**Thesis for the Degree of Master of Fisheries Science**

# A Bioeconomic Analysis of Alternative Management Policies for the Fiji Long-line Fishery

by

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February, 2014

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A thesis submitted in partial fulfilment of the requirement for the degree of

Master of Fisheries Science

in KOICA-PKNU International Graduate Program of Fisheries Science

Graduate School of Global Fisheries

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February 21, 2014

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## List of Acronyms

| | |
|---|---|
| **EEZ** | Exclusive Economic Zone |
| **EU** | European Union |
| **FFA** | Pacific Islands Forum Fisheries Agency |
| **FJD** | Fijian Dollar |
| **GDP** | Gross Domestic Product |
| **ICCAT** | International Commission for the Conservation of Atlantic Tuna |
| **MCS** | Monitoring Control and Surveillance |
| **MT** | Metric tonnes |
| **NPV** | Net Present Value |
| **SPC** | Secretariat of the Pacific Community |
| **TAC** | Total Allowable Catch |
| **WCPFC** | Western and Central Pacific Fisheries Commission/ Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean |
| **WCPO** | Western and Central Pacific Ocean |
| **UNCLOS** | United Nations Convention on the Law of the Sea |
| **UNFSA** | United Nations Fish Stocks Agreement |
| **UK** | United Kingdom |
| **US** | United States |
| **USD** | United States Dollar |

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## Abstract

A bioeconomic model of Fiji's tuna longline fishery is developed to examine the effectiveness of management measures and to select an effective measure that increase biomass of the Fiji's target tuna species as well as generate high economic returns for the longline fishery.

The study employs the use of a basic bioeconomic model, the Schaeffer Model and uses its methodology to conduct the analysis. The target species used in the bioeconomic model are Albacore tuna (*Thunnus alalunga)*, Bigeye tuna (*Thunnus obesus*) and Yellowfin tuna (*Thunnus albacares*) which are the commercially important species targeted by the longline fleet in Fiji. A sensitivity analysis is also carried out to address the uncertainties associated with variations in the intrinsic growth rates of the target species on biomass and the net present value.

Six management scenarios were simulated in order to gauge the effectiveness of reducing effort levels and TAC on biomass and economic returns from the fishery. Of the management scenarios simulated, the most effective scenario resulting in increased biomass and a high net present value of the fishery was shown to be Scenario (II) a 25% reduction in the number of fishing days.

On the analysis of the effectiveness of the current total allowable catch (Scenarios IV to VI) a reduction in TAC to 10,000MT combined with a 25% reduction in the number of fishing days resulted in increased biomass, whereas a reduction in TAC alone, resulted in high economic returns in terms of net present value. Policy implications are suggested.

# CHAPTER I INTRODUCTION

The fisheries of the Fiji Islands are a nationally important sector to the economy of Fiji. The fisheries sector employs a large number of people, the fish provides an endless source of nutrition and sustenance to the diet of the local people and the fisheries are cherished for both its recreational and traditional aspects (Gillet, 2011). As an economically important sector, Fiji's fisheries currently contributes approximately 2.7% to national GDP raking in real domestic export earnings of FJD205million which equates to 20.5% of all exports for the country (Department of Fisheries, 2012)

Fiji's marine sector is divided into two distinct categories, the offshore fisheries and the coastal fisheries. The offshore fisheries consists almost exclusively of tuna long lining from vessels that are both local and foreign based; and the coastal fishery is carried out for semi-commercial and subsistence purposes, for sale in local markets and to some extent for overseas export market. The country's location, $17^{o}$ south of the equator, lies on the periphery of the world's richest tuna grounds between $10^{o}$ north and south of the equator (Barclay et al., 2006) and as such Fiji's waters are often targeted by long liners due to their high productivity in the tuna stocks that migrate through Fiji waters. As a result of this the majority of fish that is exported out of Fiji is produced from the tuna industry, with the targeted species for export being Big-eye tuna, Albacore and Yellow-fin tuna and other tuna related species of fish. The coastal fisheries of Fiji, on the other hand, is also a thriving sub-sector and contributes, to a small extent, to the significant primary producing sector of the country.

Fiji's fisheries are now recognized as the second largest exporting industry for the nation, and as such the demand for more fish to feed the export industry and to sustain the semi-commercial sectors and local communities is increasing. With the onset of advancing technological capabilities available to harvest fish being realized in many Pacific island developing countries such as Fiji, the ability to harvest fish has improved significantly in the past years. This has led to some fisheries hanging on the verge of being over-exploited. Overfishing is also one of the many problems that Fiji fisheries managers are now faced with and which are now having a likely impact on the sustainability of Fiji's fishery. Other current key management issues include, an out-dated and inadequate legislation, which does not consider changing and emerging regional and international management instruments crucial to the management of fisheries; the lack of enforcing current fisheries regulations are not always effectively implemented and the failure to heed scientific advice on adopting effective management measures are some key problems that are faced by Fiji fishery managers. Such issues warrant immediate attention by fishery managers if they are to realize a biologically and economically healthy stock of fish for the future.

Tuna, being the more developed industry in Fiji has over the years being largely targeted by local and foreign interests alike and the successful sustainable management of Fiji's tuna fisheries is now at a point where existing legislations require immediate reviewing in order to sustain the fishery for future generations. A recent policy brief issued by SPC in 2010 on an overview and status of tuna stocks of the WCPFO tuna fishery showed that responsible management is crucial now more than ever to maintain profitable fisheries and food security for Pacific Island countries. The key message outlined by SPC was that it was now time for countries of the western and central pacific region to think about limiting tuna catches or fishing effort to around the current levels of 2010 (SPC, 2012). Fiji's coastal fisheries on the other hand as a study undertaken by Cakacaka et al**.** in 2010 revealed that Fiji's coastal fisheries, which houses the largest source of food security and cash income for its coastal fishers are also facing the same fate, the continued high extraction of fisheries resources, at rates highlighted by a study done in 2008 by Teh et.al. (2009) estimating annual catches of reef-associated fish in Fiji to be 7,743mt, the fisheries may not be sustainable. The laws and regulations that govern the harvesting of fish is out-dated- the Fiji Fisheries Act Chapter 158 is now thirty years old and does account for modern trends that affect this important sector.

In order to realize the importance of managing the nation's fisheries, the Ministry of Fisheries has begun on a complete review of its fisheries regulations whereby it incorporated three decrees based on three different commercially thriving industries; the Offshore Decree, the Inshore Decree and the Aquaculture Decree. The Offshore Fisheries Management Decree of 2012 was recently passed and adopted by Cabinet and the Department is now engaged in developing the necessary regulations that would see an improved regulatory framework for the offshore fisheries. The former two are currently under review. The review of Fiji's primary fisheries legislations would create an empowering environment whereby the management of fisheries is powerfully legislated and would put Fiji up to par with regional and international management instruments and ensure healthy fish stocks for harvesting.

**Objectives of the study**

In recognizing the importance of the Fiji's offshore fishery's contribution to the economic sector and the need to adopt effective management measures to sustainably manage the effort levels of this resource, this study proposes to examine the effectiveness of current management measures for its tuna resources. This will be examined through the use of a basic bioeconomic modelling approach which would model the relationship between associated management measures and their influence on the biological and economic performance of this fishery. The study will evaluate the performance of six simulated management scenarios and propose a biological and economically beneficial management measure that would sustain the biomass of the targeted fish species and generate profitable economic returns for the longline fleet. The scope of the study is focussed on Fiji's tuna longline fishery, particularly the fleet of Fiji flagged vessels that target fish in the waters of the Western and Central Pacific Ocean (WCPO).

**Bioeconomic Modelling Approach**

Bioeconomic analyses approaches employ the use of bioeconomic models by taking an integrated approach to evaluate relevant alternative fishery management strategies. This is done by incorporating both the biological and economic parameters of a fishery through the models (Thunberg et al., 1998). Such models have long been advocated as important tools for determining sustainable catch and effort levels in fisheries. Fundamentally the models are a mathematical representation of the biological and economic systems, which typically links economic and biological components and parameters together. The biological components are represented by the natural resources, the fishery, while the economic are represented by the resource users or the fishermen (Prellezo et al., 2012).

Much of the existing work in bioeconomic modelling is focused on the interactions between effort, harvest and stock size relationships. Thunberg et al. (1998) in their bioeconomic analysis of the US Atlantic Silver Hake Fishery evaluated both the biological and economic effects such as future yields, rebuilding of parent stock and future revenues and net returns on vessels; Lee et al. (2000) on the other hand developed a bioeconomic model of the North Atlantic swordfish fishery to evaluate policy relevant management options. Pascoe (1998) undertook a bioeconomic analysis of the fisheries of the English Channel in order to estimate the potential economic benefits that could accrue in the English Channel given efficient management policies and also examined the effects of these management policies on the economic performance of the UK fisheries of the English Channel.

More recent studies have utilised bioeconomic models to estimate resource rents by certain fisheries for various levels of fishing methods and effort and also examines the trends of catches in particular fisheries against total revenues (Reid et al., 2002.); similar approaches of the use of bioeconomic models was done by Prellezo et al. (2012) who studied the value of the use of such models in assessing the interactions between the biological and economic components of different bioeconomic models. Prellezo et al. noted that such models are used to address the effectiveness of management scenarios.

In any approach fishery managers see fit to analyse the biological and economic performances of a particular fishery, it is evident that the bioeconomic modelling approach allows fishery managers to assess potential economic benefits from a fishery, to analyse the effectiveness of management policies in a given fishery and most importantly they determine sustainable catch and effort levels for a given fishery.

The approach taken in this bioeconomic analysis is adopted from the basic bioeconomic model developed by Schaeffer. The focus of the study is to evaluate the current management measures adopted by Fiji's longline tuna fishery through the use of a basic bioeconomic model, the Schaeffer model. The model considers various biological and economic parameters of three tuna species namely Albacore, Bigeye and Yellowfin tuna that are targeted by Fiji's longline industry. Biological parameters, such as each species intrinsic growth rate, catchability coefficient and carrying capacity are derived to estimate the biomass of each species; fishing effort, fishing days at sea and the current total allowable catch (TAC) measures are modelled and evaluated according to their impacts on the biomass and economic parameters such as revenue, costs, profits and net present values of each species are derived to estimate the economic performance of the fishery in light of current fishing effort and management measures in place.

The model projects the performance of the fishery in the next twenty five years under current fishing effort and management measures of limiting license numbers and total allowable catch and compares this performance to several scenarios whereby modifications, through reductions in effort and TAC are simulated in order to gauge the effectiveness of these modifications in increasing biomass and profits from the fishery. The Schaeffer model, a bioeconomic comparative fishery model is adopted for this measurement based on various factors including constant harvest price, constant unit cost of effort and fishing effort.

The other leading chapters of this paper are Chapter II overviews Fiji and its Fisheries and introduces Fiji's tuna industry and its management policies on the domestic long line fishing industry. It outlines the history of Fiji's domestic tuna long line industry, the laws that govern the management of tuna in Fiji's waters and the systems currently in place to oversee the management of these resources. An overview of how the industry has contributed economically to the nation is introduced and in addition to this, current regional and sub-regional instruments that Fiji is a party to and that Fiji currently implements at the national policy level are introduced.

Chapter III discusses the research methods that are applied to this study; the bioeconomic modelling approach, the examination of previous studies that have employed the use of this approach and introduces the biological and economic variables used in this bioeconomic analysis approach to assess the biological and economic performance of Fiji's long line tuna fishery.

Chapter IV presents the outcomes of the research and discusses these in light of their effectiveness in increasing biomass and generating profits. The chapter will also consider a sensitivity analysis that is undertaken to address uncertainties that are associated with $r$ values and its influence on the biomass and NPV of the fishery.

The final chapter V summarizes and concludes by presenting effective management measures that increase biomass and profits from the fishery and their policy implications.

# CHAPTER II – FIJI AND ITS FISHERIES

## Fiji

The Fiji islands are a group of islands that lie in the heart of the Pacific Ocean midway between the Equator and the South Pole and between longitudes $174^0$East and $178^0$West of Greenwich and latitudes $12^0$S and $22^0$South. Fiji's EEZ contains approximately 330 islands of which about a third are inhabited. This covers about 1.3 million square kilometers of the South Pacific Ocean.

Fiji's total land area is 18,333 square kilometers. There are two major islands-Viti Levu which is 10,429sq.km. and Vanua Levu 5,556 sq.km. Indigenous iTaukeis own 87% of the land while 3.9% is State Land. Freehold land comprises of 7.9% and Rotuman land is 0.3%.

The capital is Suva and it is one of the two cities in Fiji. The other is Lautoka City and both are located on the island of Viti Levu.

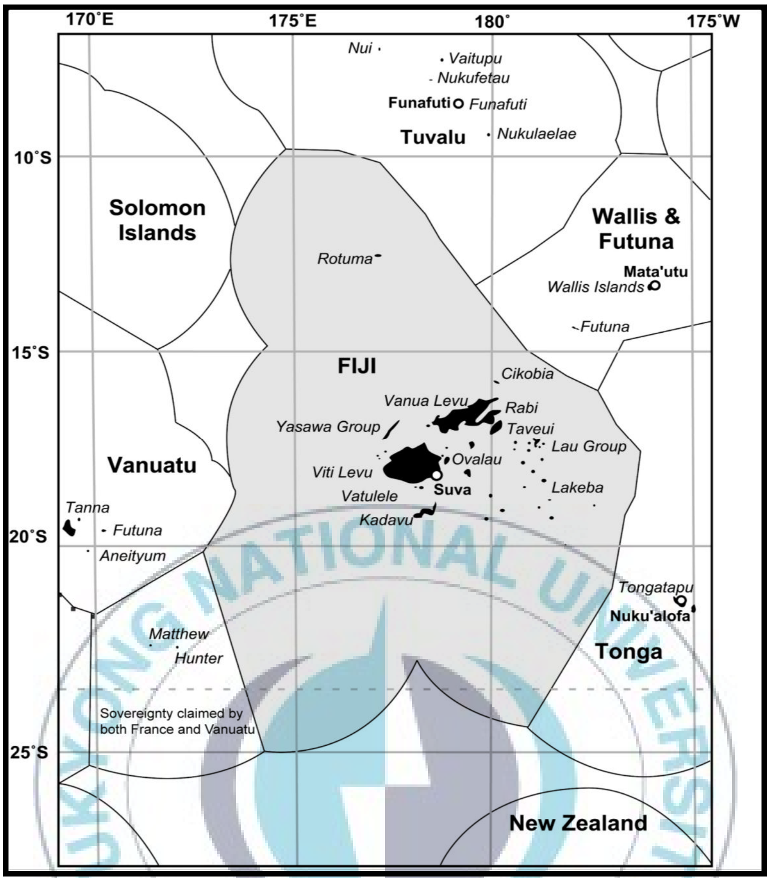


**Figure 1. Map of the Fiji Islands showing Fiji's location relative to its neighboring Pacific Island countries and depicting Fiji's Exclusive Economic Zone**

Fiji enjoys a tropical South Sea maritime climate without great extremes of heat or cold. The islands lie in area which is occasionally traversed by tropical cyclones, and most confined between the months of November to

April every year. Temperatures average $22^0$Celsius for the cooler months (May to October) while November to April temperatures are higher with heavy downpours.

English is the official language. However, the vernacular iTaukei and Hindi languages are also optionally taught in schools (Bureau of Statistics, 2011)

**Historical Background**

The Fiji group of islands was first sighted by Dutch Explorer Captain Abel Tasman in 1643. A decade after this first sighting, English navigators including James Cook made further explorations in the $18^{th}$ Century. However, in Fiji's history Captain William Bligh was given the credit for discovering and recording the islands of Fiji after the mutiny on the Bounty in 1789 (Bureau of Statistics, 2011)

In 1874 Fiji was ceded to Britain and proclaimed a British colony and a decade later in 1970 became Independent. Fiji became a Republic in 1987.

## Fisheries of Fiji

### *History of Fisheries Development in Fiji*

Traditionally as with many coastal communities, fisheries are a means of sustenance, a source of income and as such these communities depend on fisheries for daily life. Fijians, in one of the first reports written on Fiji fisheries were described as a people whose fish supply is met with minimum effort and to whom money was not an incentive (Veitayaki, 1995). Their fisheries were intended for subsistence purposes and fishing was carried out only when they desired to eat fish or for traditional or ceremonial gatherings.

