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HARVESTING OF FLYINGFISH IN THE EASTERN CARIBBEAN: A BIOECONOMIC PERSPECTIVE

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ABSTRACT

Important commercial fisheries such as large oceanic highly migratory species (e.g. yellowfin tuna, swordfish), more regional large pelagics (e.g. wahoo, dolphinfish), and small pelagics (e.g. flyingfish) all occur within the eastern Caribbean. Numerous fleet types are used; therefore these fisheries can be described as multi-species and multi-gear in nature since gillnets, trolled or stationary hook and line gears or both are used to fish both small and large pelagics during the same trip. Flyingfish and dolphinfish are two species that are usually targeted together. The goal of this project is to develop a bioeconomic model based on the predator-prey relationships among flyingfish, dolphinfish and other commercial fish species in the eastern Caribbean. Flyingfish has a low ex-vessel price compared to the predator species. The model is applied to the management question of whether direct harvest of flyingfish or indirect harvest through converted predator biomass is more profitable. The benefits obtained from direct harvest of flyingfish are $1.7 million US. Harvest of the increased predator biomass associated with reduced flyingfish harvest results in benefits of $474 thousand US. The net benefits represent a loss of $1.3 million US (76%) of what is obtained by direct harvest of flyingfish. The conclusion is clear; direct harvest of flyingfish is the better management strategy.

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LIST of ABBREVIATIONS & ACRONYMS

CARICOM	Caribbean Community
CRFM	Caribbean Regional Fisheries Mechanism
CI	Confidence Interval
CLME	Caribbean Large Marine Ecosystem and Adjacent Regions Project
LAPE	Lesser Antilles Pelagic Ecosystem Project
EAF	Ecosystem Approach to Fisheries
EC	Eastern Caribbean
EEZ	Exclusive Economic Zone
ECFFP	Eastern Caribbean Flying Fish Project
FAD	Fish-Aggregating Device
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FL	Fork Length
GDP	Gross Domestic Product
GSI	Gonadosomatic Indices
ICCAT	International Commission for the Conservation of Atlantic Tunas
MSY	Maximum Sustainable Yield
SL	Standard Length
TL	Total Length
UNCLOS	The United Nations Convention on the Law of the Sea
WECAFC	Western Central Atlantic Fishery Commission (FAO)
WCA	Western Central Atlantic

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1 INTRODUCTION

1.1 Overview of the CRFM Secretariat and the CLME

The Caribbean Regional Fisheries Mechanism Secretariat (CRFM) was established in 2003 to further develop the Region's institutional capacity in the fisheries sector. CRFM promotes the sustainable use of fisheries and aquaculture resources in and among its 18 Member States, by developing, managing and conserving these resources in collaboration with stakeholders for the benefit of the people of the Caribbean region (CRFM 2008). Currently, there are many initiatives within the region, which are also seeking to improve the management of marine resources.

The Caribbean Large Marine Ecosystem and Adjacent Regions Project (CLME) is one such initiative, it began on 1 May 2009 and will continue until 30 April 2013. The CLME Project aims to assist Caribbean countries in improving the management of their shared living marine resources, most of which are considered to be fully or over exploited, through an ecosystem level approach. One of the pilot projects under the CLME is the Flyingfish Pilot project. The overall coordination for this Pilot will be provided by the CRFM Secretariat.

The following are priority actions for the sustainability of the Eastern Caribbean flyingfish fishery identified under the CLME Flyingfish Pilot project:

i. Improvement of data availability and information including catch/effort information, in the Eastern Caribbean taking into account long lining and mixed landings;
ii. Bioeconomic studies of the fishery to establish the bioeconomic criteria and set reliable management measures for the fourwinged flyingfish;
iii. Assessment of species interaction between flyingfish and large pelagic fishes to provide for these in management using EBM principles; and
iv. Assessment of economic risk and social impacts to refine the management for the fourwinged flyingfish.

The goal of this project is to develop a bioeconomic model based on the predator-prey relationships among flyingfish, dolphinfish and other commercial fish species in the eastern Caribbean.

In this thesis, the model will be applied to the management question: 'Considering the low ex-vessel price of flyingfish, is it optimal to continue direct harvest of flyingfish instead of leaving it in the sea as prey for other more valuable species?'

This model will allow the evaluation of different management strategies with respect to flyingfish and the other commercially important predator species, which prey on it. The skills and knowledge acquired by working with this model could also be used for future assessments of fisheries within the Caribbean. This would facilitate the development of scientifically based recommendations, which policy makers and fisheries managers could use to design and implement efficient fisheries management policies.

2 BACKGROUND

2.1 Overview of the Multi-species Pelagic Fishery in the Eastern Caribbean

Important commercial fisheries for: large oceanic, highly migratory species (e.g. yellowfin tuna, skipjack tuna, swordfish, billfish); more regional large pelagics (e.g. wahoo, dolphinfish, blackfin tuna and mackerel species); and small pelagics (e.g. flyingfish) all occur within the eastern Caribbean (FAO 2004). The movement and migration of these stocks are transboundary; however the large regional pelagics are mostly confined to the WECAFC area, while the large oceanic pelagics go beyond this range (FAO 2004). These fisheries can be described as multi-species and multi-gear in nature since gillnets, trolled or stationary hook and line gears or both are used to fish both small and large pelagics during the same trip.

The flyingfish and dolphinfish are two species, which are usually targeted together on the same fishing trip with different gear. In Barbados, these two fisheries are well developed and inextricably linked, however the majority of fishers in the other islands focus their efforts on capturing the larger pelagics, with flyingfish usually being taken incidentally and sometimes as bait.

2.2 Overview of the Eastern Caribbean Flyingfish (*Hirundichthys affinis*) Fishery

The flyingfish (*H. affinis*) is an epipelagic species, distributed throughout the western tropical Atlantic. Commercial fisheries for this species occur seasonally in the eastern Caribbean, Curaçao and off northeast Brazil. Flyingfish also occurs in the eastern tropical Atlantic (Parin, 2002).

The flyingfish has been recognised as the single most important small pelagic species in the southern Lesser Antilles; and the seven countries which fish this resource are: Barbados; Dominica; Grenada; Martinique; St. Lucia; St. Vincent and the Grenadines; and Trinidad and Tobago (Figure 1) (FAO 2002a). It is a small fishery, with the maximum total recorded landings being 4700 t (FAO 2009a). There are approximately 1700 boats involved, and fishing operations range from small to large scale, with landings occurring at both rural and commercial facilities.

The largest flyingfish fishery is in Barbados, where approximately 62% of the reported regional catch is landed (FAO 2009a). In Barbados, flyingfish accounts for the highest value added benefits out of all fish species landed, since the estimated ex-vessel value of flyingfish is $1.79 million US while the preliminary total value calculated by adding the value of the flyingfish products consumed is $15.12 million US per year (Mahon *et al*. 2007). This represents almost a nine-fold increase in the value of the flyingfish product. In Barbados, the majority of the catch is sold for human consumption; it is also used as bait. Important fisheries also exist in Tobago, Martinique and St. Lucia for human consumption; however these islands do not gain as much value-added benefits as Barbados (Ferreira 2002a). In Grenada, the flyingfish fishery is considered as a bait fishery, while fishers in St. Vincent and the Grenadines do not target the species. Fishers in Dominica target flyingfish both as food and bait (FAO 2002a, FAO 2009a).

