelagic fishery in Cape Verde. The major obstacle has been limited data mainly on running costs of fishing vessel, and biological data (abundance). However, the data on harvest and effort are available and seem to fit quite well with the assumptions of the static model. The estimates obtained seem to be realistic in terms of describing the current situation and the possibilities for improvements in management. There is no optimal dynamic model applied in this paper due to lack of data. Static analysis precludes the consideration of the time it takes the fish stock to adjust to changes in effort (Anderson and Seijo, 2010). Future studies could explore different specifications and apply the optimal dynamic model that takes into consideration changes in biomass, effort, costs and benefits (profits) over time.

The results for historical profitability of the fishery are as predicted. The fishery operates close to and sometimes beyond the BE. Analysis of the period 2003 to 2012 shows very high fluctuation in the net benefits of the fishery. The net benefits were most of the time small or negative due to excessive fishing effort which has resulted in high costs, while the total revenue has remained low. The short-run and long-run sustainable fishery analyses indicates excessive fishing efforts. The harvests are lower, however, the total cost are very high, which has resulted in a weak net benefits from the fishery over time. Consequently, the fishery finds itself at a stage close to the BE. Despite this, this current state may present an opportunity for management. The MEY short-run solution showed that the fishery has a potential for sustainable profits around 32,827 thousand CVE annually equal to 6% of the total revenue, slightly higher when compared with the current profits of 20,987 thousand CVE annually equal to 3.5% of the total revenue. This would however require an adjustment in the fishing effort levels.

The short-run solution showed that some improvements in the pelagic fishery could be realized in order to maximize economic rents, if the MEY optimal management solution is applied. It was also shown that the MSY option not only increases the revenue but also reduces the total cost consequently increasing the net benefits of the fishery. It is important as well that the short-run solution has shown that excessively high effort levels would eventually lead to BE. Therefore, the results indicate that in order to reach the optimum sustainable yield and maximise economic yield, fishing effort needs to be reduced from 6,264 to 5,042 days at sea.

The sensitivity analysis has also shown that the model is very sensitive to changing fish price, keeping the costs at the current situations. This means that if this happens an adjustment of fishing effort is needed. However, the model is a little bit sensitive to changing variable cost, showing changes in the profit levels.

On the other hand, the long-run solution shows a potential for substantial improvements in profitability that could be realized in the large-scale fishery by applying long-run MEY optimal management. The result shows that the MEY long-run solution fishery has a potential for sustainable profits around 111,602 thousand CVE annually, equal to 22% of the total revenue, compared with the current profits around 61,592 thousand CVE annually equal to 10% of the total revenue. Moreover, in order to reach the maximum benefits, fishing effort needs to be reduced from 6,264 to 3,752 days at sea.

The sensitivity analysis has shown that even if the biological parameter estimations and information on price and costs change considerably, the industrial pelagic fisheries has the potential to generate economic rents, ranging between 41,325 thousand CVE to 190,817 thousand CVE from the model.

However, the bioeconomic models developed here show that the industrial pelagic fisheries are generally slightly profitable. It shows further that suitable effort management can substantially increase profits.

6.2 Management solutions

These results raise questions about what type of fisheries management systems may be best to achieve the optimal fishery in a sustainable sense. The fundamental problems of Cape Verde fishery are like those in many other fisheries around the world. Different interests may influence what kind of management options are used, especially in the light of the common property nature of the resource (Seijo *et al.*, 1998). There are very little or no incentives for individual fishers to invest in a fish stock, the resource tends to be overexploited and fishing effort and fleets to be excessive (for a short-term gain). This is what is called an open-access situation, where the individual fisherman, acting alone, has no incentive to do what would benefit the group as a whole. This results in a waste of valuable resources used to obtain competitive advantages in obtaining catches rather than achieving economic efficiency in the methods of harvesting. However, the fisherman will make sacrifices for future gain, agreeing to a smaller catch, or fishing under frustrating regulations, whether they are assured that everyone else must do the same.

To generate efficiency in fisheries, that is, to solve the “common resources” fisheries problem, one way could be to establish adequately high-quality property rights in the fishery. High-quality property rights are sufficient to generate efficiency because (a) they make efficient operations possible and (b) the initial lack of efficiency implies that the opportunity to obtain efficiency will be used. It has been recognized for a long time that property rights constitute a foundation for economic efficiency (Smith, 1977).