The commercial exploitation of marine resources in Fiji began around the 1830s with the beche-de-mer (*Holothurian*) trade. Within a decade sea cucumber stocks had become depleted in the western, northern and south eastern parts of Fiji. Despite the intensity of this early trade, little coordinated commercial fisheries development only occurred years later with the adoption of the necessary provisions for the regulation of fishing under the 1942 Fisheries Act. Following this, the Fisheries Division was established within the Department of Agriculture in 1968 to cater for the specific needs of fisheries development. In 1977 Parliament passed the Marine Spaces Act giving Fiji a 200 nautical miles (370km) Exclusive Economic Zone (Veitayaki, 1995).

From this early foundation, the Fiji fisheries sector has become the third largest natural resource sector in Fiji, behind sugar and tourism. It is one of the priority economic sectors for Fiji given its daily impact on the lives of the people and communities and its important contribution to the country's GDP, approximated at 2.7% with real domestic export earnings of FJD$205 million or 20.5% of all exports for the country as of September 2011 (Fisheries Department, 2012). The sector boasts one of the most diverse resource bases of marine species in the country spanning an area 1.3 million square kilometers of fisheries waters.

**Fishery Sector Structure**

The Fiji Department of Fisheries recognizes three primary sub-sectors of the fisheries sector:

I. The industrial fishery, which operates on a large scale and is primarily export oriented. This sector includes fish processing plants and the capture tuna long line industry;
II. The coastal fishery and subsistence fishery, which includes most small-scale commercial production for domestic sale and overseas exports and a significant source of domestic fish supply and employment; and the subsistence fishery which involves catches for home consumption, with the occasional sale of surplus catch;
III. The aquaculture sector which has over years developed consistently into a thriving industry for the future.

The industrial fishery or Fiji's offshore fishery is dominated by the long line tuna industry. This fisheries sub-sector has since its early establishment in the 1950's developed as major contributor to the economic development of the country in terms of its volume of exports and the returns it generates for the country. In 2010 Fiji's tuna industry was valued at FJD160 million.

Fiji's coastal fisheries are also a vital component of the economy and are a source of both income and employment for many local communities. Domestic fish and invertebrates catch landings recorded in 2011 totalled 7245 MT and valued at FJD39.5 million (Fisheries Department, 2012). Fin fish is mostly supplied to the local markets while products such as ornamental aquarium products and sea cucumber are exported to overseas markets. Targeted species include mostly reef fishes. There are also invertebrates that are fished intensively, such as sea cucumbers, crabs, bivalves, molluscs, prawns, lobsters and octopus. The fisheries products are sold in the main urban centres to the local markets, shops, hotels, restaurants and other non-municipal markets.

Another category that exists is the informal village based subsistence fishery, which is largely carried out by women and children. The value of this fishery is generally under-estimated because of its informal nature but this fishery contributes to the rural food security and nutritional sustenance. Traditional fisheries exist in fishing villages in subsistence fisheries, and new innovations and fishing gears have resulted in the faster depletion of valuable resources. In 2011 the subsistence fisheries sub-sector was estimated to have landed 18,000 MT of fish and invertebrates valued at USD40 million (Fisheries Department, 2012).

Fiji's aquaculture sector is categorized into two distinct culture systems-the mariculture and freshwater aquaculture sectors. The sector was developed and introduced to rural communities as an alternative source of nutritional sustenance to the limited inshore fisheries resources. It also provided a means of food security, income and employment. More importantly, the aquaculture industry was developed with the aim to substitute the imports of fish and fishery products and as a management tool to relieve fishing pressure from the inshore fishery. In 2011, production from aquaculture sub-sectors totalled 259.8 MT valued at FJD17.8million (Fisheries Department, 2012)

**Institutional Arrangements**

The Department of Fiji Fisheries under the Ministry of Fisheries and Forests are the custodians of Fiji's fisheries and have the sole responsibility for the regulation of the fisheries thereby having the mandate to manage the country's fisheries. The management of the industrial, artisanal, subsistence and aquaculture fisheries is governed by the Fisheries Act Chapter 158 and the new Offshore Fisheries Management Decree 2012 which was recently approved by Cabinet late 2012. The former provides for the regulation of fisheries resources and the Department is in the final stages of drafting the Offshore Fisheries Management Decree 2012. In addition the Department is also obligated to carry out certain regulatory roles under other legislative Acts such as the Endangered and Protected Species Act, the Environment Management Act, the Biosecurity Act and the Health Act.

Under the Fisheries Act, the Minister of Fisheries and Forestry can make decisions on any input or output controls. The management practices are through the issuing of licenses and permits, restrictions on exports, usage of proper fishing gears, banning of extracting certain species, restrictions on destructive fishing and area restrictions. Issuances of licenses for the industrial fisheries sub-sector are restricted to long-line fishing vessels and for the artisanal sub-sector for smaller fishing boats or punts. The subsistence fishery sub-sector does not require permissions or licenses for harvesting resources as the harvests are purely for home consumption. The aquaculture sector's management regime is still under consideration through the drawing up of a new legislation to govern and manage this sector.

**Fiji Fisheries Law**

The laws that govern the use of marine resources in Fiji are laid out in Chapters 158 and 158A of the Laws of Fiji. Chapter 158 is the Fisheries Act which empowers the role of Fisheries Officers as custodians of the marine resources. The main objective of the Fisheries Act is the management, conservation and sustainable use of the marine resources that Fiji is bestowed with. Several regulations have also been promulgated under the Act covering license and registration, fees, prohibited fishing methods and prohibitions on the harvesting of certain marine species, limitations on mesh size, fish size limits and exemptions.

Recently Fiji's Cabinet passed the Offshore Fisheries Management Decree of 2012. The Decree has repealed certain section of the Fisheries Act Chapter 158. The Decree has been in force since January 1st 2013.

The review of the existing Fisheries Act Chapter 158 resulted in the drafting of three separate legislations to cover the Inshore Fisheries, the Aquaculture sector and the Offshore Fisheries Sector.

**Fiji's Industrial Fishery – The Offshore Tuna Fishery**

The tuna industry dominates the industrial fisheries sector in terms of output and exports and is the major foreign exchange earner for Fiji's fishing industry. The Fiji Bureau of Statistics reported in 2010 fish contributed to 20.5% of total major domestic exports (Figure 2), the majority of fish being tuna and non-tuna species exported to overseas markets such as the US, EU, Japan and other markets.

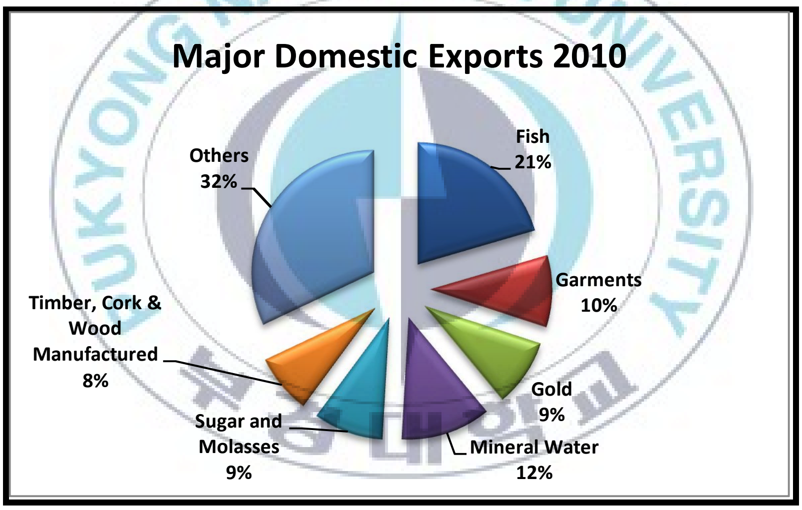


**Figure 2. Major Domestic Exports of Fiji-2010**

*(Source: Fiji Bureau of Statistics, 2012)*

The development of Fiji's tuna long line industry dates back to the 1960's when the Fiji fishing zone attracted foreign fishing activity. Commercial tuna fishing gained strength in the mid-1970s with the development of the pole and line industry. The long line industry became the predominant industry in the 1980's with the setting up of the Taiwan and Korean long line activity in Fiji.

Since then, Fiji's fishing industry is the second largest exporting industry after tourism and has significantly contributed to the Fiji economy since its establishment in the 1960s. Within the last 7 years, the contribution of this industry to the economy rose from FJD21million in 2006 to just over FJD200million in 2011 (Reserve Bank of Fiji, 2010). The long line industry is indeed an important economic sector for Fiji and the Pacific region and this being so as it lies in the most important tuna fishing ground in the world and contributes to the one third of global catches of tuna and to the 40-50% supply to tuna canneries of the world (World Bank n.d.)

Since the tuna industry's establishment in the early 1950's, tuna and billfish catch (Figure 3) in Fiji waters has steadily increased over the years with some notable periods showing significant declines in catch due to environmental factors and increases in effort over the years.

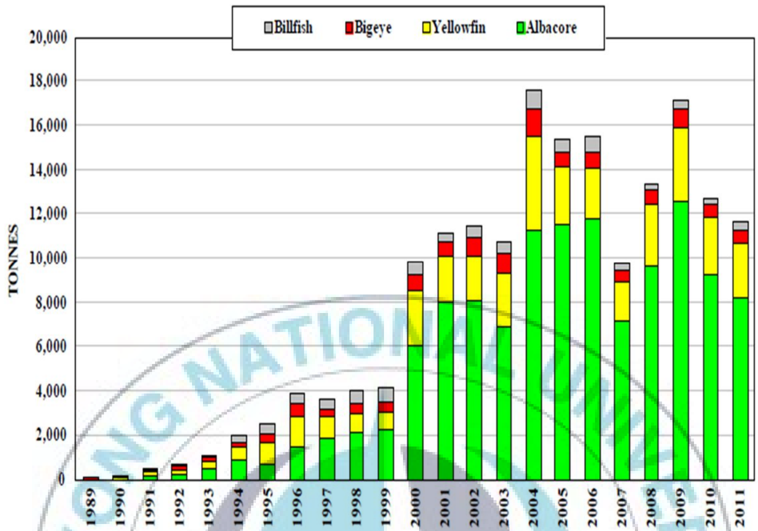


**Figure 3. Tuna and Billfish Catch by Fiji's Long-line Fleet 1989-2011**

*(Source: WCPFC/SPC Tuna Fishery Yearbook 2011)*



Over the years enabled by technological innovation the extensive development of this industry has led to increased levels of effort and harvest of the tuna resources that industry is dependent upon. Climate change phenomenon have also been predicted to place pressure on the stocks that straddle the Fiji waters and the Western Central Pacific region and as such will lead to decreasing the natural abundances of some target species which could result in unsustainable fishing pressures from long line fleets. DeMers et al., (2012) highlighted the prevalence of overfishing in the last 20 years have led to the decline in tuna stocks and the significant trend in tuna fishing away from the heavily fished regions like the North Atlantic and North and Eastern Pacific and towards the less exploited Western and Central Pacific Ocean. DeMers et al., (2012) added nearly 60 per cent of the world's yellow-fin, big-eye, albacore and skipjack tuna were caught in the WCPO in 2008. Now, yellow-fin, big-eye and albacore tuna are either fully exploited or overexploited in the WCPO.

Fiji being located within the WCPO region and within the migratory routes of these straddling stocks is now facing the pressure of the diminishing catches on their fleets. Such developments and natural phenomena episodes warrant the need for advanced policies and effective management strategies to address the pressing issue of overfishing.

**Economic Importance of Fiji's Tuna Fishery**

The tuna fishery of the Pacific Islands region is an integral and important component of the world tuna fishery. Fiji is located in the middle of the world's most important tuna fishery, the Western Central Pacific fishery, and these tuna fisheries represent a critical store of "natural capital" for economic growth both for Fiji and for other Pacific small island developing states.

Fiji's tuna industry is an important sector to its people and to the economy. The sector contributes to Fiji's economy through exports, employment, and revenue whilst also providing recreational and social benefits for the people. The main commercial target species of this industry are Albacore (*Thunnus alaluga*), Big eye (*Thunnus obesus*), Skipjack (*Katsuwonus pelamis*) and Yellowfin (*Thunnus albacores*). Other species caught as by-catch in Fiji waters include sailfish, mahimahi, opah, sharks, dolphin fish, wahoo and barracuda. Fiji's export markets for its commercial target species are Japan, USA, China, Australia, New Zealand and the EU.

The economic role of this sector is evident in terms of its contribution to GDP, government revenue, exports, fish supply, food security and through the employment sector (Kitolelei et al., n.d.). A 2005 Fiji Fisheries Sector

Review report estimated the Fiji fisheries contribution at FJD78.4 million (USD43.7 million) to the Fiji Island's economy. The report noted an estimated 6847 Fijians were engaged in either commercial or subsistence fishing, furthermore the total economic contribution of the fisheries sector was estimated at FJD91.9 million (USD51.49 million) or 2.5% of total GDP (ADB, 2005). A more recent estimation provided by the Fiji Reserve Bank estimated Fiji's fisheries sector contribution at 19.2% of total major domestic exports, with the majority of fish being tuna and non-tuna species (Fiji Bureau of Statistics, 2010). Table 1 below shows the value and percentage of fishery exports from Fiji;

**Table 1. Value and percentage of fishery exports from Fiji 2004-2011**

*(Source: Reserve Bank of Fiji, 2012)*

| Year | Value of fishery exports (USD millions) | Value of all Fiji exports (USD millions) | Fishery exports as % of total export |
|---|---|---|---|
| **2004** | 49.1 | 696.2 | 7.1 |
| **2005** | 50.9 | 705.5 | 7.2 |
| **2006** | 56.9 | 694.2 | 8.2 |
| **2007** | 63.3 | 518.0 | 12.2 |
| **2008** | 81.7 | 598.0 | 13.6 |
| **2009** | 78.4 | 448.2 | 17.5 |
| **2010** | 108.4 | 562.0 | 19.2 |
| **2011** | 55.3 | 586.8 | 9.4 |

**Management of Fiji's Offshore Tuna Fisheries**

Fiji's offshore tuna fishery is governed by the Fisheries Act Chapter 18 and the Marine Spaces Act Chapter 158A. More recently Fiji's Cabinet had passed the Offshore Fisheries Management Decree of 2012 which has repealed certain sections of the both the Fisheries Act and Marine Spaces Act. The Offshore Fisheries Management Decree 2012 had come into force on January 1st 2013 and the Ministry of Fisheries and Forests are currently developing the necessary regulations to implement the new Decree.

The Offshore Fisheries Management Decree makes provisions for the management, development and sustainable use of fisheries and living resources of the Republic of Fiji. The objective of the decree is to conserve, manage and develop Fiji fisheries to ensure long term sustainable use for the benefit of the people of Fiji (Government of Fiji, 2012).

In addition to this, the Department of Fisheries has in place an institutional arrangement that specifically looks at the management and development of Fiji’s tuna fisheries. This arrangement is implemented under the Fiji Tuna Development and Management Plan.

The plan adopted in 2002 saw the realization of a defined management system that helped improve disparities within the segments of the Fijian population by providing preferential criteria for indigenous Fijians to have access to licenses and also one that was supported by an appropriate management regime governing the sustainable harvest of the tuna resources targeted by the long line fleet.

Since its inception in 2002 the Tuna Development and Management Plan has been used to define the roles and responsibilities of the Department of

Fisheries Offshore Fisheries Division, which currently assumes the leading role for the management, control and surveillance of Fiji's offshore fisheries. The Offshore Fisheries Division under the Department of Fisheries commits to deliver the targets of the Plan. The plan is also maintained as a guide to establishing the relevant management measures pertaining to the governance and sustainable harvests of the tuna stocks that migrate through Fiji's waters.