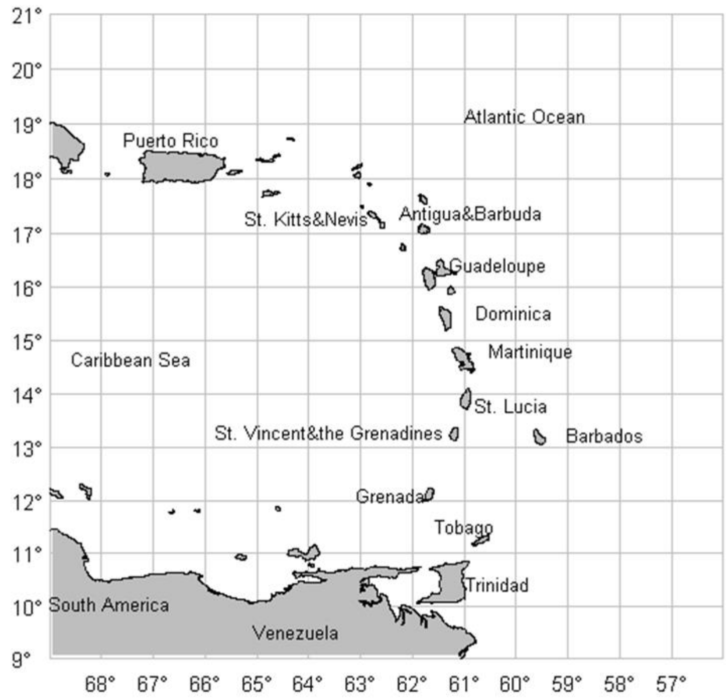

Figure 1: A map of the Eastern Caribbean.

2.2.1 Vessels and Gears

The flyingfish fishery is based on the spawning behaviour of flyingfish, which spawn on floating objects between November and July. The main gears used are combinations of gillnet, dipnets and fish attracting devices (FADs) regionally known as 'screelers', which are usually palm fronds or sugar cane leaves (FAO 2002a). The ‘screelers’ can be attached to the gear, the vessel or simply deployed in the water near the vessel and gear. Dipnets are used as supplemental gear when fish concentrations are high. In the case where flyingfish is taken as bait, hook and line gear may be used (FAO 2002a). A wide variety of vessels are utilized in this fishery and a summary of their characteristics is provided in Appendix 1. The vessels typically utilized measure between 5-15 m in length with engines ranging from 50-350 hp. Longliners also capture flyingfish, however this is not usually a target species and may be used as bait. The longliners measure between 12-27 m in length and have engines ranging from 220-470 hp.

2.2.2 Economic Profile of the Flyingfish Fishery

The number of fishers involved in the flyingfish fishery in the six countries (excluding Martinique) is approximately 3500 (FAO 2002a, FAO, 2009a); while the total investment value per unit (boat, engine and gear) ranges from $3400 USD to $130,000 USD (FAO 2002a).

It is difficult to determine the exact contribution of the flyingfish fishery to the Gross Domestic Product (GDP) of the countries, which fish this resource. Due to its multi-species nature, employment opportunities such as fishing, vending and processing within the fisheries sector cannot be attributed to the flyingfish alone. The various indicators of the economic importance of flyingfish to the region are summarised in Appendix 2 and are best estimates from studies conducted in 2002 and subsequent updates in 2008. The indicators include estimates of: the contribution of the flyingfish fishery to national employment; the number of vessels; the total flyingfish catch for 2007; the price ranges of flyingfish and the value of flyingfish production.

2.2.3 Biological Characteristics of Flyingfish

Flyingfish has a lifespan of approximately one year and is considered an annual species (Campana *et al*. 1993, Oxenford *et al*. 1994). The maximum size of flyingfish is 23 cm fork length (FL) and 29 cm total length (TL), with maturity being attained at 18 cm FL (approximately 5 months of age) and the mean size taken by the fisheries is between 20-22 cm standard length (SL) (FAO 2002a). Flyingfish becomes vulnerable to the commercial fishing gear (gillnets and dipnets) at first sexual maturity and is considered fully vulnerable at age 7 months (20.3 cm FL) when the majority of flyingfish are mature (Mahon *et al*. 2000). They have relatively high gonadosomatic indices (GSI) values of around 11.5% for females and 6.5% for males and are batch spawners, with females laying approximately 7000 eggs per batch (Khokiattiwong *et al.* 2000).

Gonadosomatic indices of adults and the seasonal distribution of juvenile hatch dates indicate that flyingfish spawn between November and July (Oxenford *et al.* 1994, Khokiattiwong *et al.* 2000). This spawning period also coincides with the seasonal availability of adult flyingfish targeted by commercial gear (Oxenford *et al.* 2007). Bimodality in the size composition and timing of catches is known to occur, however this appears to reflect variations in growth rate and spawning time within the single cohort rather than separate cohorts (Hunte *et al*. 2007). Seasonal patterns in catches are also observed and are most likely due to a combination of the inter-cohort gap in adults and emigration from known fishing areas (Khokiattiwong *et al.* 2000).

Preliminary investigations into the stock recruitment relationship of flyingfish indicate that it is typical of short-lived pelagic species, and abiotic and biotic environmental factors are more influential than the adult population size (Mahon 1989). Given that the average life span of flyingfish is one year, and a maximum of 18 months, it can be concluded that mortality rates are high. There are many estimates for instantaneous natural mortality (M) (e.g. M = 1.8 yr^{-1} to 3.1 yr^{-1}, Samlalsingh and Pandohee 1992, and M = 4.4 yr^{-1}, Oxenford *et al.* 1993, Oxenford *et al.* 2007), all of which can be approximated to actual natural mortality rates of between 83.5% and 98.8% of the population dying per year. A crude catch curve estimate of instantaneous total mortality (Z = 5.8 yr^{-1}) was reported by Samlalsingh and Pandohee (1992), and can be approximated to an actual mortality rate of 99.7% of the population dying per year. The most recent mortality estimates for flyingfish in the eastern Caribbean are: total mortality (4 yr^{-1}); fishing mortality (0.013 yr^{-1}); predation mortality (3.78 yr^{-1}); and other mortality (0.2 yr^{-1}) (Mohammed *et al.* 2008a).

In terms of food web interactions with other species, flyingfish consume mostly zooplankton and nekton and occupy a trophic level of 3.03 (Mohammed *et al.* 2008a). This indicates that they are relatively low down in the food web given that the estimated trophic level for large zooplankton is 3.01 (Mohammed *et al.* 2008a). Juvenile and adult flyingfish are the prey of many large pelagic species (e.g. dolphinfish, wahoo, tunas, billfishes) and in the eastern Caribbean it has been estimated that more than 40% of the dolphinfish's diet consists of flyingfish (Oxenford and Hunte 1999, Heileman *et al.* 2008). Interestingly, the importance of flyingfish in the diet of dolphinfish was not as significant in other areas within the Western Central Atlantic (WCA) (Oxenford 1999).

It has been shown by Oxenford *et al.* (1993) that there is mixing of adult flyingfish throughout the eastern Caribbean and therefore, the resource should be managed as a single stock. Subsequent research has also indicated that the eastern Caribbean stock is distinct from the neighbouring stocks exploited by the fisheries of Brazil and Curacao (Gomes 1997). The research determined that there is restricted gene flow within the eastern Caribbean which has additional implications for the way that the stock is managed, as there may be sub-stocks within the region (Gomes 1997).