It is well known that the two pillars of economic efficiency and progress are specialization in production and accumulation of capital. Overall there are two pillars of economic efficiency and progress are specialization in production and accumulation of capital (Barro, 1995; Smith, 1977). Without property rights, the accumulation of capital is not individually attractive because any accumulated capital will be seized by others. With property rights, however, savings and accumulation of physical, human, and natural capital can become individually profitable (Arnason, 2012). In summary, the lack of an appropriate property rights system is perhaps the main reason why fish stocks tend to be misused under an open access regime (Anderson and Seijo, 2010).

The solution to the fishery problems lies in the development and implementation of a property rights-based fisheries management (PRBFM) system to overcome the common property problem and generate economic efficiency in fishery. According to Hannesson (1993), the rights owners have strong incentive to harvest as efficiently as possible and limit fishing effort to any level that will maximize his profits from the fishery. PRBFMs are used widely in fisheries management worldwide to varying extents and include, but are not limited to, sole ownerships, aces licences, territorial user rights in fisheries (TURFs) and various forms of harvest quota systems (Arnason, 2008). The one chosen in many fisheries was limited licensing, and as has already been shown in the previous chapter, Cape Verde has adopted the limited licensing, most of them involved putting a limit both on the number of licences and on the permitted inputs (effort) available to each licence. In Iceland in the 1970s, for instance, there was a limit on the number of hours during which licence holder (each vessel) could fish. In other places there was a limit on the size of the licensed vessel, or its horsepower, or perhaps the number of traps or nets that it could carry (for an inshore fishery). These were all improvements on simple limited licensing, and versions of them are still being refined. But still each vessel under limited licensing wanted to beat the other vessel and beat the regulators too. Permits and licences are seen as property rights that are weak. Of these PRBFM systems, individual quotas (IQs) have proven to be most effective in solving the common property problem, particularly those that have been made transferable (Hannesson, 1993).

There are a number of conditions that must be developed for PRBFM to be successfully implemented. An effective property right is one which is secure in title, exclusive to the owner, durable in tenure, and preferably transferable to allow for a less efficient right holder to sell that right to a more efficient user (Arnason, 2008). However, improves the property rights in Cape Verde require better monitoring, control and surveillance (MCS) systems as well as judicial arrangements issuing sanctions to violators.

There are a number of ways that effort or catch management may be established but it is the way that they are imposed that will determine which, if any, objectives are satisfied. Hence, a more ideal option for the case of industrial pelagic fishery in Cape Verde, should start to implement the short-run sustainable fishery model, although, applying this model implies introducing some improvements in the approach to the current fisheries management. So, the short run suggestions here are basically in terms of reinforcing the input controls or fishing effort management, such as limited entry, as conservation measures. This is done to protect the fish stocks from becoming over-exploited and encouraging the recovery of the pelagic stocks. Restrictions might be put first on number of fishing licence issue, on the intensity of use of gear that fishers use to catch fish, on the number and size of fishing vessels (fishing capacity controls), and on the amount of time fishing vessels are allowed to fish (vessel usage controls) or the product of capacity and usage (fishing effort controls). These types of limited entry systems help to prevent outsiders from taking part in the fishery.

Stronger management of the existing fleet is needed in order to be more economically efficient, to try to develop it from the current situation of overcapacity towards long run profitability. One way to achieve this is to set up a system of total allowable number of boat days at sea for the fleet. Once use rights are allocated, the fisher is permitted to rent or lease use rights to another fisher within a fishing season. The rights then revert to the original fisher at the end of the season. This mechanism provides important flexibility so that a fisher who happens to become sick or whose vessel breaks down one year can still obtain some income by renting out the use rights. Transferability is often promoted as a means to improve economic efficiency, using an argument such as the following. According to FAO (2002) to be economically efficient, the participants in a fishing fleet should be those most profitable in harvesting the available fish. In theory, a market-based system, with divisibility and transferability of input or output rights, improves efficiency, as vessel owners who maximise the profits resulting from a given quota will buy up that quota from others - like a commodity on the market. The idea is that with transferability, the more ‘efficient’ vessel owners remain in the fishery, while others sell their quota and leave, in a ‘survival of the fittest’ process leading to increasing overall efficiency of individual fishers.