The Plan has been in place for twelve years now and had undergone a thorough a review in 2012. In this recent review, the Fisheries Department (et al., 2012) highlighted the general principles and approaches the reviewed Plan has taken and these include such issues as; (i) a rights based integrated fisheries management system ; (ii) an integrated ecosystem based approach which incorporates a holistic view to ensure ecosystem health and ecosystem principles are well reflected in an integrated fisheries framework relative to fisheries management, development, conservation and monitoring, control and surveillance (MCS) aspects. These approaches would address issues in the marine environment and also include by catch management and the general impacts of the fishing industry on ecosystem services and the marine environment; (iii) the application of the precautionary principle to address issues lacking scientific and economic data to assist in the sustainability and conservation of tuna and tuna like species; (iv) the application participatory and co-management approaches that will encourage participation of all stakeholders and adopt a cooperative management regime to sustainably manage, develop and conserve Fiji tuna fisheries; (v) the plan will ensure equal and fair distribution of wealth by encouraging employment and investment opportunities that promote equal and fair distribution of wealth in the fishing sector; (vi) consider trans-boundary and by-catch management; (vii) ensure the implementation of robust monitoring, control and surveillance (MCS) policies and guidelines for activities within Fiji's EEZ and for Fiji flagged vessels authorized and licensed to fish in other zones including the high seas and foreign vessels operating out of Fiji.

Fiji's Tuna Management and Development Plan is currently being implemented as a guiding policy for Fiji's Tuna Longline fishery and the Department of Fisheries remains committed to its implementation in line with the revised Offshore Fisheries Management Decree.

Fiji's tuna longline fishery is in effect currently managed under a system of catch and effort limits. In addition to this the Department of Fisheries also authorizes its flagged vessels to fish in high seas pockets and in other country's EEZs.

**Regional and International Agreements Relating to Conservation and Management of Tuna**

Due to its smallness, limited financial and technical resources, Fiji as with other Pacific Island states, has often relied on regional collaboration as the most practical approach to dealing with common problems and issues that affect small island developing states (Bidesi-Ram et al., 2004). Being a party to and developing a number of cooperative instruments have enabled islands of the Pacific region, including Fiji to support the conservation and management of tuna stocks as they migrate through the ocean areas of Pacific island states.

Regional collaboration is known to be well established in the WCPO region. Regional intergovernmental organizations play a key role in the political and economic affairs of the region, including the management of fisheries resources and therefore approaches by Governments of Pacific Island States have been both strategic and political. Small islands states such as Fiji realized that their interests could be best protected through a more collaborative and collective effort in the face of limited institutional resources (Pepe, nd).

Fiji is a member of two key fisheries management institutions; the Pacific Island Forum Fisheries Agency which was established to assist member countries in sustainably managing their fishery resources that lie within the 200 mile EEZs. The agency acts as an advisory body to member countries through the provision of expertise, technical assistance and support to its members. Fiji is one of 17 members of this forum. The second key fisheries management institution that Fiji is a member too is the WCPFC established in 2004 and provides the framework for how tuna resources are to be WCPO region.

Fiji is also a party to a number of treaties and agreements relating to the management of regional fisheries. Such instruments include UNCLOS, UNFSA, WCPFC and other regional and bilateral agreements relevant to the management of tuna resources in the WCPFO region. Such regional collaborative efforts between

Pacific Island States have provided necessary financial and technical assistance to assist member countries in ensuring that the tuna resources that straddle their waters are well conserved enabling these nations to maximize their economic benefits out of these resources. This type of collaboration continues to be crucial in the sustainable management of this rich transboundary resource.

# CHAPTER III-RESEARCH METHODS AND DATA ANALYSIS

## 3.1 Bioeconomic Modeling Approach

Fisheries managers have an important role to play in managing their fisheries, their ultimate goal being to ensure their resources are exploited in an optimal manner. The two key tasks fishery managers are confronted with are to identify the target level of catch or effort in the fishery that best fits the objectives of fisheries management and to derive a set of policies to progress the fishery towards these target levels. Generally the objectives of fisheries management consist of a range of biological and economic objectives and in order to determine the appropriate levels of catch and effort, fishery managers must consider the interactions between these biological and economic parameters (Pascoe, 1998). However, fishery managers cannot consider these interactions by experimenting with a real world situation; hence a bioeconomic model is utilized as an alternative and as a means to enhance our understanding of the ways in which a fishery is likely to behave given these interactions.

The use of the bioeconomic modeling approach has now become an important approach through which decisions are made on fisheries management strategies and are applicable in most fisheries of the world. Bioeconomic models provide a means of combining what is known about the biology and the fleet into a single framework for policy analysis. Such an approach employs an integrated method of evaluating different management strategies for a fishery. Prellezo et al. (2012) stated the study of bioeconomics as an “integrated analysis of the economics and biology of the exploitation of the natural resources applied to fisheries”.

The classification of fisheries bioeconomic models can be done in a number of ways; they can be developed to estimate the long run outcome of a particular scenario (equilibrium models) or they can examine changes over time arising from a particular scenario (dynamic models). In addition to this bioeconomic models can also be utilized to estimate the best possible outcomes (optimization models) or the expected outcome from a given set of events (simulation models, however they are not mutually exclusive, most models fall into either the equilibrium or dynamic model categories and the optimization or simulation categories. The appropriateness of using either a dynamic or an equilibrium model is highly dependent on the objectives of the fishery manager. Should the objective be to determine sustainable yields or profit levels of a fishery, then an equilibrium model is the appropriate model to use; in contrast to this should the objective be to determine the benefits and costs of a change in a management strategy of a fishery, the use of the dynamic model will provide more beneficial information for the fishery manager.

The bioeconomic approach used in this research, utilized a basic bioeconomic model, Schaeffer's dynamic model which is basically designed to provide an indication of the short term effects of changes in effort on the level of catch and economic profits for Fiji's longline tuna fishery. This basic bioeconomic model was used to examine the effectiveness of current management tools in place for Fiji's longline fishery, in addition to this by way of generating results from the model, we then seek to select the most effective management regime that would sustain the targeted species biomass levels and generate sufficient revenue for the longline fishery. The bioeconomic analysis is modeled on five scenarios and these scenarios are projected over a 25 year time period. The study will furthermore conclude with identifying policy implications that will arise out of the identification of these alternative management options, and recommend the best option(s) for the management of this fishery.

The study is based on the current conditions in the fishery, including input costs, fish prices, regional stock exploitation levels and the structure and fishing patterns of the active vessels in Fiji waters. The analysis models the fishery as a whole and the results do not apply to a particular vessel but rather a broad range of vessel sizes and associated costs in the fishery.

*1.2 The basic bioeconomic model – The Schaeffer model*

The bioeconomic model selected in this study is the Schaeffer model, in the field of resource economics, this model is a well-known theoretical model that enables us to capture the mechanisms of resource fluctuations by using essential biological and economic variables. This model has been applied to assess a variety of fish stocks in many local fisheries.

*The Schaeffer Method*

The Schaeffer method assumes that in equilibrium, the growth of a population is equal to the catch, however in most cases; the catch is either greater or less than the growth in population. This change in population is attributed to the difference between the sustainable level of catch at a given population biomass, $C_e$ and catch $C$. This is given as:

$$\Delta \boldsymbol{B} = \boldsymbol{C_e} - \boldsymbol{C} \qquad (1.1)$$

Where $\Delta B$ is the change in biomass during a year, therefore, it is assumed that from this point, if the fishery harvests more than the equilibrium catch level, the biomass will decline. On the other hand, biomass will increase if the fishery harvests less that the equilibrium catch level. The equilibrium catch equation is expressed as;

$$\boldsymbol{G_y} = \boldsymbol{rB_y}(\boldsymbol{1} - {}^{\boldsymbol{B_y}}/_{\boldsymbol{k}})$$

Where $G_y$ is the growth of the population over a given year, $r$ is the intrinsic growth rate, $k$ is the carrying capacity of the environment and $B_y$ is the biomass in that year, from this equation the equilibrium catch function can be expressed as a function of the mean biomass;

$$\boldsymbol{C_e} = \boldsymbol{a\overline{B}}\,(\boldsymbol{k} - \boldsymbol{\overline{B}}) \qquad (1.2)$$

Where, $C_e$ is the equilibrium catch function, $a = r/k$ and $\overline{B}$ is the mean biomass during the year.

This equilibrium catch function in Schaeffer's method assumes that in equilibrium the growth is equal to the catch, however in reality this is not entirely the case, as catch is either greater or less than the growth in the population. Therefore, the change in population is then the difference between the sustainable level of catch at a given population biomass, $C_e$, and the actual catch, $C$, as given in equation *1.1*.

An additional key assumption of the Schaeffer method is that catch per unit of effort is proportional to the stock biomass, this equation is given by $\boldsymbol{U_y = qB_y}$ , where $U_y$ the catch per unit of effort, $q$ is the catchability coefficient and $B_y$ is the biomass in that year, it follows then that

$$\boldsymbol{\overline{U} = q\overline{B}} \qquad (1.3)$$

where $\overline{U}$ is the mean catch per unit of effort over the year and;

$$\boldsymbol{\Delta U = q\Delta B} \qquad (1.4)$$

where $\Delta U$ is the change in catch per unit of effort over the year. Rearranging the equations 1.4 and 1.1 and substituting for $\Delta B$ results in

$$\boldsymbol{C_e = C + \Delta U/q} \qquad (1.5)$$

Similarly, rearranging equation *1.4* and substituting for $\overline{B}$ in equation *1.2* results in

$$C_e = a\overline{U}(k/q - \overline{U}/q^2) \quad (1.6)$$

Equating equations *1.5* and *1.6* results in

$$C + \overline{U}/q = a\overline{U}(k/q - \overline{U}/q^2) \quad (1.7)$$

which can be rearranged to produce

$$\frac{\Delta U}{\overline{U}} = aq\left(k/q - \overline{U}/_{q^2}\right) - q\left(\frac{C}{\overline{\overline{U}}}\right) \quad (1.8)$$

A finite difference approximation of $\Delta U$ is given by;

$$\Delta U \approx \frac{U_{t+1} - U_{t-1}}{2} \quad (1.9)$$

Substituting equation *1.9* into equation *1.8* and substituting $a = r/k$ results in

$$\frac{U_{t+1} - U_{t-1}}{2\overline{U}_t} = r - \frac{r}{qk}\overline{U} - q\overline{E}_t \quad (1.10)$$

Where $\overline{E}_t$ is the level of effort, replacing the term for catch, *C*, divided by the mean per catch of unit effort,$\overline{U}$ (Pascoe, 1998)

The resultant equation *1.10* is Schaefer's logistic function formula that is used in this bioeconomic analysis to derive values of *r*, *q* and *K* and furthermore used to analyze and derive the bioeconomic models for the three individual species under different management scenarios.

### *1.3 Management scenarios*

The effectiveness of several management measures currently being implemented to manage Fiji's longline tuna fishery was examined. Six management scenarios were evaluated using the bioeconomic modeling approach, these are as follows:

<u>Scenario (I) Status Quo</u>

This scenario evaluates the current management situation in place for Fiji's longline fleet. It examines the current level of effort and biomass over a 25 year time period.

For this analysis, we use the term "active vessels" as referring to Fiji flagged vessels (licensed and unlicensed) that are registered under the WCPFC Record of Fishing Vessels (RFV). The number of active vessels is obtained by using the 2011 baseline effort level extracted from the WCPFC/SPC Tuna Fishery Yearbook 2012.

The bioeconomic model is projected over a 25 year time period to gauge the effectiveness of status quo management measures on the fishery. In 2011 there were 109 longline vessels actively fishing for the three tuna stocks in the Western and Central Pacific Ocean.

Scenario (II) Reduction in number of vessels by 25%

From status quo, a reduction in fishing effort through a 25% decrease in the number of active vessels was examined. This scenario as in the first, examined how a 25% reduction in fishing effort would influence biomass and profits from the fishery over the same projected period.

Scenario (III) Reduction in fishing days by 25%

A similar 25% reduction in fishing effort was assessed in terms of a reduction in the number of fishing days an analysis on the effect of a reduction in the number of fishing days on biomass and profits was examined. Fiji currently does not restrict the number of fishing days for its longline fleet, hence this analysis is not undertaken to analyze this as a management measure rather the analysis uses fishing days as a measure of effort to assess this effect this may have on the biomass, catch and net present value of profits per vessel of the stock and fleet.

Scenario (IV) Total Allowable Catch 15,000mt at current level of fishing effort

An analysis of the current level of TAC and its interaction with the biological and economic components of the fishery are examined in this scenario.

As a precautionary approach in managing the tuna fishery, the Fiji Government settled on a TAC based on the previous history of catches, available information on the productivity of the fishery, the present mix of gears, and existing regional assessments of the stocks. The TAC was set at 15,000mt (Albacore, Bigeye and Yellowfin tuna).

This TAC has been in place since 2000 and has not changed since. The TAC, as conveyed by prominent members of the tuna industry, was seen to be economically unsustainable, and felt that the maximum economically sustainable annual catch should be less than 15,000 MT. This was supported scientifically by fisheries scientists who suggested a 10,000 MT TAC for the three target species, however, the TAC has remained at 15,000 MT.

The TAC is evaluated by using the IF function on Excel and where a comparative analysis was done on the trends of biomass and NPV when

TAC is in place and when TAC is not in place. The trends shown and how they impact on the biomass and NPV are examined.

Scenario (V) Reduction of Total Allowable Catch at 10,000mt for 5 years

A reduction on the total allowable catch and its effect on the biomass, catch and net profits are considered. At the onset, Fiji's TAC was scientifically proposed to be set at 10,000mt by fisheries scientists who made the suggestion as a result of an analysis of historical catch rates for Fiji's main tuna target species. However, the Fiji Fisheries Department set the TAC at 15,000 MT, although seen as economically unsustainable by prominent members of the tuna industry, as an interim measure according to the precautionary principle based on catch data from the 1990's but as there was not enough scientific studies to corroborate this, the 15,000mt TAC was felt to be unreliable (Barclay, 2007).

In this scenario, we examine the results of reducing TAC at 10,000mt, as initially proposed, for Fiji's main tuna target species and compare this to the current TAC. The analysis is done by studying the effect of this reduction on biomass and NPV over the same forecasted period of 25years.

Scenario (VI) Total Allowable Catch 10,000mt for 5 years with 25% reduced fishing effort

Scenarios (IV) and (V) assumed fleet size or the level of fishing effort remained at status quo level (160 fishing days). In this final scenario, the model was used to determine how a combination of a reduction in TAC, as in Scenario (V) and a reduction in the number of fishing days by 25% will influence the biomass and net profits, and net present value of the fishery.

**3.2 Previous Studies**

The study of bioeconomics and its application in fisheries management is not entirely a new field of research. The integration of biological and economic parameters of a fishery enables fisheries managers to predict different scenarios relating to the performance of a fishery and allows them to make better decisions on the management of stocks that they target.

The earliest study undertaken using a bioeconomic model was done by Schaefer in 1957 according to the Schaefer model, in the bioeconomic analysis of fisheries, the growth of fish biomass and the short term catch function was shown as;

$$\frac{dP}{dT} = KPt\,(L - Pt) - Yt, \quad (2.1)$$

$$Yt = qXtPt \quad (2.2)$$

Where $P_t$ is the fish biomass in time $t$; $K$ $(=r/L)$ is the intrinsic growth rate over fish stock $r$ over the carrying capacity of the environment $L$; $Y_t$ is the fish catch in time $t$; $q$ is the catchability coefficient, defined as the fraction of the biomass fished by an effort unit; and $X_t$ is the fishing effort (Oishi et al. 2012).

In the Western Central Pacific region, the application of bioeconomic modeling was described as a new strategy for managing tuna fisheries. Campbell (2000) in his paper described a bioeconomic model of the western and central Pacific tuna fisheries where three main gear types exploit four main tuna species. The bioeconomic model was used to calculate fishery rent and incorporated four tropical tuna species-Albacore, Bigeye, Skipjack and Yellowfin tuna exploited by four different gear types-purse seine, frozen tuna long-line, fresh tuna long-line and pole and line vessels. Biological information of the tuna stocks were extracted from SPC, who model spawning, recruitment, movement, mortality and age structures of tuna populations in the WCPF region, and the data was used to predict the availability of tuna stocks in specified areas in the Pacific Ocean. The model was calibrated to ensure that stock biomass predictions are equal to those that were obtained independently from tagging studies and or other stock assessments.