2.2.4 Catch and Effort Data

Total catches of flyingfish from the eastern Caribbean stock are available from Barbados, Dominica, Grenada, Martinique, St. Lucia, St. Vincent, and Tobago. These catches were reconstructed from landings records and data interpolation from 1950-2007 during the Third *Ad Hoc* WECAFC Flyingfish Meeting and represent the best available estimates of landings of flyingfish in the eastern Caribbean (FAO 2009a). The time period for the commercial catches by country are: Barbados (1950-2007); Tobago (1955-2008); Grenada (1978-2007); and St. Lucia (1981-2008). Commercial catches of flyingfish in St. Vincent and the Grenadines are small, therefore an estimate of one tonne per year was assumed for 1978-2007. Limited data are available for Martinique and Dominica; therefore for Martinique, the landings estimate obtained by the Eastern Caribbean Flyingfish Project (ECFFP) for 1988 was applied to all subsequent years; and for Dominica the landings estimate obtained by the ECFFP was used for 1988-1995; data provided by the Dominica Fisheries Division at the Second Annual CRFM Scientific Meeting were used to guide estimates from 1996-2000 and landing estimates obtained by the Lesser Antilles Pelagic Ecosystem (LAPE) project were used for the period 2001-2007 (Medley *et al.* 2009).

The Third *Ad Hoc* Flyingfish Working Group recognised that the available data were an underestimation of actual flyingfish catches from the eastern Caribbean stock, and did not include the harvest of flyingfish as bait. A proxy of 859.51 t was therefore used for flyingfish caught as bait across all countries (except Grenada) for the years 1980-2007 (Medley *et al.* 2009). As Grenada's flyingfish fishery is considered as mostly a bait fishery, estimates for 1982-2007 were developed based on the known number of longline vessels and an assumed quantity of bait utilized each year in Grenada (Medley *et al.* 2009).

The flyingfish catch time series is shown in Figure 2 for the eastern Caribbean stock. Prior to the 1980s many Caribbean islands did not routinely gather catch data, so data before this time represent estimations. The fluctuations observed in the catches are most likely due to a combination of factors including: environmental conditions, stock size and inadequate or inaccurate data reporting by countries.

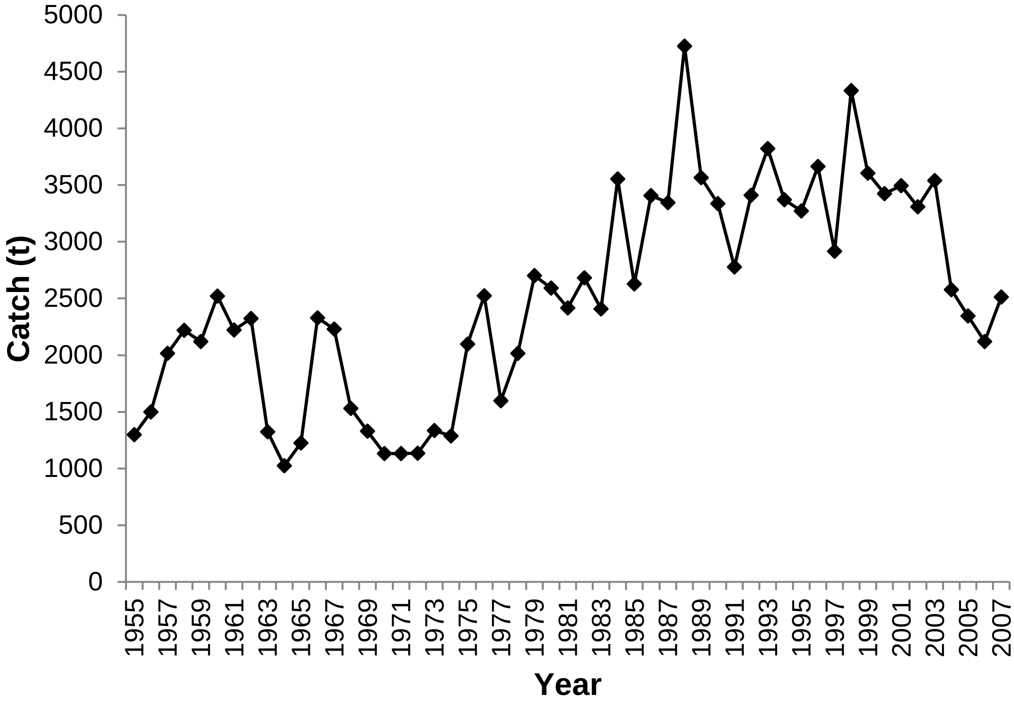

Figure 2: The estimated total catches of flyingfish from the Eastern Caribbean stock (1955-2007).

The multispecies nature of the flyingfish fishery makes the calculation of fishing effort very difficult. Medley *et al.* (2009) have produced the most recent estimates of fishing effort within this fishery for Barbados, Tobago and St. Lucia from (1988-2008). The mean total number of flyingfish fishing trips conducted per year by the fleets of these three countries during that period exceeds 78,200 (Medley *et al.* 2009). Barbados dayboats account for the majority of fishing trips with an average of 43,300 per year (55%), followed by Barbados iceboats with an average of 21,800 trips (28%) (Medley *et al.* 2009). Tobago dayboats contribute on average 10,800 (14%), while St. Lucia dayboats make around 2300 trips per year (3%) (Medley *et al.* 2009).

The difference in fishing power among the various fleet types within the countries is also problematic especially when determining catch per fishing trip as a measurement of effort over time. Medley *et al.* (2009) standardised the catch per unit effort data of Barbados, Tobago and St. Lucia from 1988-2008 against the January catches of the dayboat fleet in Barbados each year. The catch per unit effort time series is shown for 1988-2007 (Figure 3) and suggests that flyingfish abundance has remained stable over the long term (Medley *et al.* 2009).