Also, since it is needed to regulate the impact on fish stocks, an ‘efficient’ fishery should be seen as one that produces the greatest net benefits for every fish caught. This implies that it is not a matter of getting large quantities of fish quickly and cheaply out of the sea, but rather getting the most from each fish that is taken. There is no reason to expect that buying and selling of transferable rights will reflect this broader idea of efficiency. The transferability increases the ‘mobility’ of individual fishers, allows each to exit the fishery when the revenue to be gained from the sale of the use right exceeds the expected benefits of remaining in the fishery (FAO, 2002). This provides maximum flexibility for the fisher and makes it easier for managers to reduce participation in the fishery. Conversely, non-transferrable systems provide better stability, but reduce mobility of the fishers - making it more difficult to reduce fishing power over time (capacity reduction). In particular, incentives exist to keep non-transferable rights in use as long as possible, to maximise actual benefits, and in the hope of a financial windfall should there be a later decision to allow transferability. This may mean that a boat will be used beyond its technological life, which can also create safety problems (FAO, 2002)

Thus input/effort allocations can be a viable approach to rights-based management if care is taken in defining the rights and if a suitable portfolio of rights is established (Hilborn *et al.* 2001), and if a plan is put in place to deal with fishing efficiency improvements and capacity control - as noted in the Code of Conduct. Note, however, that any quantitative rights system, whether involving effort rights or harvest quotas (see below) inherently requires certain data collection and monitoring schemes to operate; naturally, the cost and feasibility of these must be taken into account.

The main goal is to reach the long run sustainable fisheries. Once reached that input control or fishing effort management, it is possible to apply the output controls or catch management as conservation measures in a long-run. and the suggestion is implementation of the ITQs, an individual transferable quota (ITQ) system which has been successfully used to promote economic efficiency as well as biological conservation in some of the world`s most developed fisheries. Obviously, this requires added research and adds to the monitoring and enforcement costs under ITQ system, compared with another system like licencing system.

However, additional requirement would include deeper biological and economic programmes to assess the stock and determine TACs. Despite these challenges it seems certain that the fishery has the potential for sustainable profits and therefore an investment in an optimal management system may be worthwhile.

7 CONCLUSION

In this paper, a bioeconomic model has been developed to identify optimal management of pelagic fisheries, applied to the industrial pelagic fisheries of Cape Verde. It is found that the fishery was very close to and sometimes negatively overtaking the bioeconomic equilibrium and found to be at a stage that requires care in terms of management. On this basis, it is concluded that management in the years under analysis (2003-2012), did not work very well. Hence, the fisheries produce only small net benefits in some years that were analysed. So, this paper confirms the excessive effort level applied to this fishery. The paper identifies substantial opportunities for generating rents from the fishery. The results indicate that it can be increased 81% compared with the current profit in a long-run analysis, or 56% in a short-run analysis, implying that the fishery have potential to achieve the economic efficiency, but in order to reach this, the result suggest a reduction in fishing effort from the current 6,264 to 3,752 or 5,042.

Furthermore, the analysis suggests that in order to increase the economic efficiency, the biggest potential is in applying the long run sustainable fishery solutions, with the implementation of tradable property rights based system.

The literature on ecosystem-based fisheries management clearly shows that the exploitation of a pelagic stock might have a significant impact on the marine environment. Furthermore, pelagic species often have highly fluctuating recruitment, which influences management strategies. The model applied in this paper lacks deeper integration of these aspects, but they are important for a fully comprehensive fisheries management analysis.

8 RECOMMENDATIONS

- Effort levels should be reduced from 6,264 to 5,042 days at sea in a short-run solution, or from 6,264 to 3,752 days at sea, if the aim is to maximise the economic efficiency in a long-run solution.
- Development of legislative and institucional arrangements that allows the gradual implementation of an approprieted property rights-based fisheries management system.
- Improvement of the long-term biological and economic research programme and securing the national stock through improved MCS.
- Improve the local and international partnerships regarding the development and implementation of property rights in the fishery.
- Develop and implement the long-run sustainable fishery solution.
- Implementation of the ITQs for the harvest sector.
- Focusing on the quality and value of the product landed, or aggregation of value to fishery products rather than maximizing catch.