The stocks of tuna predicted by the population and migration model by SPC encounter the various fleets whose levels of effort are set at historical average levels of effort in the areas designated within the WCPF region. The catch equation in the bioeconomic model, takes the simple form $H = AEX$, where $H$ is the weight of the catch, $A$ is the catchability coefficient, $E$ is the amount of fishing effort, and $X$ is the tuna stock. The catchability coefficient is then differentiated by species, age class, gear type and fleet; effort is differentiated by area, month, gear type and fleet and stock is differentiated by species, age class, area and month resulting in catch being differentiated species, age class, area, month, gear type and fleet. In addition to catch information, price and cost estimates required to calculate fishery rent are also derived.

The model was then used to perform a series of four simulations to calculate fishery rent; the simulations were done by looking at alternate levels and mixes of the four types of fishing effort. The first simulation varied the effort levels of all fleets to determine the relationship between total effort and fishery rent. The results showed that an increase in effort levels led to a decline in fishery rent and vice versa and confirmed that reducing overall effort levels would increase the net value of the fishery. The second set of simulations raised the current levels (at the time the study was undertaken) of effort of each fleet keeping the effort levels of other fleets constant and measured the amount of rent generated by each fleet. The results showed that rents generated by each fleet decreased as its own levels from effort increased. The third and fourth simulations looked at the relationship between the level and mix of effort (in namely the frozen sashimi and frozen albacore fleets) that maximizes rent generated by the fishery and the relationship between a variation in prices of two broad categories of products (namely canned tuna and other forms of tuna products) and the level and mix of effort. Results clearly showed that fishery rent is maximized by reducing purse seine effort and expanding the frozen sashimi long-line fleet. By doing so, it was shown that the estimated fishery rent increased by twice the current levels. The last simulation showed that the main result of allowing tuna prices to vary is to increase profit of the purse seine fishery. This showed that the effect of introducing variable prices to the simulation, as compared to fixed prices, is to increase fishery rent and to reduce effort levels from the long-line fleet, thereby changing the fleet composition.

In effect the results of this bioeconomic study suggested that the profits of tuna fleets can indeed be increased two-fold by a reduction in total fishing effort, and switching from an emphasis of purse-seine fishing to long-line fishing-which essentially means a switch from targeting younger age classes of fish to targeting older age classes of fish.

Similar bioeconomic modeling approaches were undertaken by Bertignac et al. (2010) who used a multi species multi fleet bioeconomic model to estimate rent generated by tuna fisheries in waters of Pacific island countries; the result of the modeling showed fishery rent can be increased by decreasing the size of fleets. Reid et al. (2006) developed a bioeconomic model of the long-line, pole and line and purse seine tuna fisheries of the Western Central Pacific region, known as the Western and Central Pacific Ocean Bioeconomic Tuna Model (WCPOBTM), the multi species, multi fleet bioeconomic model was used to estimate, as in Campbell's (2000) model, rents generated by the tuna fisheries of Pacific island countries from various levels and combinations of fishing methods namely purse seine, pole and line, frozen tuna longline and fresh tuna longline fishing effort; the model was also used to estimate the potential for FFA members to increase access fee revenue generated from the purse seine fishery and examined the impacts of increasing catches of Bigeye and Yellowfin tuna in the purse seine fishery on total revenues generated by all tuna fisheries within the FFA region. The results reveal the same solutions to managing the stocks of tuna targeted in the waters of the Pacific island countries, decreasing effort levels through reduction in fleet size substantially increased rents generated by the purse seine fishery and likewise increased revenues from access fees through changing the level of access fees levied as a percentage of the total catch.

In these studies, bioeconomic models integrated biological and economic parameters in order to predict the relationships between stock and catch, effort, cost and revenue resulting in a catch effort relationship. The bioeconomic analysis undertaken in this study adopts a comparable method whereby a basic bioeconomic model which incorporates similar biological and economic parameters is used to ascertain the relationship between catch and effort in the fishery and predicts a likely outcome of how the fishery will benefit or lose in a 25 year period. Economic parameters used include price, revenue, costs of fishing operations and total profits vessels may gain or lose with the corresponding catch and effort levels. Net present value of the individual species is also considered which gives us an economic value of the species under study.

Bioeconomic perspectives have also been studied in other fisheries such as the groundfish fishery in New England. Overholtz et al. (1995) used a multi species model of this New England groundfish fishery in an effort to investigate selected biological and economic implications of effort control on the fishery. The study incorporated performance measures such as catch, stock spawning biomass, catch per unit of effort, harvest revenue and consumer surplus to compare different levels of effort. A multispecies technological model approach was used in this study on eight primary stocks of groundfish found of the New England coast. The model was the most appropriate in that it was useful for investigating the impacts of changes in fishing effort, fleet dynamics and other factors and due to the high levels of fishing rates being the major cause of the decline in groundfish resources in the region. The study aimed at estimating the changes in selected biological and economic performance measures that would occur if fishing effort changed from current levels( when study was undertaken). The model is age structured and incorporated simulations that measured error levels in the estimation of age-specific stock sizes, species specific recruitment and species specific and size specific price models. Simulations were undertaken for 11 constant levels of effort that ranged from +30% to -70% of the then current levels of effort (45,000d). The basic model dynamics was similar to many of the more common age-structured models of fishery population dynamics, using parameters as catchability coefficients and instantaneous mortality rates. The Baranov catch equation was used to estimate catch in numbers. Stock size error was accounted for, a recruitment sub-model that modeled the recruitment process using a three parameter equation was used and a price sub-model is used to generate time-series models of landing prices (according to three weight categories) in order to estimate prices for each species size group. The simulation results from this study suggested that relative to status quo level of fishing effort, significant gains in catch, spawning stock biomass (SSB) and CPUE resulted from a reduction in fishing effort. Initial short term losses were found, however, catches improved substantially for all eight groundfish species. Positive cross-over in revenue relative to current conditions was shown to occur after 3-5years of a 30 and 50% reduction in fishing effort.

Despite these short term losses in revenues and consumer surplus, present value calculations show that these would be offset by long-term gains. Revenues would eventually become larger and consumers would result in paying lower prices for their fish.

A different approach is shown in a study done by Prellezo et al. (2012) whereby a number of bioeconomic models were in effect reviewed and the value of the use of a diversity of models was studied in thirteen existing European bioeconomic models used in the evaluation of EU policies.

The study reiterated the study of bioeconomics as an integrated analysis if the economics and biology of the exploitation of the natural resources applied to fisheries and classified bioeconomic models into two categories, simulation (what if?) and optimization (what's best?). A clear distinction between these two types of models was presented as;

I. A simulation model simulated a system by projecting a set of biological and economic variables or parameters into scenarios to evaluate alternative management strategies and;

II. An optimization model is designed to find an optimal solution to an objective function under certain economic and/or biological constraints. In such models the objective function is maximized by considering revenue, profit, fishing days, harvest etc. or minimized by considering costs or ecosystem impacts. Constraints would be limitations on quota, days at sea, biological stock status and sustainability, effort distribution and other factors.

Simulation models also factor in the same parameters and set of boundaries; however they are considered as a set of rules that in effect determine the dynamic consequences of a fishery. Functions that are optimized in optimization models can vary according to the type of model and possibilities include profit, harvest, sea days, vessel numbers, value added and employment. Simulation models on the other hand, are all capable of assessing management strategies and many include economic indicator, such models in effect simulate rather than optimize the economic performance of the fishery.

Prellezo et al. (2012) noted considerations that must be addressed when using the two different models such as whether the fishery management is input or output driven as there are operational differences concerning data requirements of input and output oriented models. He goes on to highlight that bioeconomic models can also be classified as either deterministic or stochastic through the implementation of uncertainty. In addition to this, Prellezo noted that structures of bioeconomic models reflect the main features of the fishery under analysis and hence differ greatly according to different management regimes in place.

The study concludes that a degree of flexibility should be built into the models in order to allow for adaptability to address other management strategies or scenarios and that when a model is developed, initial attention must be given to the fishery management problem as it would dictate the nature of the model to be developed.

A bioeconomic model which analysed alternative swordfish policies was developed for the US North Atlantic swordfish fishery by Lee et al. (2000). The model's objective was to evaluate policy relevant management options as they changed from the status quo. The bioeconomic model used in the study considered the biological dynamics of the swordfish population which were based on the traditional model developed by Ricker (1975) and is also the method used by ICCAT for the official swordfish stock assessments. The economic components of the model included equations which determined total revenues and costs from the harvests of all species, including tuna, shark and dolphinfish and were assumed to be proportional to swordfish landings. Data obtained for this part of the study were fleet characteristics, fish prices and weight, catch rates, fishing costs, swordfish stock characteristics and swordfish quota share.

The model executed nineteen (19) mathematical equations which were used to determine the economic components of the study and the swordfish population dynamics and these were simultaneously solved using the MINUS nonlinear solver in the General Algebraic Modelling System. An evaluation of the effect of specific swordfish regulations, both domestic and international, on returns to the U.S. Atlantic PLL over a five year period, was then developed through this model.

Five management scenarios (1)Status quo; (2)Lowering total swordfish quota; (3)Reducing domestic mortality of undersize swordfish; (4)Retiring inefficient domestic pole and line vessels and (5)Maximizing returns to domestic pole and line owners were developed and these aimed at evaluating the proposed regulatory changes and concerns regarding the North Atlantic swordfish fishery.

A parameter sensitivity analysis was also executed in order to consider the sensitivity of the model to certain parameters which may have an effect on the alternative policy goals being examined. This analysis was done by reoptimizing the model with conservative estimates of key economic parameters, swordfish price, variable harvest costs etc. The sensitivity analysis used the fifth scenario as a baseline for its analysis.

The concluding discussions of the paper suggested the following:

I. *Status quo* continuing the current management strategies for the U.S. North Atlantic Swordfish fishery can yield greater net returns for the fishery over the projected 5 year period;

II. *Lowering total swordfish quota* could significantly increase stock size, however it would reduce returns by 52%;

III. *Reducing domestic mortality of undersized swordfish* or increasing the survival rate of discards through the implementation of a cost-effective strategy, the entire North Atlantic industry could benefit from the resulting stock effect. Assuming price levels remain constant and do not increase costs, net returns for the industry will eventually increase from the resulting explosion in annual harvesting rates.

IV. *Reducing inefficient domestic pole and line vessels* from the proposed 60 vessel reduction size is insufficient.

V. *Maximizing returns to pole and line vessel owners* a 28% reduction in the number of permitted vessels could increase net returns to the PLL fishery by 40% with individual vessels gaining net returns of $66,837 annually. Retaining the most efficient vessels and retiring the inefficient vessels is done in a number of ways, the most efficient vessels would include vessels placing the most efficient number of sets per trip.

The sensitivity analysis revealed an optimum fleet size would be unaffected by the many economic changes that were anticipated. Total returns were shown to be sensitive to all parameter tests.

A similar approach taken by Thunberg et al. (1998) is using a bioeconomic model to analyze alternative selection patterns in the United States Atlantic Silver Hake Fishery. The bioeconomic simulation model combined the elements of age-structured population and harvest yield models with the economics of the silver hake fishery. The analysis evaluated both the biological and economic effects that were of interest to fishery managers, such a future yields, rebuilding of parent stock as well as future revenues and net profits to vessels.

The biological components considered include stock recruitment and stock dynamics whilst the economic components considered were ex-vessel price, fleet shares, catch per day fished, fishing effort and fleet costs and returns.

The selection patterns are defined as the suite if age-specific selection coefficients that are applied to fish over time.

The results of the analysis indicated that shifting fishing pressure to younger age classes may result in short run gains in the economic value of the fishery that may be unsustainable due to the longer run declines in biomass, as result this lowered the fishery yield and value. In contrast to this, approaches to delay age at first capture could improve economic value over current levels with modest reductions in short-run fishery yield.

The Department of Fisheries (2012) commissioned an economic analysis on the longline fishery in the national waters of Fiji. The study was prepared by the Pacific Island Forum Fisheries Agency and the Secretariat of the Pacific Community. The analysis was carried out as a review of a similar analysis that was previously undertaken. The analysis sought to estimate the level of effort associated with maximum economic yield from the longline fishery in Fiji's national waters when considering (1) the economic benefits rising from the harvest sector and (2) the economic benefits rising from combining the harvest and processing sectors.

In the analysis effort is measured in terms of the number of hooks set and estimates the level of annual effort, in terms of hooks set, that is associated with the maximization of economic benefits. The methodology considered 2 scenarios; (1) estimated the MEY for the harvest sector by considering the relationship between revenue and effort and between the costs per unit of fishing effort. After establishing this, the level of effort that maximizes the difference between the total revenues and total costs of fishing (or net economic benefits from the harvesting sector) is then calculated; (2) estimated the relationship between revenue and effort, this is done by analyzing the relationship between the values of historical catches under current prices and the level of effort deployed to harvest the catch. The relationship between revenue and annual effort (hooks) was estimated by fitting a second order polynomial function using a least squares fitting procedure.

A sensitivity analysis is also carried out to investigate how estimated levels of effort and vessel numbers associated with MEY changed under alternative cost structures.

The results of the economic analysis are as follows; Scenario (1) in relation to the consideration of the relationship between total fishing effort and revenue, the results show that there is an increase in revenue with increased effort. Furthermore, the economic model predicted the MEY for the harvest sector occurs at an effort of 16.5 million hooks with net economic benefits from the harvest sector at USD3.8 million, converting this to vessel numbers, the number of vessels associated with MEY for the harvest sector is estimated at 45 vessels; Scenario (2) which estimated MEY for both the harvest and processing sectors predicted the MEY occurring at an effort level of 21 million hooks with net economic benefits from the harvest sector and value added from the processing sector totaling USD728,000, converting this vessel numbers estimates the optimum number of vessels associated with MEY for this scenario at 57 vessels.

From previous studies it is evident that the use of such an approach to ascertain the relationships between catch and effort and the effects of effort on net revenues from fisheries is indeed an essential tool whereby fishery managers are able to model a fishery. Considering both the biological and economic components through a bioeconomic model analysis of a fishery at status quo and examining the effects of varying different effort variables on the biomass and net revenues from a fishery are an essential approach in assisting fishery managers in making sound decisions on the appropriate management measures to be undertaken in their respective fisheries.

## 3.3 Data Analysis

### *3.1 Catch and Effort*

Annual total catch data of the three main targeted commercial tuna species (Table 2) for Fiji's active longline fleet within Fiji waters were extracted from the Tuna Fishery Yearbook 2012 published by the Western and Central Pacific Fisheries Commission and the Secretariat of the Pacific Community. These were later used to calculate the CPUE for each year.

**Table 2. Number of vessels active and catches (tonnes) for Fiji longliners**

| Year | Vessels Active | Albacore Catch | Bigeye Catch | Yellowfin Catch | TOTAL CATCH |
|---|---|---|---|---|---|
| **1989** | 4 | 3 | 14 | 10 | **27** |
| **1990** | 6 | 68 | 27 | 23 | **118** |
| **1991** | 9 | 208 | 123 | 106 | **437** |
| **1992** | 18 | 243 | 187 | 202 | **632** |
| **1993** | 22 | 463 | 204 | 319 | **986** |
| **1994** | 37 | 842 | 249 | 625 | **1716** |
| **1995** | 48 | 702 | 378 | 949 | **2029** |
| **1996** | 42 | 1446 | 593 | 1376 | **3415** |
| **1997** | 34 | 1842 | 409 | 970 | **3221** |
| **1998** | 39 | 2121 | 460 | 862 | **3443** |
| **1999** | 43 | 2279 | 462 | 725 | **3466** |
| **2000** | 61 | 6065 | 687 | 2465 | **9217** |
| **2001** | 95 | 7971 | 662 | 2082 | **10715** |
| **2002** | 103 | 8026 | 853 | 2027 | **10906** |
| **2003** | 129 | 6881 | 889 | 2482 | **10252** |
| **2004** | 118 | 11290 | 1254 | 4164 | **16708** |
| **2005** | 103 | 11504 | 721 | 2591 | **14816** |
| **2006** | 80 | 11802 | 771 | 2231 | **14804** |
| **2007** | 110 | 7145 | 556 | 1721 | **9422** |
| **2008** | 96 | 9613 | 671 | 2763 | **13047** |
| **2009** | 117 | 12515 | 768 | 3440 | **16723** |
| **2010** | 104 | 9252 | 539 | 2602 | **12393** |
| **2011** | 109 | 8166 | 604 | 2516 | **11286** |

*(Source: WCPFC/SPC Tuna Fishery Yearbook 2012)*

On the whole, the trends show that with an increase in effort catches have also increased over the periods 1989 to 2004, from 27mt to 16,700mt, after this period the trend shows a slight decrease in catch, from 16,700mt in 2004 to 14,800mt in 2006 alongside decreased effort levels of 188 to 80 active vessels, this may somewhat be due to variations in oceanic conditions during the time. The periods 2007-2011 show that despite varying degrees of effort levels, catch continued to increase until 2009, when a slight increase in effort resulted in declining catches from 16,700mt in 2009 to 11,286 in 2011.