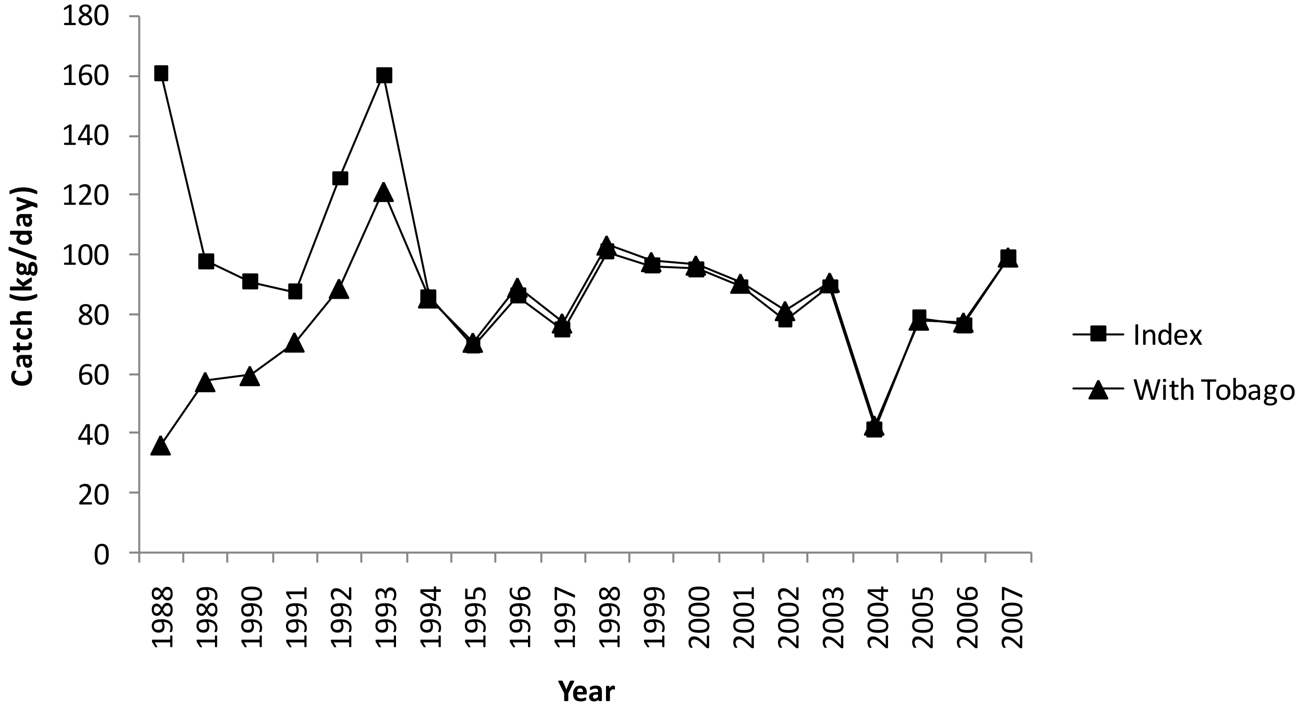

Figure 3: Standardised index of abundance for the Eastern Caribbean flyingfish stock representing catch per unit effort for Barbados, St. Lucia and Tobago (1988-2007).

2.2.5 Present Status of the Flyingfish Stock

The stock assessment conducted in 2008 suggested that the flyingfish stock was not overfished and that overfishing was not occurring (FAO 2009a). Indicators of interest from the stock assessment included: an estimated unexploited biomass ranging from 10,870 t(5% CI) to 131,428 t (95% CI) with a median of 26,351 t; and a Maximum Sustainable Yield (MSY) ranging from 3312 t (5% CI) to 36,291 t (95% CI) with a median of 7897 t. The results indicated that no immediate management action was required for stock conservation, unless a significant increase in catches occurs (Medley *et al.* 2009). However, a catch trigger point of 5000 t was suggested for when further management action may be taken to ensure that the stock does not become overfished (FAO 2009a). The most significant uncertainty in the flyingfish stock assessment was due to incomplete catch and effort data (FAO 2009a).

2.2.6 Management of the Eastern Caribbean Flyingfish Fishery

There is currently a Draft Sub-Regional Management Plan for Flyingfish in the eastern Caribbean, which represents an amended version of the preliminary draft produced inter-sessionally, after the Second *Ad Hoc* Flyingfish Working Group meeting (FAO 2009a). The management objectives are provided below:

- To ensure responsible and sustained fisheries, such that the flyingfish resource in the waters of the eastern Caribbean is optimally utilized for the long-term benefit of all people in the eastern Caribbean region.
- To use the precautionary approach for responsible management in the face of uncertain information on the true status of the flyingfish stock.

- To use an ecosystem-based approach for the management of the flyingfish fisheries and the fisheries targeting large pelagic species (e.g dolphinfish, wahoo, tunas, billfishes) due to the significant trophic, technical and economic linkages among these fisheries.
- To develop an institutional arrangement, which would allow sub-regional collaborative management due to legal obligations, and the shared nature of the flyingfish stock.
- For regional states to co-ordinate their management efforts given: the regional distribution of flyingfish; the fact that numerous jurisdictions fish the resource and the increasing demands for flyingfish as food and bait.

2.3 Overview of the Eastern Caribbean Dolphinfish (*Coryphaena hippurus*) Fishery

The dolphinfish is considered a highly migratory pelagic species (FAO 2006) and occurs in the Western Central Atlantic (WCA) from as far north as George's Bank, Nova Scotia (Vladykov and McKenzie 1935, and Tibbo 1962 in Oxenford 1999) to as far south as Rio de Janeiro, Brazil (Ribeiro 1918, and Shcherbachev 1973 in Oxenford 1999). However, it is generally considered to be most common from North Carolina, throughout the Gulf of Mexico and the Caribbean to the northeast coast of Brazil (Oxenford 1999).

2.3.1 Economic Profile of the Dolphinfish Fishery

Dolphinfish has traditionally been harvested in the WCA and is seasonally important to the commercial and recreational fisheries of many countries. Dolphinfish has significant economic importance throughout its distribution (Oxenford *et al.* 1999) and from 1986 to 1990, it ranked among the top seven oceanic pelagic finfish species landed in the Western Central Atlantic (WCA) region (Mahon 1999). In terms of weight and revenue, dolphinfish is considered to be the most important large pelagic fish landed by commercial fishers in the eastern Caribbean (CRFM 2006). The seasonality of dolphinfish within the eastern Caribbean is November to June (Oxenford 1999).

Dolphinfish has the highest ex-vessel value out of all fish species landed in Barbados, with an average of $2.5 million US from 1999-2003. The overall value of the dolphinfish in Barbados is $5.5 million US, with the value added processes accounting for 55% of this increase. The difficulties associated with determining the exact contribution of this fishery to the GDP are the same as those for the flyingfish fishery.

2.3.2 Vessels and Gears

Dolphinfish are captured from the same types of vessels utilized in the flyingfish fishery throughout the eastern Caribbean (Appendix 2). The most common gear used is hook and line, which may include: hand held hook on line; trolling hook and line; rod and reel used mainly by the recreational fishers; and vertical and horizontal long line arrangements (Parker *et al.* 2001). The lines vary in length from 60-90 m, and have baited hooks at the end. Lines are deployed from the stern, bow and port side of the vessel, usually the same side with the gillnet used to catch the flyingfish (CFRAMP 2001). Other large pelagic species such as wahoo, skipjack tunas and mackerels are targeted with the same gear.

2.3.3 Biological Characteristics of the Eastern Caribbean Dolphinfish

Dolphinfish is similar to the flyingfish in that it is a short lived (< 2 years), fast growing species, which reaches sexual maturity within the first year of life (Oxenford 1999). The maximum size of dolphinfish is 200 cm TL and 25 kg, with full vulnerability to the commercial fishery occurring at (77.5 cm SL, 4months) (Oxenford 1999). In the eastern Caribbean, specifically Barbados, reported sizes at first maturity for male and female dolphinfish were 80.5 and 66.7 cm FL respectively; although there was a size difference, the ages were similar for the males (108 days) and females (112 days) (Oxenford 1999).

Batch fecundity estimates for dolphinfish in the WCA are high and range from 58,000 to 1.5 million eggs (Oxenford 1999). It is believed that spawning occurs between two to three times within a spawning period due to the occurrence of different egg size classes in the gonads (Oxenford 1999). There are limited GSI data available for dolphinfish from the WCA; estimates from Barbados are between 1.02 to 7.09% for mature females, and between 0.19 to 0.48% for mature males. In Barbados, fish with both ripe and spent gonads are reported to occur in all months that the dolphinfish fishery is active (November-June) and peak spawning appears to be from May to June (Oxenford 1985 in Oxenford 1999).