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APPENDIX

Appendix 1: Basic bioeconomic data and calculations for the period 2003 to 2012

Year	Harvest			Total Harvest	Effort		CPUE			Total Revenue	Costs		Net Benefit (1000 CVE)
	Small Pelagic	Tuna	Other		Day at sea	No. Boat	S. P	T.	O.		V. Cost	Fixe Cost	
2003	2,088	987	121	3,196	5,123	61	0.41	0.19	0.02	229,062	90,242	121,574	-52,163
2004	2,027	1,294	94	3,415	2,682	66	0.76	0.48	0.04	248,036	53,616	134,839	-37,629
2005	2,358	675	135	3,168	1,068	69	2.21	0.63	0.13	245,410	26,541	130,618	-21,183
2006	3,743	1,366	548	5,657	1,738	66	2.15	0.79	0.32	481,934	42,363	138,139	81,647
2007	3,360	801	271	4,432	4,916	61	0.68	0.16	0.06	405,205	110,963	127,674	19,447
2008	3,158	835	109	4,102	4,971	73	0.64	0.17	0.02	386,869	110,510	130,890	7,290
2009	2,762	1,438	120	4,320	6,184	73	0.45	0.23	0.02	450,956	171,900	193,378	-53,850
2010	3,377	1,316	138	4,831	7,197	96	0.47	0.18	0.02	541,424	232,321	244,705	-90,153
2011	2,977	1,429	214	4,620	6,818	96	0.44	0.21	0.03	549,625	253,289	251,425	-103,257
2012	3,946	1,709	296	5,951	6,264	96	0.63	0.27	0.05	775,980	218,040	215,905	63,065

Appendix 2: Linear regression Calculations

CPUE					
SMALL PELAGIC	TUNAS	OTHERS	EFFORT	D05_06	Lin_05_06
0.407573687	0.192661	0.023619	5123	0	0
0.755779269	0.482476	0.035048	2682	0	0
2.207865169	0.632022	0.126404	1068	1	1068
2.153624856	0.785961	0.315305	1738	1	1738
0.683482506	0.162937	0.055126	4916	0	0
0.635284651	0.167974	0.021927	4971	0	0
0.446636481	0.232536	0.019405	6184	0	0
0.469223287	0.182854	0.019175	7197	0	0
0.43663831	0.209592	0.031388	6818	0	0
0.629948914	0.272829	0.047254	6264	0	0

SUMMARY OUTPUT (SMALL PELAGIC)

Regression Statistics	
Multiple R	0.99291
R Square	0.98587
Adjusted R Square	0.97881
Standard Error	0.10107
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4.276745	1.425582	139.553256	0.000006
Residual	6	0.061292	0.010215		
Total	9	4.338037			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.92167	0.15144	6.08613	0.00089	0.55111	1.29222	0.55111	1.29222
EFFORT	-0.00007	0.00003	-2.47074	0.04841	-0.00013	0.00000	-0.00013	0.00000
D05_06	1.37266	0.34297	4.00227	0.00710	0.53344	2.21188	0.53344	2.21188
Lin_05_06	-0.00002	0.00021	-0.07014	0.94636	-0.00054	0.00051	-0.00054	0.00051

RESIDUAL OUTPUT

Observation	*Predicted CPUE*	*Residuals*	*Standard Residuals*
1	0.58418	-0.17661	-2.14009
2	0.74499	0.01079	0.13078
3	2.20787	0.00000	0.00000
4	2.15362	0.00000	0.00000
5	0.59782	0.08566	1.03804
6	0.59420	0.04109	0.49790
7	0.51429	-0.06765	-0.81978
8	0.44755	0.02167	0.26257
9	0.47252	-0.03588	-0.43483
10	0.50902	0.12093	1.46541

PROBABILITY OUTPUT

Percentile	*CPUE*
5.00000	0.40757
15.00000	0.43664
25.00000	0.44664
35.00000	0.46922
45.00000	0.62995
55.00000	0.63528
65.00000	0.68348
75.00000	0.75578
85.00000	2.15362
95.00000	2.20787

SUMMARY OUTPUT (TUNAS)