Fiji's tuna industry grew substantially from the latter half of 1980's. The Department of Fisheries then, established the offshore and EEZ licensing regimes and other related management regimes relating these targeted species, such as a total allowable catch (TAC) system for the major tuna species (3000mt each for ALB, BET and YFT)and limitations on the number of vessels entering into the fishery (NA. 1996)

The increasing effort levels shown from the late 1990's and early 2000's represented poor management, where the number of vessels active jumped from 43 in 1999 to 103 in 2002. In line with this, domestic operators reported large financial losses as a direct result of this rapid influx in vessels.

The adoption by Cabinet of Fiji's Tuna Development and Management Plan in 2002 which was primarily intended to limit fishing effort in Fiji waters, saw the establishment of catch limits 15,000mt for Albacore, Bigeye and Yellowfin tuna harvested from Fiji's EEZ despite SPC recommending a limit of 10,000mt; license limits were set at 90 longliners with 20 solely reserved for indigenous Fijians; despite these efforts and with little time to allow for controlled harvests through the above measures, Government increased license numbers to 110 in 2003, in addition to this, other proposals for changes were made since the adoption of the TDMP in 2002. However, with the change in policies, which were initially intended to limit fishing effort in Fiji waters, catch levels have continued at a slight declining rate.

In this analysis, a forecast is presented on how biomass levels will perform in a 25 year period and to achieve this fishing effort is measured by the number of vessels active in a given fishing year and the average number of fishing days per year for the fleet. The method by which this forecasting is undertaken is discussed further in this section.

### *3.2 Catch per unit of effort (CPUE)*

Using the catch and effort data, catch per unit effort was calculated. The resulting CPUE data was then used to estimate the biological parameters for each species (as required in Schaefer's formula) and to run the bioeconomic models for each targeted species of this fishery.

### 3.3 *Biological variables*

Values of *r, q, k* were derived using the resultant CPUE data calculated as mentioned above. Using Schaefer's formula;

$$\frac{U_{t+1} - U_{t-1}}{2\overline{U}_t} = r - \frac{r}{qk}\overline{U} - q\overline{E}_t$$

and the resulting CPUE values, the independent $(r - \frac{r}{qk}\overline{U} - q\overline{E}_t)$ and dependent $(\frac{U_{t+1} - U_{t-1}}{2\overline{U}_t})$variables required to fit into the formula were then derived.

The dependent variables were calculated from CPUE values whereas the independent values were calculated from CPUE and effort values. This was carried out for each individual species. The resulting values were then used to run the regression analysis, using the Data Analysis tool bar on Microsoft Excel 2010 and values of *r, q, k* were then solved.

### *3.4 Bioeconomic model*

Biological variables

Bioeconomic models for each of the target species was formulated using the results from the regression analysis where r, q, and K values were derived. These values represent the parameters that influence the biomass of a stock or population. r is denoted as the intrinsic growth rate, q the catchability coefficient and k the carrying capacity of the population. The values of r, q and K are then used to calculate the biomass (stock, growth and catch) of each species and the biomass is forecasted for 25 years to enable the mathematical illustration of how the biomass will perform under different effort scenarios ( namely active fishing vessels and fishing days).

Economic data

The economic performance of the model is then derived. This is done by generating the following parameters:

*Price*

Price data used in this analysis is adapted from the Department of Fisheries (2012). The prices used reflect current pricing conditions. It is assumed that supply from the longline fishery has no impact on prices.

*Total revenue (TR)*

Total revenue for each individual species per year was derived by:

| |
|---|
| ***Total Revenue (TR) = Price (USD) × Catch (MT)*** |

*Total cost (TC)*

| |
|---|
| ***Total cost (TC) = Number of vessels × Total cost per vessel*** |

Total cost was calculated using financial data administered by the Department of Fisheries (2012) and was provided in various periods (2006-2012). These data were supplied by 5 companies; however due the lack of essential data sets by 2 companies, average operational costs were derived from 3 companies only. "*Number of vessels"* refers to "*vessels active*" and *"Total cost per vessel"* is calculated as the product of *operational costs per vessel* and *number of trips*

*Total profit*

| **_Total profit = Total Revenue – Total Cost_** |
|---|

Total profit gained was calculated for each species per year for the 25 year simulation. This is calculated as the difference between total revenue and total cost

*Total profit per vessel*

| **_Total profit per vessel = Total profit ÷ Number of vessels_** |
|---|

Total profit per vessel was calculated for each species for the same period. This is calculated as the total profit divided by the number of vessels.

*Interest Rate*

Net present value of each species is calculated at the present interest rate in Fiji and the cumulative profits per vessel by using the financial function toolbar (NPV) on Excel. This calculates the net present value of each species stock at the current Fiji interest rate of 2.5%.

# CHAPTER IV RESEARCH OUTCOMES

*Catch data*

The initial catch data that is used to run the regression analysis was obtained from the Western and Central Pacific Fisheries Commission Tuna Yearbook of 2012. The data consists of a time series of catch data sets from 1989 through to 2011. The data was the most accurate data available and is related to fish caught within the WCPFC region for the same period by Fiji flagged vessels authorized to catch fish within this region.

*Effort data*

Effort for the study was measured in two ways; (1) active vessels and (2) fishing days. Active vessels are referred to as those vessels listed under the WCPFC Record of Fishing Vessels and fishing days is taken as the average number of fishing days a vessel takes to fish in a given year. These data sets were derived from information provided via a simple questionnaire.

*Regression Analysis*

1. <u>Derivation of CPUE, Dependent and Independent Variables</u>

A regression analysis was done utilizing the catch and effort data as variables. Catch per unit of effort (CPUE) was also calculated from these data sets using the equation ***CPUE=C/E***, and the dependent and independent variables were calculated and fed into the regression analysis to generate r, q and K values using the following Schaefer logistic model equation;

Dependent variables: $$\frac{\overline{U_{t+1}} - \overline{U_{t-1}}}{2\bar{U}_t}$$

Independent variables: (I): ***CPUE***

Independent variables (II): $$\frac{E_t + E_{t+1} + E_{t+2}}{3}$$

2. <u>Results of the Regression Analysis</u>

Following deriving the CPUE values and the dependent and independent variables, a regression analysis was carried out using the linear regression technique by regressing the dependent variable (based on CPUE) against CPUE and level of effort for each individual species, these variables were then used to generate the biological variables of *r, q, K*. The results of the initial regression analysis for all species showed statistical significance at the 1%, 5% and 10% levels.

**Table 3. Regression results standardized by species Albacore (ALB), Bigeye (BET) and Yellowfin (YFT)-Schaeffer Model**

| **Coefficients** | **ALB** | **BET** | **YFT** |
|---|---|---|---|
| **Dependent variable** | 0.35127** | 0.6631** | 0.60937*** |
| **CPUE** | -0.0009597* | -0.0420112* | -0.0164553* |
| **Effort** | -0.002474** | -0.0039778** | -0.0019244** |
| ***r*** | 0.35127 | 0.6631 | 0.60937 |
| ***q*** | 0.00247 | 0.00397 | 0.00192 |
| ***k*** | 149,699 | 3,976 | 19,281 |

***significant at 1% level, **significant at 5% level, *significant at 10% level

The regression outcomes of the Schaeffer model are as depicted above. The theoretical validity of the Schaeffer model is as according to the outcomes of the regression where the coefficients of independent values showed negative signs.

*3. Management Scenarios and Model Results*

Six scenarios were developed to evaluate management measures for the long line tuna fishery. Discussion of the results will focus on the following key variables: biomass of the stocks at the 25th year and the net present values of returns (*NPV*) over the 25 year period. Results are summarized in below;

**Table 4. Management Scenarios and Results Pertaining to the Fiji Longline Tuna Fleet and Albacore, Bigeye and Yellowfin Biomass and Profits**

| **Management Goals** | **Biomass (MT) at 25th year** | **NPV (US$) over 25 years** |
|---|---|---|
| (1) Status Quo | **59,973** | **1,997,666** |
| (2) Reduction in vessel numbers | **79,259** | **4,170,790** |
| (3) Reduction in fishing days | **108,664** | **3,476,915** |
| (4) TAC 15,000mt | **46,896** | **1,312,584** |
| (5) Reduction in TAC to 10,000mt | **51,081** | **1,925,226** |
| (6) TAC 10,000mt and reduced FD | **77,303** | **1,613,953** |

### *Scenario (I): Status Quo*

The status quo scenario develops a baseline from which to gauge the effect of alternative management measures. Fleet size, trip frequency and catch of the three target species were set from 2011 levels and forecasted over a period of 25 years. All parameters were assumed constant during the 25 year period.

Results show that with the current fleet size and trip frequency the net present value for the fleet in this fishery would total US$1,307,666.00 over the 25 year period. This net present value is equivalent to average net revenue of US$72,344 per vessel per year. Biomass of the aggregated species totalled 47,625MT over the 25 year period with catches of Albacore, Bigeye and Yellowfin tuna totalled 8,742MT 597MT and 2,633MT at the 25$^{th}$ year. The Figures 4-6 depict graphical representations of the status quo trend in relation to the three target species biomass, catch and profits per vessel. Biomass and catch trends for the three tuna species show slight stable increases throughout the forecasted period whereas profits per vessel differ with Albacore showing higher profits as compared to Bigeye and Yellowfin tunas.

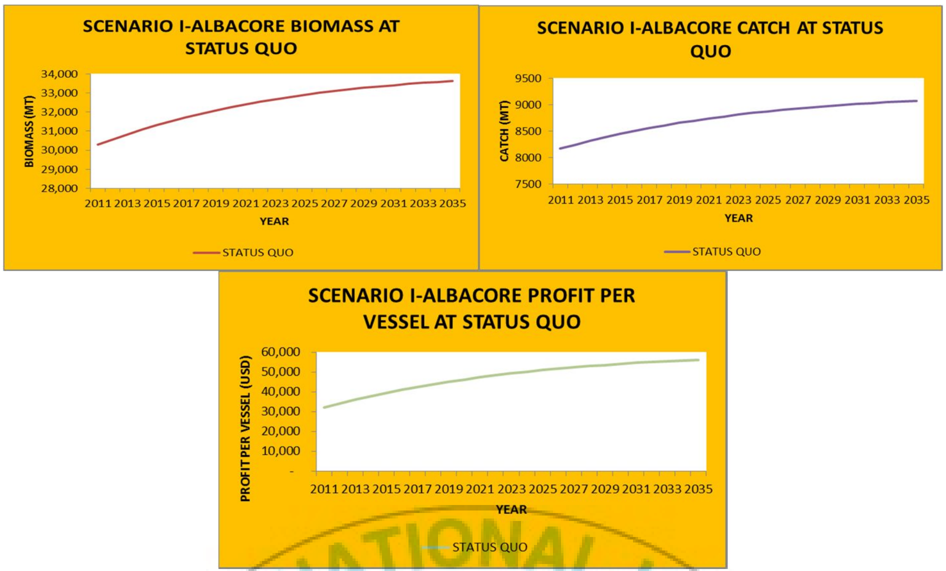


**Figure 4. Albacore Biomass, Catch and Profit per Vessel at Status Quo**

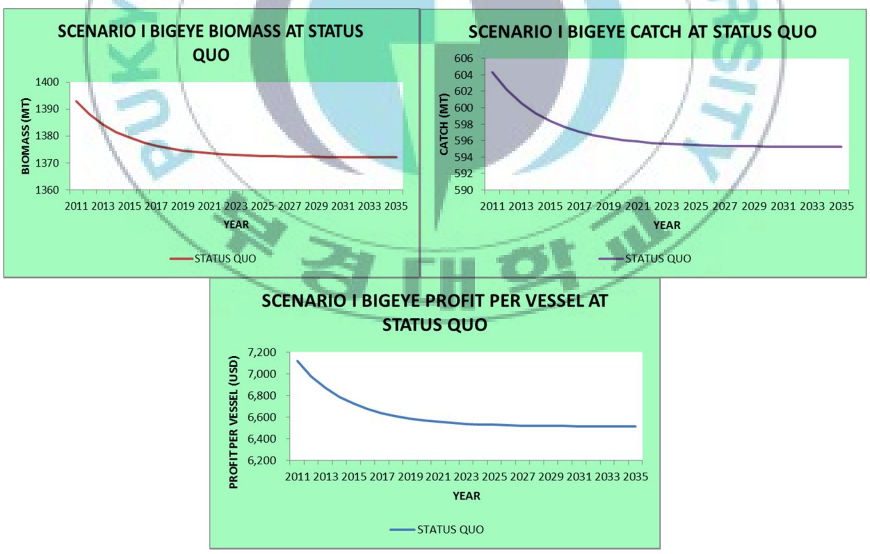


**Figure 5. Bigeye Biomass, Catch and Profit per Vessel at Status Quo**

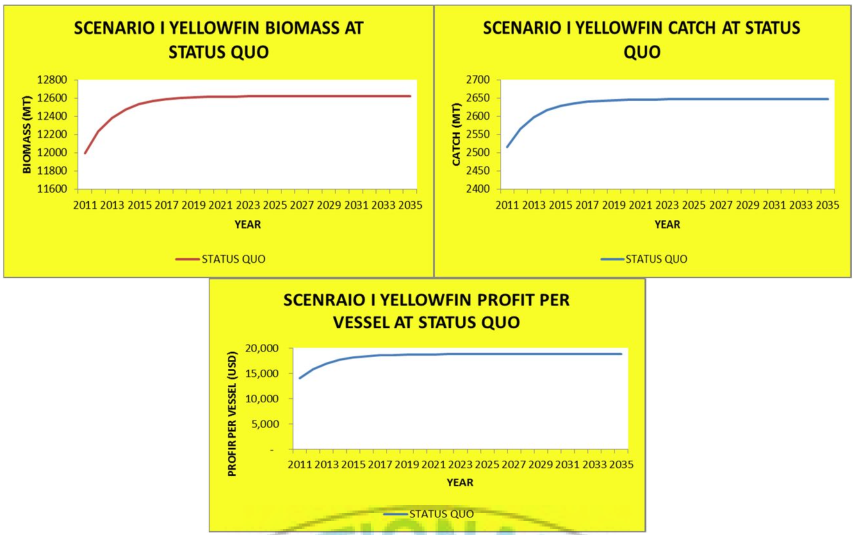


**Figure 6. Yellowfin Biomass, Catch and Profit per Vessel at Status Quo**

***Scenario (II): Reduction in number of vessels by 25%***

The Report of the FAO Technical Working Group of the Management of Fishing Capacity (1998) noted the required reduction in fishing capacity would vary from fishery to fishery and as an example a 20 to 30% reduction was suggested for tuna long line fleets. In line with this a 25% reduction in the number of active fishing vessels was simulated. This was accomplished by reducing the number of status quo vessels of 109 vessels to 80 vessels, which is approximately 25% below status quo. In practice, the optimal range within which fishing capacity can be reduced is between 15-20% or a maximum of 30% as practiced in the US and South Korea, generally the rule of thumb is a reduction of 20%. This scenario simulates the effect of this reduction in number of vessels from status quo and examines its effectiveness as an alternative management measure.