The abundance of dolphinfish is highly variable each year and the stock recruitment relationship within the eastern Caribbean is unknown. Additionally, there is little information regarding environmental effects on dolphinfish recruitment. Therefore, reduction in dolphinfish abundance could result in increased recruitment variability, and thereby negatively affect the stock sizes during the following years (Mahon and Oxenford 1999).

Total mortality rates for dolphinfish estimated by various studies within the WCA region ranged from 3.53 yr^{-1} to 8.67 yr^{-1} (Mohammed *et al.* 2008a); and all these estimates predict an actual total annual mortality of between 98 to 99.7% (Oxenford 1999). The most recent mortality estimates for dolphinfish in the eastern Caribbean are: total mortality (4.72 yr^{-1}); fishing mortality (0.13 yr^{-1}); predation mortality (4.394 yr^{-1}); and other mortality (0.196 yr^{-1}) (Mohammed *et al.* 2008a).

Dolphinfish are piscivorous and occupy a trophic level of 4.44, which is higher than that of flyingfish (Mohammed *et al.* 2008a). Within the eastern Caribbean they consume: small oceanic pelagic species such as flyingfish, half beaks; juveniles of large pelagic species such as tunas, billfish, dolphinfish; and pelagic larvae of neritic, benthic species (e.g flying gurnards, triggerfish, pufferfish) (Oxenford and Hunte 1999). They also consume invertebrates (e.g cephalopods, mysids), which suggests that they are non-selective feeders (Oxenford and Hunte 1999). The predators of dolphinfish, especially the juveniles include; large tunas, sharks, billfishes and swordfish (Oxenford 1999), dolphinfish also exhibit a high rate of cannibalism.

2.3.4 Catch and Effort Data

The most recent assessment of the dolphinfish in the eastern Caribbean was conducted in 2006 at the Second Annual CRFM Scientific Meeting. The catch and effort data time series was from 1995 to 2004. The mean catch rates, which were standardized, catch per trip of dolphinfish ranged between 50.3-61.6 kg/per trip (Parker *et al.* 2006). At that time catches were assumed to be sustainable at these levels of harvest as no decline in catch rates was observed. An attempt to estimate dolphinfish stock biomass using a surplus production model was made, however it was problematic and the results were not used to develop management advice. The dataset was also inadequate with regards to the number of fishing countries represented and the number of years for which data was available (Parker *et al.* 2006).

Currently, the general trend observed for dolphinfish landings in the WCA and eastern Caribbean is an increasing one, with maximum landings of 4503 t and 2922 t for the WCA and EC regions respectively (Figure 4). However, it is likely that these data are an underestimation of the actual landings of dolphinfish within the WCA and EC. This is due to many factors which include: non-reporting by commercial large scale longline fisheries targeting tunas and billfishes that consider the dolphinfish as incidental catch; inadequate submission of landings data by the recreational fishery; and failure of countries to submit data or in some cases submission of inaccurate data.

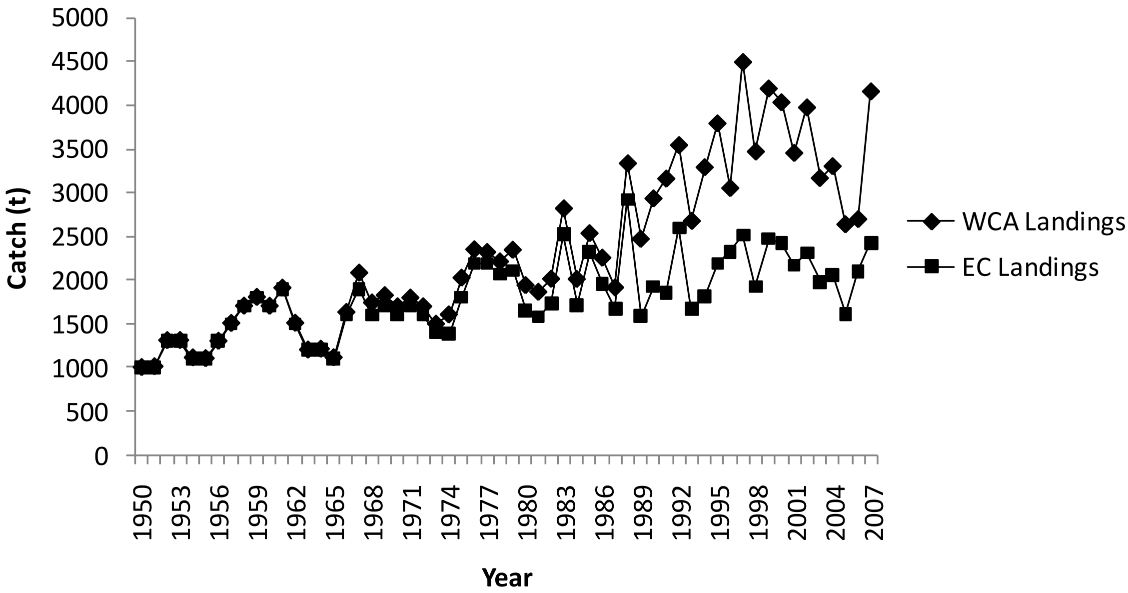

Figure 4: The estimated catches of dolphinfish from the Western Central Atlantic (WCA) and the Eastern Caribbean (EC) (1950-2007) (FAO 2009b).

2.3.5 Present Status of the Dolphinfish Stock

The existence of two separate dolphinfish stocks within the WCA was suggested by Oxenford and Hunte (1986) with ranges possibly overlapping near Puerto Rico; this was disputed by Rivera and Appeldoorn (2000), and Wingrove (2000) who suggested the existence of only one stock. However, subsequent research, which included analysis of microsatellite variation at five polymorphic nuclear loci from dolphinfish samples, suggested the existence of at least three genetically distinct populations in the region (an eastern Caribbean, southern Florida (Daytona Beach south west to the Gulf of Mexico) and a Carolina/Bermuda stock) (Chapman *et al.* unpublished in CRFM 2006). The current status of the dolphinfish stock within the eastern Caribbean is unknown; however given that more than one country fish the resource, collaborative management is necessary.

In order to address these issues, the CRFM Secretariat intends to conduct a dolphinfish assessment in 2010 during the Sixth Annual Scientific Meeting that includes some of the other major regional fishery fleets that were not considered in the 2006 assessment (i.e. Trinidad and Tobago, Martinique and Guadeloupe, and Venezuela) (CRFM 2009). The Large Pelagic

Working Group of this meeting has the inter-sessional responsibility of obtaining the relevant data for the assessment, including contacting the non-CRFM countries within the region with regard to catch and effort data (CRFM 2009).

2.3.6 Dolphinfish Fisheries Management

Dolphinfish is listed in Annex I of UNCLOS as a highly migratory pelagic species (CRFM 2006, FAO 2006). The International Commission for the Conservation of Atlantic Tunas (ICCAT) manages highly migratory species; however it does not specifically take responsibility for dolphinfish (CRFM 2006) and currently there are no active management regulations specifically for dolphinfish in any of the eastern Caribbean countries. Given the number of nations that are likely fishing the same dolphin stock, management of this fishery should be based on collaborative arrangements between the CARICOM and major non-CARICOM fishing countries including Venezuela, Martinique, Guadeloupe and the United States of America (CRFM 2009).