Regression Statistics	
Multiple R	0.9499
R Square	0.9022
Adjusted R Square	0.8533
Standard Error	0.0851
Observations	10.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.4008	0.1336	18.4540	0.0020
Residual	6	0.0434	0.0072		
Total	9	0.4443			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.5065	0.1275	3.9729	0.0073	0.1946	0.8185	0.1946	0.8185
EFFORT	0.0000	0.0000	-2.1675	0.0733	-0.0001	0.0000	-0.0001	0.0000
D05_06	-0.1199	0.2887	-0.4152	0.6925	-0.8264	0.5866	-0.8264	0.5866
Lin_05_06	0.0003	0.0002	1.5382	0.1749	-0.0002	0.0007	-0.0002	0.0007

RESIDUAL OUTPUT

Observation	*Predicted CPUE*	*Residuals*	*Standard Residuals*
1	0.2573	-0.0646	-0.9299
2	0.3760	0.1064	1.5322
3	0.6320	0.0000	0.0000
4	0.7860	0.0000	0.0000
5	0.2673	-0.1044	-1.5027
6	0.2647	-0.0967	-1.3917
7	0.2056	0.0269	0.3870
8	0.1564	0.0265	0.3813
9	0.1748	0.0348	0.5008
10	0.2018	0.0711	1.0230

PROBABILITY OUTPUT

Percentile	*CPUE*
5	0.1629
15	0.1680
25	0.1829
35	0.1927
45	0.2096
55	0.2325
65	0.2728
75	0.4825
85	0.6320
95	0.7860

SUMMARY OUTPUT (OTHERS)

Regression Statistics	
Multiple R	0.99215
R Square	0.98436
Adjusted R Square	0.97655
Standard Error	0.01411
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.07521	0.02507	125.91687	0.00001
Residual	6	0.00119	0.00020		
Total	9	0.07641			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0443	0.0211	2.0965	0.0809	-0.0074	0.0961	-0.0074	0.0961
EFFORT	0.0000	0.0000	-0.6185	0.5590	0.0000	0.0000	0.0000	0.0000
D05_06	-0.2190	0.0479	-4.5744	0.0038	-0.3362	-0.1019	-0.3362	-0.1019
Lin_05_06	0.0003	0.0000	9.4697	0.0001	0.0002	0.0004	0.0002	0.0004

RESIDUAL OUTPUT

Observation	*Predicted CPUE*	*Residuals*	*Standard Residuals*
1	0.033	-0.009	-0.773
2	0.038	-0.003	-0.269
3	0.126	0.000	0.000
4	0.315	0.000	0.000
5	0.033	0.022	1.920
6	0.033	-0.011	-0.951
7	0.030	-0.011	-0.927
8	0.028	-0.009	-0.745
9	0.029	0.003	0.240
10	0.030	0.017	1.506

PROBABILITY OUTPUT

Percentile	*CPUE*
5.00	0.02
15.00	0.02
25.00	0.02
35.00	0.02
45.00	0.03
55.00	0.04
65.00	0.05
75.00	0.06
85.00	0.13
95.00	0.32