Results show that with a 25% reduction in fleet size, holding all other variables constant, the net present value for the fishery increases two-fold from status quo totalling US$4,170,790. Average total revenue over the 25 year period came to US$42,943,773 with each vessel profiting an average of US$240,213 per year.

Furthermore, results of the biological analysis indicate substantial increases in stock, catch and growth for all three species, with the most marked increase shown by the albacore biomass increasing from 30, 278MT to 62,814MT at the 25$^{th}$ year. Bigeye and Yellowfin tuna likewise showed gradual increases in biomass. Figures 7 through to 9 depict graphical representations of the trends of biomass, catch and net profits per vessel shown by each species as compared to status quo (Scenario I):

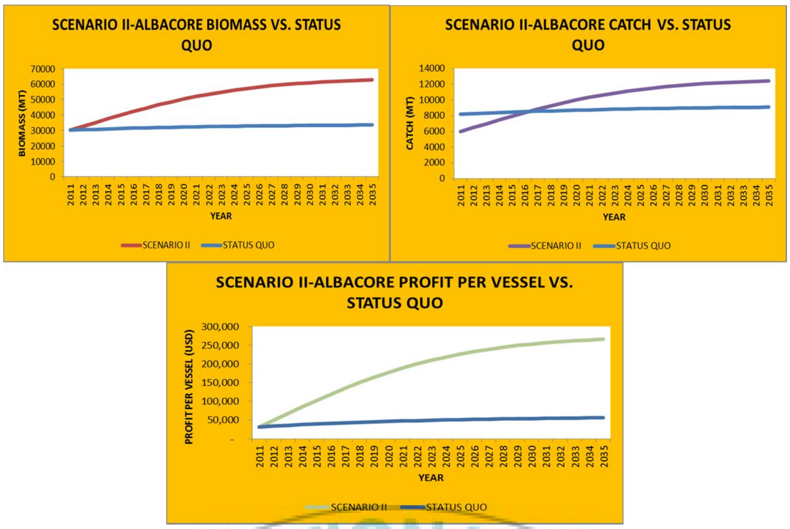


**Figure 7. Albacore Biomass, Catch and Profit per Vessel at 25% reduction vs. Status Quo**

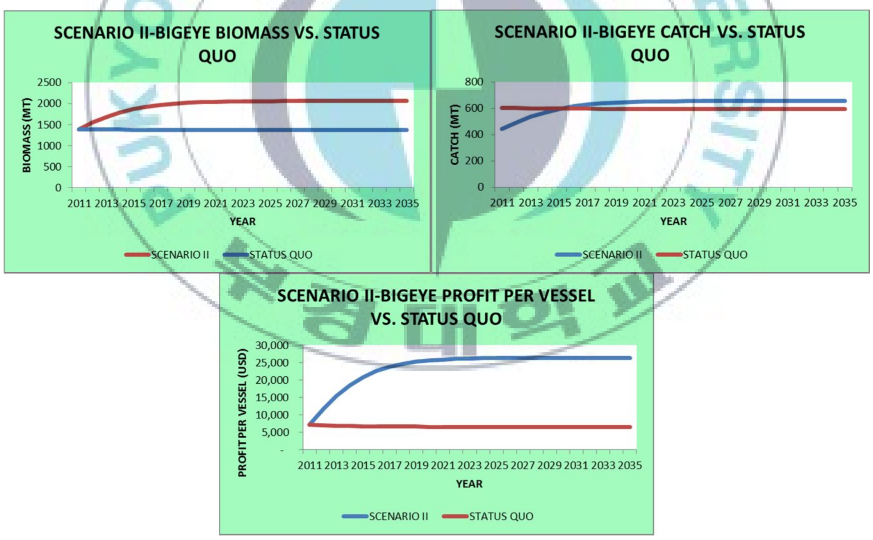


**Figure 8. Bigeye Biomass, Catch and Profit per Vessel at 25% reduction vs. Status Quo**

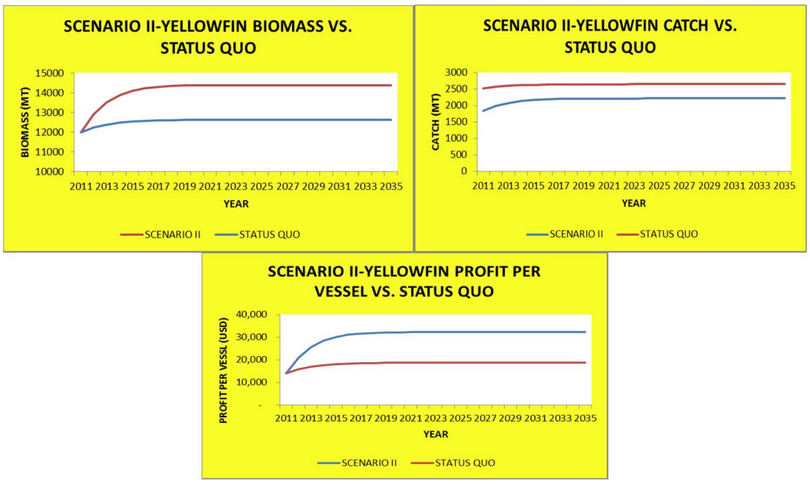


**Figure 9. Yellowfin Biomass, Catch and Profit per Vessel at 25% reduction vs. Status Quo**

A 25% reduction in the current fleet size for all active vessels fishing around Fiji waters would allow the target species biomass to rise by 31,000MT from status quo thereby increasing net present value of the fishery by USD2.8 million. Catch averaged at 13,000MT for all three species, an increase of 720MT from status quo. These results show that a 25% reduction in fishing vessels undoubtedly increases biomass, catch and potential economic benefits resulting in greater profits for vessels.

***Scenario (III): Reduction in fishing days by 25%***

A 25% reduction in the number of fishing days is simulated under this third scenario. This reduction follows the same rationale of reduction in Scenario (I). It is important to note here that two effort measures are being simulated under this study, the first being the number of fishing vessels and second the number of fishing days. Both these measures are studied to see how the two measures of effort influence both the biomass and net profits from the fishery.

Results of this scenario show that a 25% reduction in the number of fishing days had substantially increased the biomass of the three stocks from status quo. This increase totalled 77,253MT, an increase of 29,988MT from Scenario (I) over the 25 year period. In terms of net present value, with a 25% reduction in the number of fishing days the net present value of the fishery was US$1.6million higher than status quo (Scenario I) when assessed over the 25-year time period. Figures 10 through to 12 depict these changes in biomass, catch and net profits per vessel over the 25 year time period for the three tuna species as compared to status quo levels of the same parameters.

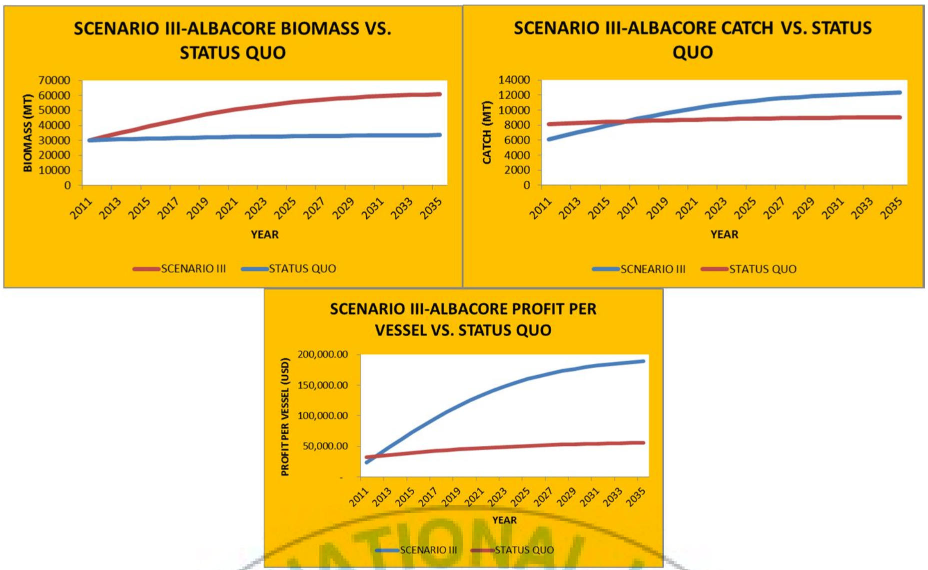


**Figure 10. Albacore Biomass, Catch and Profit per Vessel at 25% reduction in fishing days vs. Status Quo**

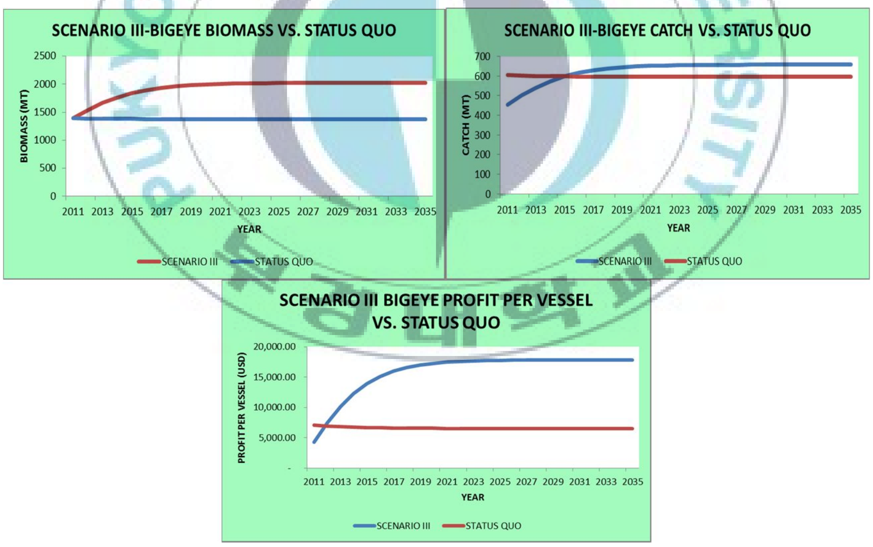


**Figure 11. Bigeye Biomass, Catch and Profit per Vessel at 25% reduction in fishing days vs. Status Quo**

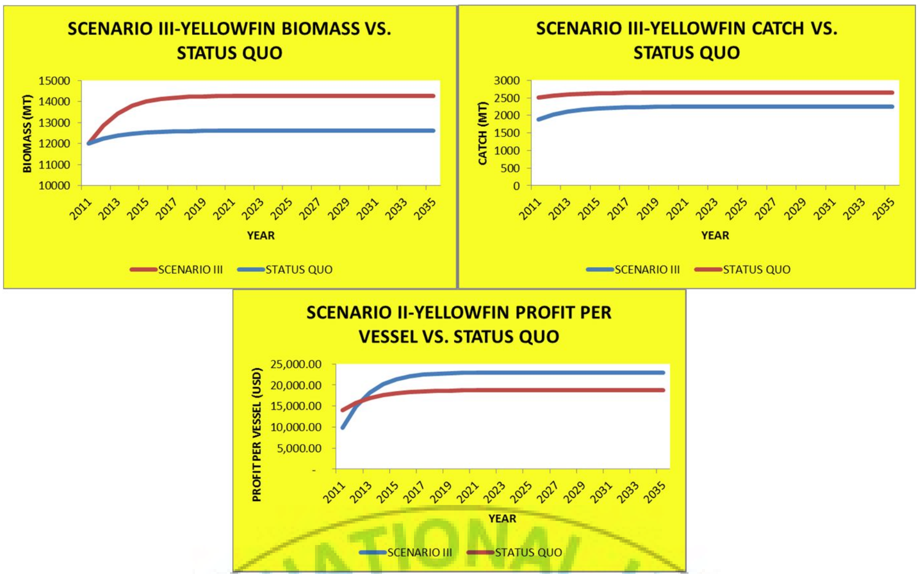


**Figure 12. Yellowfin Biomass, Catch and Profit per vessel at 25% reduction in fishing days vs. Status Quo**

As depicted by the graphical results, significant changes are observed as shown by the increases in biomass, catch and net profits of each species, showing that a reduction in this level of fishing effort by 25% from 160 to 120 fishing days at the current fleet size, results in increased biomass, catch and net profits per vessel for all three target species.

***Scenario (IV) 15,000mt Total Allowable Catch (TAC)***

In this scenario, we examined status quo situation in relation to the current TAC of 15,000 MT and forecasted its application over an initial period of 5 years and on-going to the 25th year, trends in future biomass, catch and profits per vessel of the fishery are examined. Effort in this scenario is measured as the number of fishing days at status quo (160 days). Figures 13 through to 15 represent the graphical results of the analysis against status quo (Scenario I) levels.

Noteworthy in this scenario is the interaction between both the biological component (fishing activity and biomass) and the economic component (fishing activity and economic returns) of the fishery. It is shown that given the current TAC, biomass, catch and net profit levels will decrease in the next five years after which a more gradual increasing stable inclination is seen, this trend is evident in all three target species. This trend supports the statement made by the tuna industry members that a TAC of 15,000MT is not economically and biologically sustainable as evident through the resulting interaction between biomass, catch and net profits. Biomass levels at the $25^{th}$ year in this scenario as compared to status quo will decrease by 18% and catch levels will follow a similar reduction, decreasing to

10,039MT from 12,313MT. In terms of net present values for the three target species at current TAC, NPV totalled USD251, 307 a decrease of 80% from status quo level. If the current TAC is maintained, the fishery will experience an 80% loss in profits and an 18% reduction in biomass and catch levels

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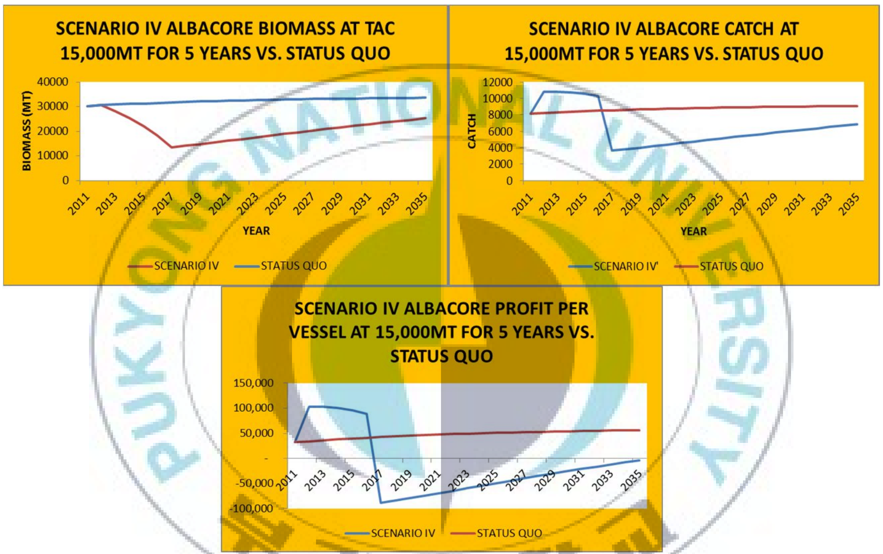



**Figure 13. Albacore Biomass, Catch and Profit per Vessel at 15,000 MT TAC for 5 years vs. Status Quo**

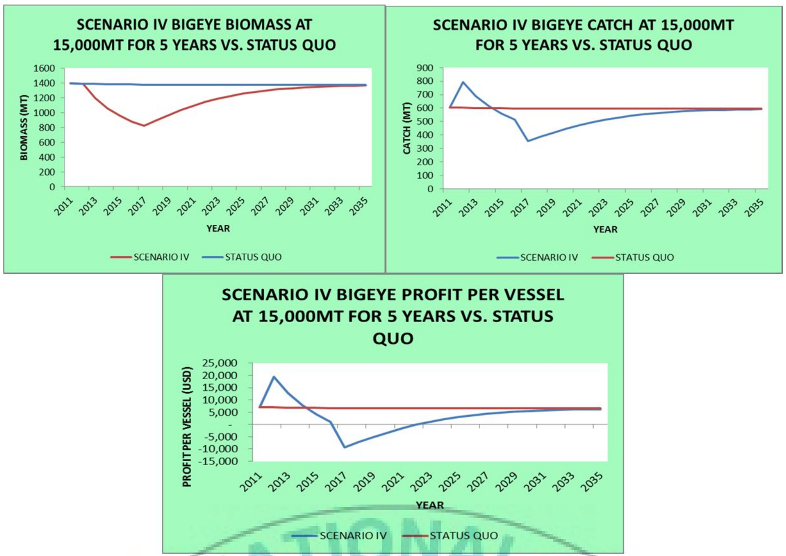



**Figure 14. Bigeye Biomass, Catch and Profit per Vessel at 15,000 MT TAC for 5 years vs. Status Quo**

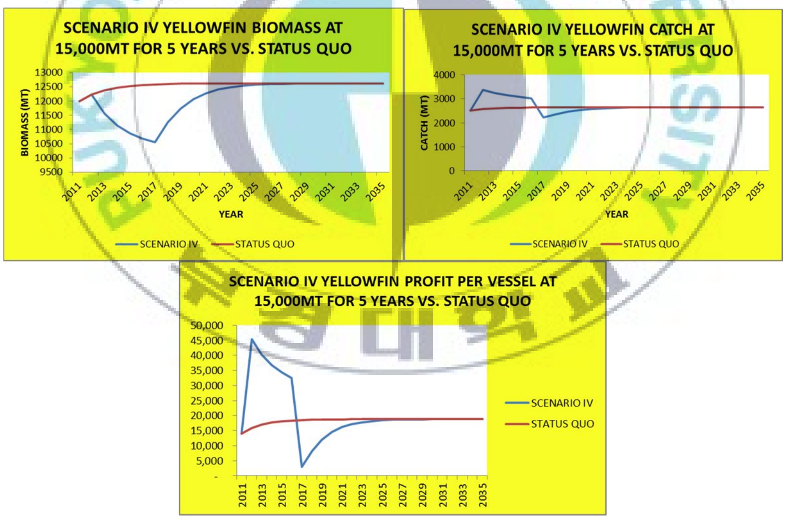



**Figure 15. Yellowfin Biomass, Catch and Profit per Vessel at 15,000 MT TAC for 5 years vs. Status Qu**

***Scenario (V) Reduction of TAC to 10,000 MT at 160 fishing days***

A reduction in TAC from 15,000 MT to 10,000 MT is simulated in this scenario. Fiji's Tuna Management and Development Plan of 2002, established the catch limit of 15,000 MT for the three main target species, however subsequent to the release of the plan, the Secretariat of the Pacific Community (SPC) had indicated that the appropriate catch limit should be 10,000 MT (ADB, 2005).