2.4 The Lesser Antilles Pelagic Ecosystem (LAPE) Project

The LAPE Project was completed in 2007 and introduced the concept of the Ecosystem Approach to Fisheries (EAF) in the Lesser Antilles and the wider eastern Caribbean region (Mohammed *et al.* 2008a). The EAF is defined in FAO 2003 as follows:

'An ecosystem approach to fisheries (EAF) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.'

The LAPE trophic model represents the entire pelagic ecosystem, defined to be the nominal Exclusive Economic Zone (EEZ) (within either equidistant or 200 nautical mile lines, whichever is lesser) of all the islands from Antigua and Barbuda and St. Kitts/Nevis in the north to Trinidad in the south, excluding the Gulf of Paria (Mohammed *et al.* 2008a). It is important to note that the Lesser Antilles pelagic ecosystem is an open system; therefore EEZs are only representative of the area over which the countries are responsible for management. A 200 nautical mile buffer zone was also used around the EEZs of the countries for which data would be acceptable to make inferences about the functional groups in the LAPE area (Mohammed *et al.* 2008a). The total area of the ecosystem defined was 610,000 km^2 and the model was constructed to represent an average year between 2001 and 2005 using the Ecopath with Ecosim (Version 5.1) software. An average habitat temperature of 28 ºC was used and 31 functional groups were described for the LAPE area (Mohammed *et al.* 2008a). These functional groups were representative of species, which share common trophic characteristics (Fanning and Oxenford 2009). The model was used to analyze various scenarios including the impact of increasing flyingfish fishing on the biomass, catch, and value of dolphinfish.

2.4.1 Flyingfish and Dolphinfish Linkages

The high proportion of flyingfish in the dolphinfish's diet within the eastern Caribbean indicates that dolphinfish are trophically dependent on flyingfish (Oxenford and Hunte 1999), and it is likely that this is reflective of the large regional concentration of flyingfish in the LAPE area.

Ecopath model results indicated that the dolphinfish stock is very sensitive to changes in the flyingfish biomass (Mohammed *et al.* 2008a, Fanning and Oxenford 2009). The model estimated that the instantaneous predation mortality rate of dolphinfish cannibalism is 4.3 yr^{-1}, which is almost four times its rate of predation on flyingfish (Mohammed *et al.* 2008a, Fanning and Oxenford 2009). Therefore increased flyingfish fishing, even without increases in dolphinfish catches can result in declines in dolphinfish biomass due to increased cannibalism. It was found that flyingfish biomass was dependent on the balance between increased fishing and reduced predation. The model also showed that predation mortality (3.787 yr^{-1}) is more important in the flyingfish stock dynamics than fishing mortality (0.013 yr^{-1}), which is low (Mohammed *et al.* 2008a, Fanning and Oxenford 2009).

Results from the Ecopath with Ecosim model of Mohammed *et al.* (2008a) explored various scenarios in which the biomass of dolphinfish is negatively affected by increased catches of flyingfish. The fishing mortality was increased for flyingfish and dolphinfish as single species and then for both. Increased fishing mortality on dolphinfish resulted in an increase of flyingfish biomass due to predation release (top-down control) (Mohammed *et al.* 2008a, Fanning and Oxenford 2009). Increased fishing mortality on both species resulted in biomass decreases for the flyingfish and dolphinfish; a similar result was also observed if only flyingfish fishing mortality was increased. This showed that prey availability was a stronger control in the dolphinfish - flyingfish dynamics (bottom-up control) than predator control (Mohammed *et al.* 2008a, Fanning and Oxenford 2009).

Increased effort in the gillnet/troll fishery which targets flyingfish, dolphinfish and wahoo also resulted in decreased biomass of dolphinfish; whereas the model showed that the impact on flyingfish could be positive, negative or neutral and depended on offsetting changes between increased fishing and reduced predation (Mohammed *et al.* 2008a, Fanning and Oxenford 2009).

2.4.2 Ecosystem Linkages

Many other non-commercial organisms (e.g sharks, squids and large mesopelagic fish) exist within the Lesser Antilles pelagic ecosystem and commercial fisheries can negatively impact these as many are linked through biological interactions, such as predator prey relationships, and through technological interactions such as being taken by the same fishing gear (Mohammed *et al.* 2008a).

3 MODELLING

3.1 Predator-Prey Relationship

This bioeconomic model attempted to explore the benefits obtained by harvesting flyingfish; i) directly and, ii) indirectly as converted predator biomass.

Flyingfish is a very short-lived species with a life cycle of only one year, within which it is eaten by predators, caught or dies. The growth rate of flyingfish can therefore be determined by:

$$0 = \dot{x} = G_x(x) - \alpha y - \beta z - \gamma w - h_x - \delta$$

Where x is the stock size of flyingfish, y is the stock size of dolphinfish, z is the stock size of other commercial fish species, w is the stock size of non-commercial species, $\propto$ is flyingfish mortality due to dolpinfish, β is flyingfish mortality due to other commercial fish species, γ is flyingfish mortality due to non-commercial species, h_x is the harvest of flyingfish and δ is other mortality. Let the growth rate of dolphinfish and other commercially important species be determined by:

$$\dot{y} = G_y(x, y) - h_y$$

$$\dot{z} = G_z(z, x) - h_z$$

where h_y and h_z are the catch rates of dolphinfish and other commercial fish species respectively. Both dolphinfish and other commercial fish species are predators and their growth is positively affected by the stock size of flyingfish.

Society's goal is to maximize the profits from harvest given by:

$$\pi = p_x h_x + p_y h_y + p_z h_z - C(h_x, h_y, h_z)$$

where p_x, p_y and p_z are prices for the three fish groups and $C(h_x, h_y, h_z)$ is the harvest cost function. Assume that the harvest of the three species is in steady state equilibrium so that $\dot{y} = \dot{z} = \dot{x} = 0$.

We assume that $p_x \ll p_y, p_z$. This begs the question: is it possible to increase the value of the fishery by reducing the flyingfish harvest and increasing the harvest of other species? To assess this issue it is possible to simply analyse the value of the flyingfish harvest directly and its value in terms of increased harvest of dolphinfish and other commercial fish species that prey on flyingfish. The shares of the flyingfish harvest that would end up as dolphinfish and other commercially important species can be estimated using the growth function for flyingfish above and feed conversion ratios, that indicate how much of the consumed feed is converted into flesh.