Appendix 3: Short-run Sustainable Relationship

Short-run Sustainable relationships									
Effort (Day at Sea)	Revenue			Total revenue	Operating cost			Total cost	Net benefits (1000 CVE)
	Small pelagic	Tuna	Other		Variable	Wages	Fixed		
2,500	206,662	162,612	18,320	387,594	87,021	150,287	168,676	405,983	-18,389
2,750	222,383	173,220	19,852	415,455	95,723	159,866	168,676	424,265	-8,810
3,000	237,204	182,801	21,328	441,333	104,425	168,454	168,676	441,555	-222
3,250	251,126	191,354	22,750	465,230	113,128	176,051	168,676	457,854	7,375
3,500	264,148	198,879	24,117	487,145	121,830	182,658	168,676	473,163	13,982
3,750	276,272	205,377	25,430	507,078	130,532	188,273	168,676	487,481	19,598
4,000	287,496	210,846	26,688	525,030	139,234	192,898	168,676	500,807	24,222
4,250	297,821	215,288	27,891	541,000	147,936	196,532	168,676	513,144	27,856
4,500	307,246	218,702	29,040	554,988	156,638	199,175	168,676	524,489	30,499
4,750	315,773	221,088	30,134	566,995	165,340	200,827	168,676	534,843	32,152
5,000	323,400	222,447	31,173	577,019	174,042	201,489	168,676	544,207	32,813
5,250	330,128	222,778	32,157	585,063	182,744	201,159	168,676	552,579	32,483
5,500	335,956	222,081	33,087	591,124	191,447	199,839	168,676	559,961	31,163
5,750	340,886	220,356	33,962	595,204	200,149	197,528	168,676	566,352	28,852
6,000	344,916	217,603	34,783	597,302	208,851	194,226	168,676	571,752	25,550
6,250	348,047	213,823	35,549	597,418	217,553	189,933	168,676	576,161	21,257
6,500	350,278	209,015	36,260	595,553	226,255	184,649	168,676	579,580	15,973
6,750	351,611	203,179	36,916	591,706	234,957	178,375	168,676	582,007	9,699
7,000	352,044	196,315	37,518	585,878	243,659	171,109	168,676	583,444	2,433
7,250	351,578	188,424	38,065	578,067	252,361	162,853	168,676	583,890	-5,823
7,500	350,213	179,505	38,558	568,275	261,063	153,606	168,676	583,345	-15,070
7,750	347,948	169,558	38,995	556,501	269,766	143,368	168,676	581,809	-25,308
8,000	344,784	158,583	39,378	542,746	278,468	132,139	168,676	579,282	-36,537
8,250	340,721	146,581	39,707	527,009	287,170	119,919	168,676	575,765	-48,756
8,500	335,759	133,550	39,981	509,290	295,872	106,709	168,676	571,257	-61,967

Appendix 4: Long-run Sustainable Relationship

DAY AT SEA PER YEAR PER VESSEL	110

Long-run Sustainable relationships

Effort (Day at Sea)	Revenue			Total revenue	Operating cost			Total cost	Net benefits (1000 CVE)
	Small pelagic	Tuna	Other		Variable	Wages	Fixed		
2,500	206,662	162,612	17,356	386,630	87,021	149,805	51,114	287,940	98,691
2,750	222,383	173,220	18,807	414,410	95,723	159,343	56,225	311,292	103,118
3,000	237,204	182,801	20,206	440,210	104,425	167,893	61,337	333,655	106,556
3,250	251,126	191,354	21,553	464,032	113,128	175,452	66,448	355,028	109,004
3,500	264,148	198,879	22,848	485,875	121,830	182,023	71,559	375,412	110,464
3,750	276,272	205,377	24,092	505,740	130,532	187,604	76,671	394,806	110,933
4,000	287,496	210,846	25,283	523,625	139,234	192,196	81,782	413,212	110,414
4,250	297,821	215,288	26,423	539,532	147,936	195,798	86,894	430,627	108,904
4,500	307,246	218,702	27,511	553,460	156,638	198,411	92,005	447,054	106,406
4,750	315,773	221,088	28,548	565,409	165,340	200,034	97,116	462,491	102,918
5,000	323,400	222,447	29,532	575,379	174,042	200,668	102,228	476,938	98,441
5,250	330,128	222,778	30,465	583,370	182,744	200,313	107,339	490,396	92,974
5,500	335,956	222,081	31,346	589,383	191,447	198,968	112,450	502,865	86,518
5,750	340,886	220,356	32,175	593,416	200,149	196,634	117,562	514,344	79,072
6,000	344,916	217,603	32,952	595,471	208,851	193,310	122,673	524,834	70,637
6,250	348,047	213,823	33,678	595,547	217,553	188,997	127,785	534,335	61,213
6,500	350,278	209,015	34,351	593,645	226,255	183,695	132,896	542,846	50,799
6,750	351,611	203,179	34,973	589,763	234,957	177,403	138,007	550,368	39,396
7,000	352,044	196,315	35,543	583,903	243,659	170,122	143,119	556,900	27,003
7,250	351,578	188,424	36,062	576,064	252,361	161,851	148,230	562,443	13,621
7,500	350,213	179,505	36,528	566,246	261,063	152,591	153,342	566,996	-750
7,750	347,948	169,558	36,943	554,449	269,766	142,342	158,453	570,560	-16,111
8,000	344,784	158,583	37,306	540,673	278,468	131,103	163,564	573,135	-32,461
8,250	340,721	146,581	37,617	524,919	287,170	118,875	168,676	574,720	-49,801
8,500	335,759	133,550	37,876	507,186	295,872	105,657	173,787	575,316	-68,130