In this scenario, we simulated this appropriate catch limit scientifically proposed by SPC and examined its effect on sustaining biomass, catch and profit per vessel levels of the fishery over 25 year projected time period. Effort is measured as fishing days at status quo (160 days). The TAC is simulated for 5 years at 160 fishing days.

The results from this simulation show that if TAC is set at 10,000 MT biomass and net profits would increase as when TAC is at 15,000 MT. This is shown in the first five years of implementation of TAC where biomass and catch levels for the three target species show an increase of 3.3% from status quo. However, relative to Scenario (IV), biomass and catch levels increase by 20.3%. As shown in Figures 16 through to 18, In comparison to Scenario (I), biomass and catch for all three species would increase in contrast to net profits, which would experience a downfall for the same period and increase substantially after the initial 5 years of implementation, remaining at a relatively constant upward trend to the 25th year. The trend is expected as the number of fishing days remains unchanged as at status quo.

In comparison to Scenario (I) status quo, NPV for the three target species totalled USD 1.5million compared to USD1.3 million at status quo. However, when compared against, Scenario (IV) at current TAC limit, NPV increased by a high of 83%, this shows that an increase in the economic value of the fishery is apparent when TAC is reduced to the scientifically proposed level of 10,000mt.

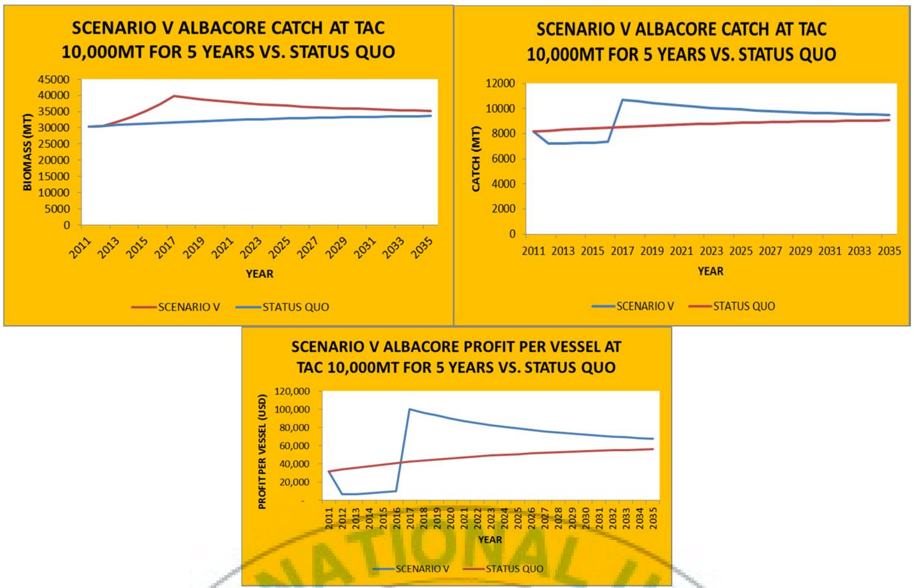



**Figure 16. Albacore Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years vs. Status Quo**

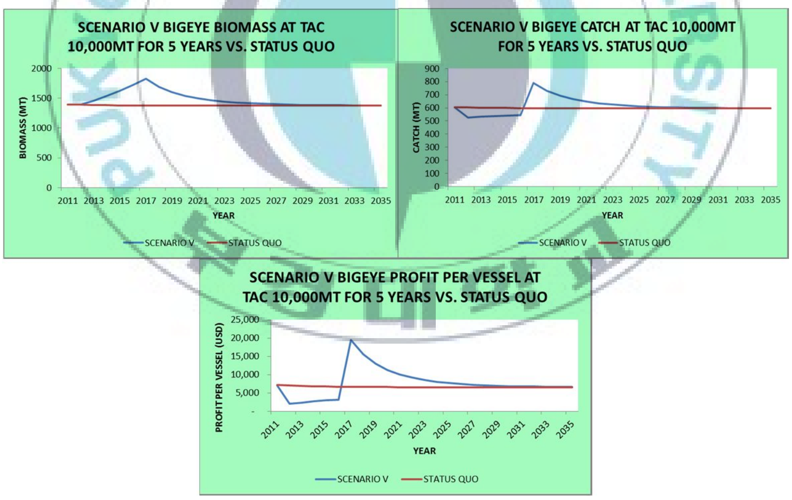
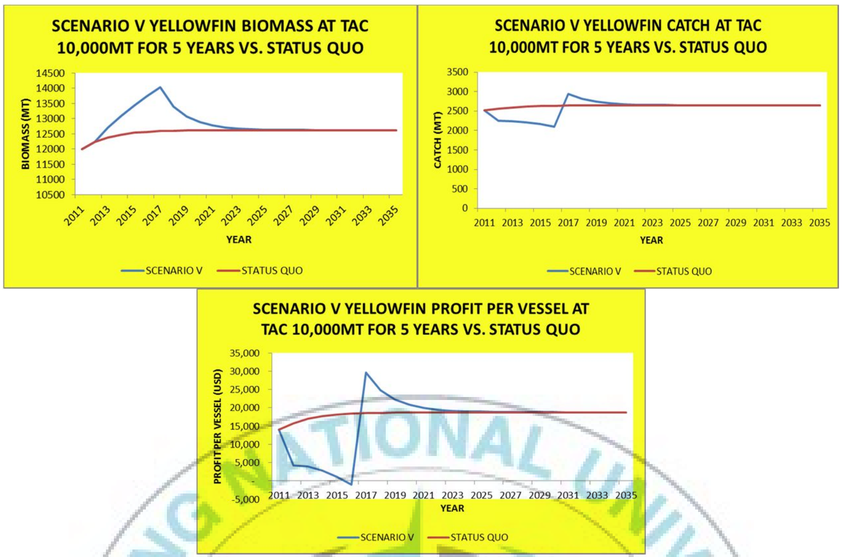



**Figure 17. Bigeye Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years vs. Status Quo**

**Figure 18. Yellowfin Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years vs. Status Quo**




### *Scenario (VI) TAC at 10,000MT and reduction in fishing days by 25%*

The effectiveness of the reduction in TAC from the status quo of 15,000MT is clearly shown in Scenario (V), where biomass, catch and profits per vessel and resulting NPV of the fishery increased as TAC was reduced to 10,000MT, showing this reduction would be the optimal level to set a TAC if the industry is to benefit economically and biologically. This scenario (VI) further simulates the same reduction in TAC combined with a 25% reduction in effort, measured in fishing days, and the outcomes for all three target species over the 25 year forecast period are graphically depicted in Figures 19 through to 21.

The results show a 25% reduction in fishing days combined with a reduced TAC of 10,000MT would increase total biomass by 38% from status quo (Scenario I) levels and resulting NPV increases by 19% totalling USD 1.6 million. This is notable because, although effort in this scenario, measured in the number of fishing days is reduced, the number of active vessels targeting the fishery remains at status quo, at 109 vessels.

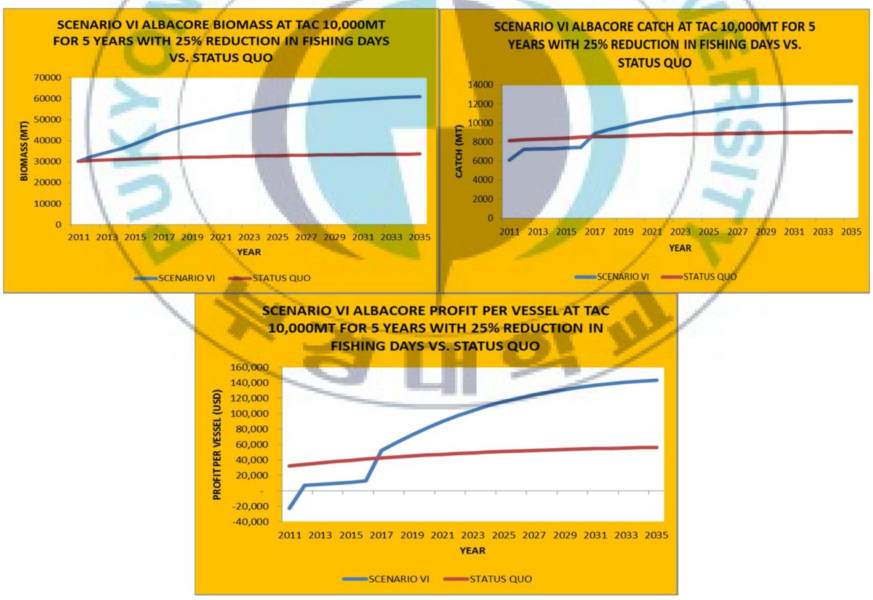



**Figure 19. Albacore Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years and a 25% Reduction in Fishing Days vs. Status Quo**

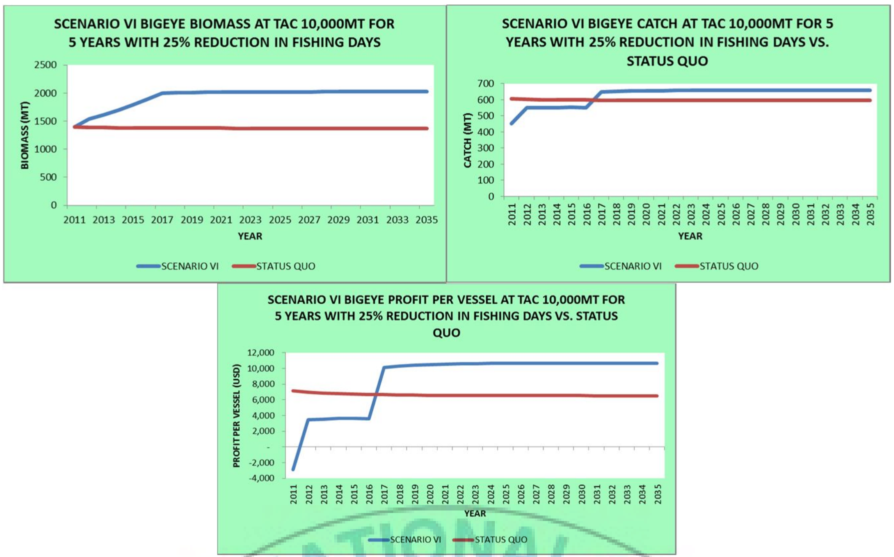



**Figure 20. Bigeye Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years and a 25% Reduction in Fishing Days vs. Status Quo**

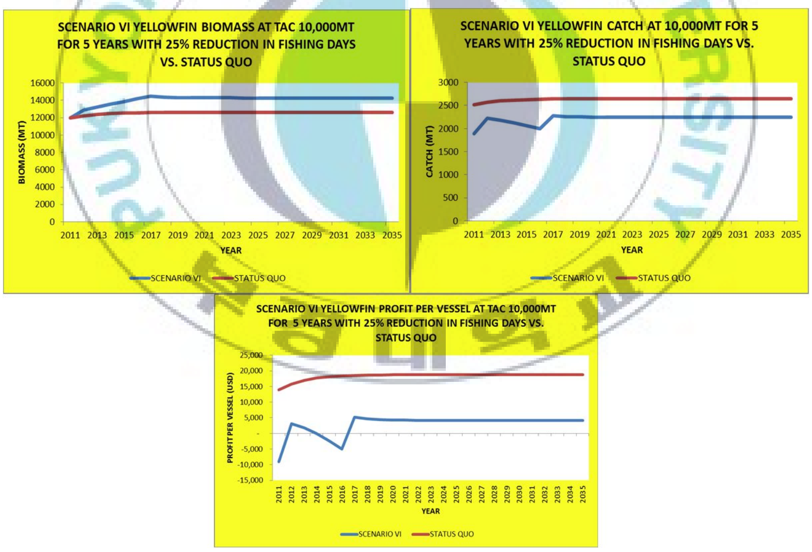



**Figure 21. Yellowfin Biomass, Catch and Profit per Vessel at 10,000 MT TAC for 5 years and a 25% Reduction in Fishing Days vs. Status Quo**

**Aggregated Scenarios Results**

Scenarios (I) through to (VI) are compared (Figure 22) by aggregating each scenarios result into a single representative format. This is done to ascertain the most effective management scenario that would generate optimal biomass levels and higher returns in terms of NPV.

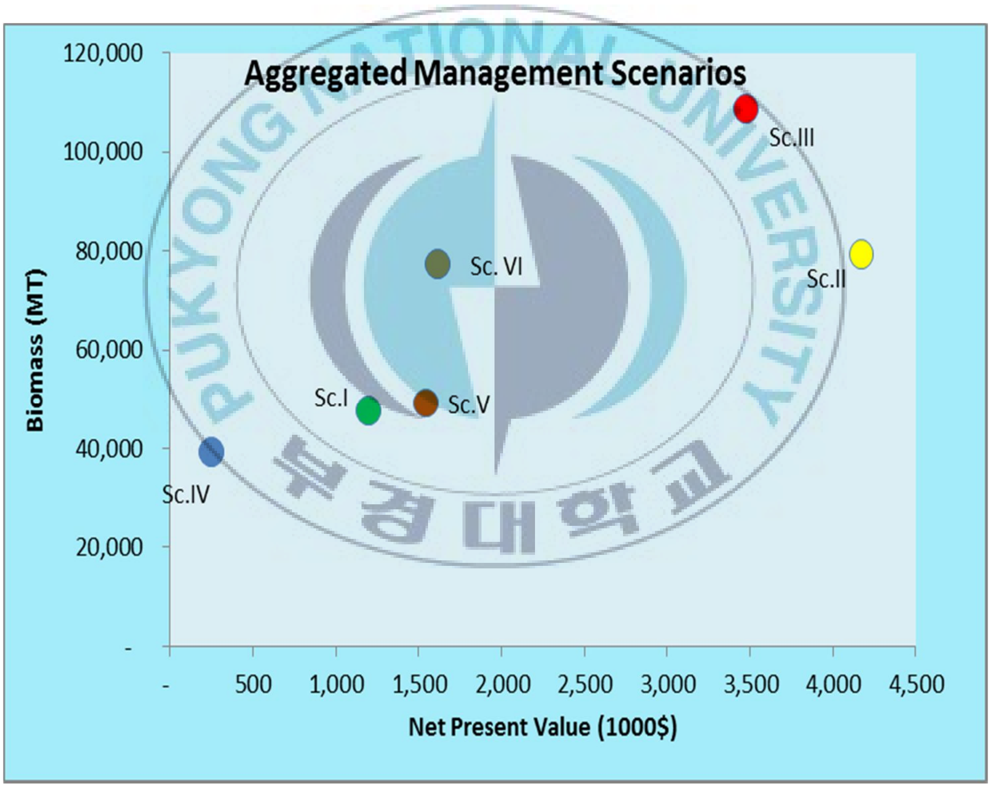



**Figure 22. Aggregated Management Scenario Plot**

The results of the systematic reductions in effort (25% reduction in the number of fishing days and the number of vessels) show benefits both biologically through increases in biomass and economically through resulting increases in NPV. These were illustrated by simulating several scenarios that involved modifying effort (Scenarios I to III) from their status quo and comparing their effectiveness in increasing biomass and NPV. Notable in these simulations, are Scenarios (II) and (III), where reductions in effort from status quo resulted in high biomass levels reflected in Scenario (III) and high NPV in Scenario (II) in contrast to status quo (Scenario I).Hence, depending on the objective of the management strategy, alternative management measures are provided herein.