3.2 Effects on predator stock sizes

The effects of reducing flyingfish harvest would be to increase the predation potential for the fish that prey on flyingfish. Assuming steady state equilibrium in nature this would indicate:

$$0 = \dot{x} = G_x(x_1) - \alpha y - \beta z - \gamma w - \delta$$

Since $h_x = 0$, which occurs at a larger stock size for flyingfish x_1. The steady state for the other species would then be:

$$\dot{y} = G_x(y, x_1) - h_y - \Delta h_y = 0$$

$$\dot{z} = G_z(z, x_1) - h_z - \Delta h_z = 0$$

where Δh_y and Δh_z are the increases in harvest of dolphinfish and other commercial fish species possible due to the increased stock size of flyingfish after reduced harvest. The profits from the fishery after this change are then:

$$\pi_1 = p_y h_y + p_y \Delta h_y + p_z h_z + p_z \Delta h_z - C(0, h_y + \Delta h_y, h_z + \Delta h_z)$$

The net profit (or loss) from this change in management is then:

$$\pi_1 - \pi = p_y \Delta h_y + p_z \Delta h_z - p_x h_x - \left(C(h_x, h_y, h_z) - C(0, h_y + \Delta h_y, h_z + \Delta h_z)\right)$$

Flyingfish is a short-lived species with a lifespan of only one year, as discussed above. It is therefore assumed that as long as harvest is limited to secure sufficient spawning, reduced harvest has no effect on future stock sizes. Then the estimation of the net effects on profits simply requires the estimation of the effect of increased availability of flyingfish on the stock size of dolphinfish and other commercially important fish species. Here we assume that the harvest of flyingfish would be distributed between other sources of predation according to mortality parameters. It is further assumed that the harvest cost is linear for small changes in harvested quantity.

4 DATA

The set of biological and economic variables/parameters utilized in the model are defined in Table 1 and Table 2 respectively. These were obtained from various sources and include: predation mortality estimates; feed conversion ratios; harvest data; fish prices; trip data; and harvest costs.

4.1 Mortality

Flyingfish mortality estimates were obtained from the LAPE trophic model (Mohammed *et al.* 2008a). Total mortality represented the sum of fishing mortality, predation mortality and other mortality (death due to old age and disease). In this model, only predation mortality and other mortality were considered. Functional groups, which did not contain commercial fish species but contributed to the predation mortality of flyingfish were: seabirds, large mesopelagics and large squids. Functional groups, which contained commercial fish species that contributed to predation mortality of flyingfish included: swordfish, billfish, skipjack tuna, bigeye tuna, blackfin tuna, mackerels, wahoo, dolphinfish, and coastal predators. A description of the functional groups, which contributed to the predation mortality of flyingfish, is given in Appendix 3.

4.2 Feed conversion ratios

Feed conversion ratio (FCR) indicates the efficiency of organisms in converting food mass into body mass (FAO 2002b). FCRs for dolphinfish were obtained from two aquacultural studies. The first study utilized dolphinfish captured near the Gulf Stream off Hatteras, North Carolina, and kept in pens in estuarine waters. Separate feeding trials resulted in food conversion ratios of 3.54 and 3.44 (grams of wet weight food per gram of live weight gain) (Hassler and Hogarth 1977). The second study involved laboratory-reared dolphinfish at the Oceanic Institute, Waimanalo, Hawaii. The mean feed conversion ratios (grams of wet weight food per gram of live weigth gain) were 3.05 and 2.94 respectively (Hagood *et al.* 1981).

FCRs for yellowfin were determined from fish collected in coastal waters in the northwest Panama Bight for use as spawning stock in a land based aquaculture facility. The mean FCR was 18.2 (grams of wet weight food per gram of live weigth gain) (Wexler *et al.* 2003). This parameter was assumed to be representative for all the fish within the other commercial fish species group.

4.3 Eastern Caribbean Harvest and Price Data

The average 2001-2005 catch data for dolphinfish and other commercial fish species were obtained from the LAPE project, for which the three main data sources were: Fisheries Departments of countries in the LAPE region, the International Commission for the Conservation of Atlantic Tunas (ICCAT) Task I Database and the FAO FISHSTAT Plus Database (Mohammed *et al.* 2008b). The catch data were summarized by fleet types described specifically for the LAPE trophic model (Mohammed *et al.* 2008b) (Appendix 4).

For this model, catches of other commercial fish species by the beach seine fleet were not included in the 2001-2005 average as this fleet does not target flyingfish. Additionally, catches by longliners and recreational vessels which target the other commercial species and not usually flyingfish were not included in the 2001-2005 average. Catch data for flyingfish were obtained from Medley *et al.* (2009) and the average catch for the same 2001-2005 time period was used. Price data were also obtained from the LAPE trophic model and represented an average year from 2001-2005 (Mohammed *et al.* 2008b) (Appendix 5).

4.4 Harvests Costs and Trip Data

Given that the flyingfish fishery in Barbados has the highest: number of fishers, landings, number of trips, and ex-vessel and value-added values within the region, the estimated fixed and variable costs from 2002 that were updated in 2008 (Mohammed *et al.* 2008b) for the Barbados dayboat and iceboat fleets were considered the best available data for variable/parameter estimations. These fleets mainly target flyingfish and the other large regional pelagic (e.g. dolphinfish, wahoo, mackerels) (Barbados Fisheries Division 2004). Therefore a main assumption was that these economic data were representative for the multi-species pelagic fisheries throughout the eastern Caribbean. A breakdown of these costs is available in Appendix 6.

4.5 Numerical Analysis

The calculated biological variables are provided in Table 3. Dolphinfish consume a larger percentage of flyingfish (9.54%) than the other commercial fish species, which consume 4.21%. This amounts to a potential increase of 90 t and 7 t of dolphinfish and other commercial species biomass respectively. It is also shown that flyingfish accounts for a little over half of the quantity of fish taken during trips, while dolphinfish and other commercial species account for 30 % and 10% respectively.

Table 1: Biological variables and parameters obtained from the literature.

Variables/Parameters	Symbols of Variables/Parameters	Value	References
Flyingfish Mortality (yr^{-1})			
Predation mortality by dolphinfish	α	1.151 yr^{-1}	Mohammed *et al.* 2008a
Predation mortality by commercial species	β	0.781 yr^{-1}	Mohammed *et al.* 2008a
Predation mortality by other species	γ	1.855 yr^{-1}	Mohammed *et al.* 2008a
Other mortality	δ	0.2 yr^{-1}	Mohammed *et al.* 2008a
Mean Food Conversion Ratios (grams of wet weight food/gram of live weight gain)			
Dolphinfish	θ	3.24	Hassler and Hoggarth 1977, Hagood *et al.* 1981
Yellowfin tuna	τ	18.2	Wexler *et al.* 2003
Average Eastern Caribbean Harvest Data 2001-2005 (t)			
Flyingfish	x	3053 t	Medley *et al.* 2009
Dolphinfish	y	2197 t	Mohammed *et al.* 2008b
Other commercial fish species	z	811 t	Mohammed *et al.* 2008b

Table 2: Economic variables and parameters obtained from the literature.

Average Eastern Caribbean Prices 2001-2005 (USD/t)	Symbols of Variables/Parameters	Value	References
Flyingfish	P_x	$ 1220/t	Mohammed *et al.* 2008b
Dolphinfish	P_y	$ 5420/t	Mohammed *et al.* 2008b
Other commercial fish species	P_z	$ 4090/t	Mohammed *et al.* 2008b
Average Trip and Harvest Data (t) 2001-2005			
No. of trips (dayboats)	T_d	2311	Medley *et al.* 2009
No. of trips (iceboats)	T_i	1805	Medley *et al.* 2009
Flyingfish harvest (dayboats)	x_d	218 t	Medley *et al.* 2009
Flyingfish harvest (iceboats)	x_i	945 t	Medley *et al.* 2009
Annual and Per Trip Harvest Cost Data (USD)			
Annual harvest costs (dayboats)	H_d	$ 47,132	Ferreira 2002a, FAO 2009a
Annual harvest costs (iceboats)	H_i	$ 155,544	Ferreira 2002a, FAO 2009a
Per trip harvest costs dayboats (fuel,oil,food)	h_d	$ 140	Ferreira 2002a, FAO 2009a
Per trip harvest costs iceboats (fuel, oil, food, ice)	h_i	$ 858	Ferreira 2002a, FAO 2009a

In order to obtain harvest costs which are correlated to the amount of each fish group harvested, the cost of harvesting each fish group separately is calculated and then weighted means harvest costs are determined (Table 4).