In modifying TAC (Scenario IV-VI), three simulations were carried out and their outcomes examined. The first Scenario (IV) examined the current TAC of 15,000MT for an initial period of 5 years and then over the remaining 20 years. As highlighted in the previous discussion, Fiji currently implements a TAC of 15,000MT which was perceived by the tuna industry operators as biologically and economically unsustainable. The results of this measure show; (i) that the current 15,000MT TAC is not effective in increasing the biomass of the fishery and (ii) will result in losses to the industry, with NPV falling as low as USD 251,307 as compared to status quo. Scenario (IV) is demonstrated to be biologically and economically unsustainable.

In Scenarios (V) and (VI) we simulated a reduction in TAC from 15,000MT to the scientifically proposed 10,000MT (Sc. V) and combining this with a of 25% reduction in the number of fishing days (Sc.VI); results show an increase in biomass by 3% and NPV by 22% from Scenario (I) when TAC is reduced to 10,000MT for 5 years and even further increase in biomass by 38% and NPV by 68% when this reduction is combined with a 25% reduction in fishing days. These results go on to substantiate the suggestion made by scientific authorities (SPC) on a sustainable TAC limit, 10,000MT for Fiji's three main targeted tuna species.

To take advantage of biomass increases and  increased earnings from the fishery, a 25% reduction in the number of fishing vessels Scenario (II) best achieves this increasing biomass to 77,260MT in contrast with the status quo situation and generating a net present value of USD 4.17million an increase of USG 2.8 million as compared to the status quo.

In light of the aggregated scenario analysis results, Scenario (II) which models a reduction in the number of fishing vessels is the ideal option to consider if the aim is to increase biomass levels and economic returns from Fiji's longline tuna fishery.

**Sensitivity Analysis**

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Haddon (2001) emphasized that no matter how closely one can fit a model to a given set of data, there is no logical inference that the model chosen best represents the system being modelled. He furthermore noted that no model can accurately predict the future or that parameters are the optimum values for the system being modelled. Hence, there is a high degree of uncertainty around accurately modelling a system and such uncertainties can stem from the data used, which may have errors and also from model uncertainty, where the model cannot fully capture the processes that occur in a natural system. To address such uncertainties in a model, a sensitivity analysis is performed. For this study, the most common basis of uncertainty in a fishery population, the population's intrinsic rate of growth, *r*, and its influence on the biomass and net present value of the fishery being studied is examined. The results show the effect of a variation in *r* from its base case to increasing and decreasing these values by ±10% has on biomass and net present values.

**Table 5. Sensitivity of results to changes in *r* values (±10%)**

| Scenario | Biomass (MT) | NPV(US$) |
|---|---|---|
| Base case | 369,908 | 11,793,049 |
| +10% on *r* value | 372,861 | 12,496,405 |
| -10% on *r* value | 365,990 | 10,950,879 |

When *r* is reduced to10% lower than the base case, total biomass decreases by almost 2% and NPV falls by 7% to USD 10.9 million from USD11.7 million. When *r* is increased by 10%, the resultant outcome would see an increase in biomass from the base case by 2,953MT and NPV increases by almost 6 % to USD 12.6 million.

The sensitivity analysis provides us with an indication of how the results differ by varying the intrinsic growth rate of the population of the three target species. An increase in the growth rate, results in higher biomass and net present value of the fishery, while a decrease in the same results in decreasing biomass and NPV.

In relation to the scenarios simulated, the base case scenario (Figure 23) shows Scenario (II) as the most effective measure to take advantage of in terms of increasing biomass and the NPV of the fishery; however, in contrast to this, increasing the base case by 10% shows Scenario (VI) as a good measure resulting in increasing biomass levels. A 10% increase in *r* results in a higher rate of population growth for all three target species and with more species growing at a faster rate, biomass will also increase. Scenario (VI) simulates a reduction in TAC from 15,000MT to 10,000 MT; this reduction in TAC would place a limit on the amount of fish harvested by fishing operators ideally enabling fish to thrive in the population and increasing biomass levels.

The results of decreasing *r* by 10% show notable changes in Scenarios (IV) to (VI) which simulates modifying TAC from its current level to a 10,000MT. Scenario (VI) shows increased biomass levels and a higher NPV relative to Scenario (IV) and (V). The current Scenario IV (TAC 15,000MT) is shown to be unreliable in increasing biomass and NPV with a low *r* value and this verifies earlier discussions of this measure being biologically and economically unsustainable. Scenario (VI) given low *r* values would be the preferred measure to consider if the goal is to increase biomass and gain higher economic returns from the fishery as compared to Scenario (IV) and (V). Relative to Scenario (I) the status quo situation, Scenario (II), (III), (V) and (VI) models performed well in increasing both biomass and NPV, with the exception of Scenario (IV) model which by far is the least effective measure.

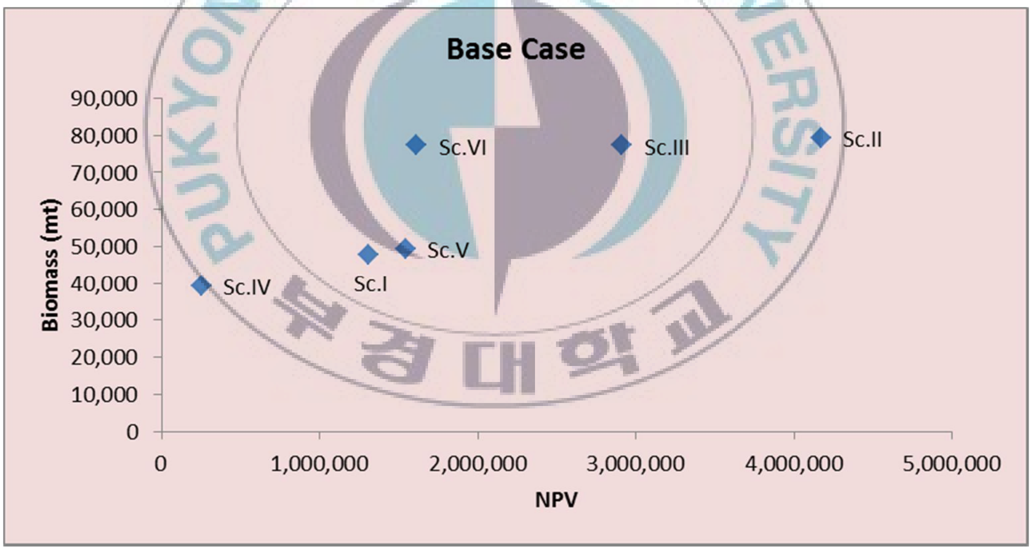


**Figure 23. Sensitivity Analysis-Base Case Scenario *r***

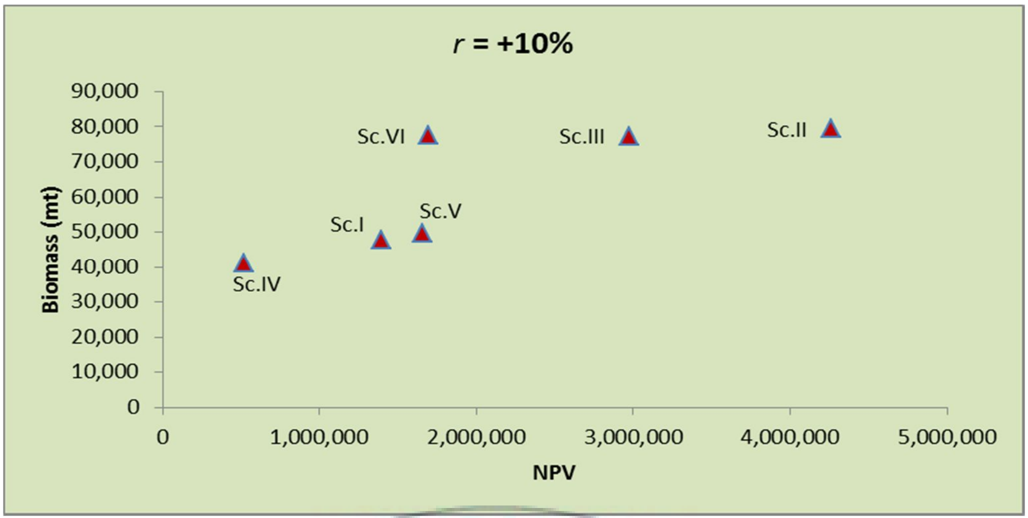


**Figure 24. Sensitivity Analysis-Increasing *r* by 10%**

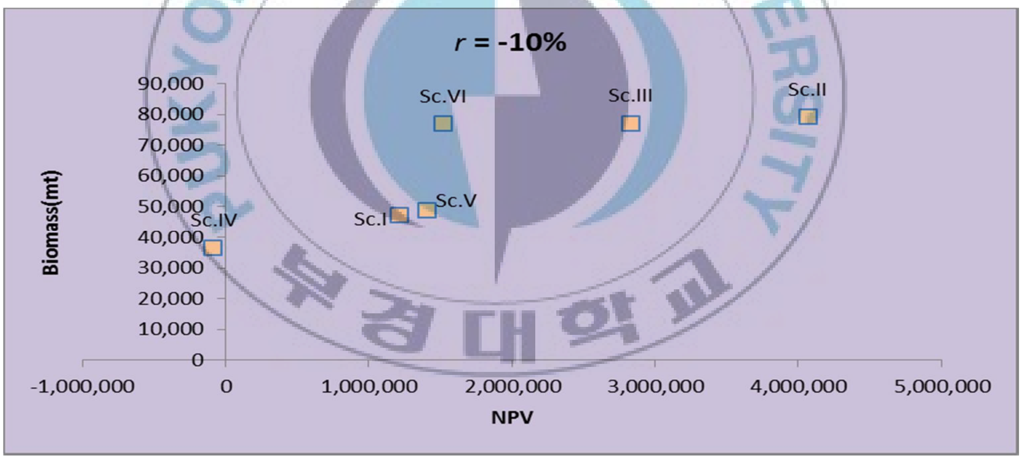


**Figure 25. Sensitivity Analysis-Decreasing *r* by 10%**

# CHAPTER V CONCLUSIONS AND POLICY IMPLICATIONS

Simulation results relative to status quo levels of fishing effort and TAC suggest that significant increases in biomass result from reductions in fishing effort (number of fishing days) of 25% and gains in net present value of the fishery result from a reduction in the number of fishing vessels by 25%. A reduction in the number of fishing days would yield a biomass of 108,600MT and a further reduction in the number of vessels would result in a net present value of USD 4.17million. A review of the current TAC of 15,000MT combined with a reduction in the number of fishing days by 25% is merited.

The bioeconomic model approach used in this paper effectively examined a range of management scenarios and gauged their effectiveness in relation to increasing biomass and generating economic profits from the fishery. The scope of the study considered Fiji flagged fishing vessels that fished within and outside of Fiji waters and made the assumption that most of the fishing by the larger fishing vessels occurred beyond Fiji's EEZ. The forecasted time window of 25 years was sufficient in modelling the assumed future trends of the fishery.

Despite the assumptions made, the bioeconomic analysis provides some guidance as to the effort levels (number of fishing days or fishing vessels) that would likely increase biomass of the stocks and increase the economic benefits from the fishery. The Fiji longline fishery is currently managed by a restriction on licensed vessel numbers and a total allowable catch (TAC) for its three target species. The findings of this study indicate that from a biological viewpoint reducing the number of fishing vessels by 25% will result in higher biomass levels and economically, net profits are increased resulting in a high NPV for tuna industry of Fiji from the exploitation of its tuna stocks as compared to the current status quo situation. The current total allowable catch of 15,000MT is shown to be both biologically and economically unsustainable in the long run, and a reduction in this to the level suggested by SPC (10,000MT) combined with a reduction in the number of fishing days would result in increased biomass and high economic returns from the fishery.

The bioeconomic simulations through the six scenarios presented in this study provides a basic framework within which expected biological and economic benefits to the Fiji tune longline fishery can be evaluated. While the limitation in the use of a single model reflects a number of uncertainties as to the exclusive use of the Schaeffer model and does not present an investigation into the performance of other models, it is suffice to note that such bioeconomic studies are data dependent and that the accuracy of the results obtained are dependent on the availability and quality of biological and economic data available for the fishery. Without good quality data, it is almost impossible assess the performance of a fishery through the use of bioeconomic models let alone obtain accurate results from the research undertaken. This has been a major challenge in the progress of this study, which had resulted in restricting the area of study of this research, which is not entirely reflective of the wide-ranging fishing areas that Fiji's tuna longline fleet target and limits the research, based on the data provided to areas of the Western and Central Pacific Ocean only.

The importance of using a wide range of applicable and high quality biological and economic data sets cannot be overstated when undertaking studies of such nature. Bioeconomic models have to be fitted to data in order to obtain the results we want from the analysis. Data can be provided at different aggregated levels, such as in terms of effort segmentation, number of hooks, crew compliment or vessel horse-power. Models should be flexible enough to adjust to the data available even if more detailed information will make models perform better (Prellezo et al. 2009).

While their exists many uncertainties about the relationships that are incorporated into bioeconomic models, fishery managers would need to manage their fisheries on the basis of the best data that is currently available, hence the flexible nature of a model can be used to provide timely advice (Pascoe, 1995).

Developing countries such as Fiji that do not have adequate data collection systems are prone to experience difficulties in using the bioeconomic modelling approach to gauge the effectiveness of their management capabilities and other such objectives fishery managers may want to consider.

In relation to this, future research will focus on adopting a similar bioeconomic modelling approach employed in this study and utilizing a wider range of applicable biological and economic data to expand and improve on the current study and comparatively examining the performance of the same model in simulating the effectiveness of Fiji’s tuna management measures with a wider range of high quality data sets.

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## Acknowledgement

I would like to express my gratitude to my supervisor Professor Dr. Kim, Dohoon for the valuable comments, remarks and engagement through the learning process of this Master's Thesis. Furthermore I would like to thank Anare Raiwalui for introducing me to the topic as well for the support on the way. Also, I would like to thank Netani Tavaga and his dedicated team of data analysts, Meli Raicebe and staff of the Fiji Tuna Management Services Divisions under the Department of Fisheries who have willingly shared their precious time in extracting data and relevant information for this study. I would like to thank my loved ones, who have supported me throughout the entire process, both by keeping me harmonious and providing the necessary moral support. I will be grateful forever for your love, patience and support. Lastly, to the KOICA/PKNU GFS Program Chairman, Dr. Lee, Sang Go, Board Members and our Coordinator Dr. Kang and members of my Thesis Advisory Committee for your support and advice. To you all I'll be forever grateful.