Table 3: Calculated biological variables

Calculated Constants	Formulae	Calculated Variables	Calculated Values
Percentage of flyingfish consumed by other Fish Groups (%)			
Dolphinfish	$\varepsilon = \frac{\propto}{\propto + \beta + \gamma + \delta}$	ε	9.54%
Other commercial fish species	$\eta = \frac{\beta}{\propto + \beta + \gamma + \delta}$	η	4.21%
Potential Biomass of other Fish Groups (t/km^2)			
Dolphinfish	$\Delta y = \frac{\varepsilon * x}{\theta}$	Δy	90 t
Other commercial fish species	$\Delta z = \frac{\eta * x}{\tau}$	Δz	7 t
Proportion of Fish Groups Harvested in Eastern Caribbean			
Flyingfish	$\frac{x}{x + y + z}$	R_x	0.53
Dolphinfish	$\frac{y}{x + y + z}$	R_y	0.31
Other commercial fish species	$\frac{z}{x + y + z}$	R_z	0.1

Table 4: Calculated harvest costs

Harvest Costs/Trip by Fish Groups and Fleets (USD/t)	Formulae	Calculated Variables	Calculated Values
Flyingfish (dayboat)	$H_d + (h_d * T_d)/x$	κ_d	$ 121
Flyingfish (iceboat)	$H_i + (h_i * T_i)/x$	κ_i	$ 558
Dolphinfish (dayboat)	$H_d + (h_d * T_d)/y$	λ_d	$ 173
Dolphinfish (iceboat)	$H_i + (h_i * T_i)/y$	λ_i	$ 794
Other commercial fish species (dayboat)	$H_d + (h_d * T_d)/z$	ν_d	$ 650
Other commercial fish species (iceboat)	$H_i + (h_i * T_i)/z$	ν_i	$ 2985
Weighted Mean Harvest Costs/Trip for Fleets by Proportion of Fish Groups Harvested (USD/t)			
Flyingfish (dayboat)	$\frac{\kappa_d + \lambda_d + \nu_d}{3} * R_x$	$\mu (\kappa_d)$	$ 167
Flyingfish (iceboat)	$\frac{\kappa_i + \lambda_i + \nu_i}{3} * R_x$	$\mu (\kappa_i)$	$ 765
Dolphinfish (dayboat)	$\frac{\kappa_d + \lambda_d + \nu_d}{3} * R_y$	$\mu (\lambda_d)$	$ 117
Dolphinfish (iceboatboat)	$\frac{\kappa_i + \lambda_i + \nu_i}{3} * R_y$	$\mu (\lambda_i)$	$ 537
Other commercial fish species (dayboat)	$\frac{\kappa_d + \lambda_d + \nu_d}{3} * R_z$	$\mu (\nu_d)$	$ 31
Other commercial fish species (iceboat)	$\frac{\kappa_i + \lambda_i + \nu_i}{3} * R_z$	$\mu (\nu_i)$	$ 143
Proportion of Total Flyingfish Harvested by Fleets			
Dayboats	$\frac{x_d}{x_d + x_i}$	R_d	0.19
Iceboats	$\frac{x_i}{x_d + x_i}$	R_i	0.81

Benefits are calculated separately for each fish group and fleet type (Table 5). The iceboats realize more benefits than the dayboats due to the larger quantities of fish taken.

Table 5: Benefits by fleets

Benefits by Fleets (USD)	Formulae	Calculated Parameters	Calculated Values
Flyingfish (dayboat)	$(P_x * x * R_d) - (x * R_d * \mu(\kappa_d))$	πx_d	$603,739
Flyingfish (iceboat)	$(P_x * x * R_i) - (x * R_i * \mu(\kappa_i))$	πx_i	$1,127,761
Dolphinfish (dayboat)	$(P_y * \Delta y * R_d) - (\Delta y * R_d * \mu(\lambda_d))$	$\pi \Delta y_d$	$89,506
Dolphinfish (iceboat)	$(P_y * \Delta y * R_i) - (\Delta y * R_i * \mu(\lambda_i))$	$\pi \Delta y_i$	$356,632
Other commercial fish species (dayboat)	$(P_z * \Delta z * R_d) - (\Delta z * R_d * \mu(\nu_d))$	$\pi \Delta z_d$	$5376
Other commercial fish species (iceboat)	$(P_z * \Delta z * R_i) - (\Delta z * R_i * \mu(\nu_i))$	$\pi \Delta z_i$	$22,623
Overall Benefits by Fish Group (USD)			
Flyingfish	$\pi x_d + \pi x_i$		$1,731,500
Dolphinfish	$\pi \Delta y_d + \pi \Delta y_i$		$446,138
Other commercial fish species	$\pi \Delta z_d + \pi \Delta z_i$		$27,998

5 RESULTS

It can be seen in Figure 5 that the benefits obtained from direct harvest of flyingfish are $1.7 million US. Harvest of the increased predator biomass results in benefits of $ 474 thousand US. The net benefits represent a loss of $1.3 million US or 76% of what is obtained by direct harvest of flyingfish.

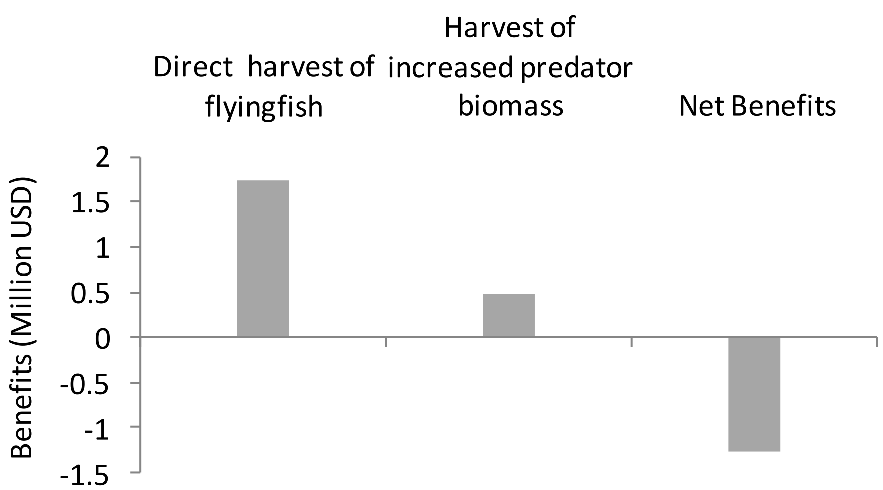

Figure 5: Benefits associated with direct and indirect harvest of flyingfish.

5.1 Model Uncertainties

Sensitivity analyses were conducted in order to document the range of uncertainty associated with some of the variables/parameters used in the model. An increase in the net benefits (less negative) is realized for the lower FCRs. However, as FCRs increase, the net benefits decrease (Figures 6 & 7). It is unlikely that such low FCRs occur in nature and even with increased availability of flyingfish as potential prey; the net benefits would still be negative.

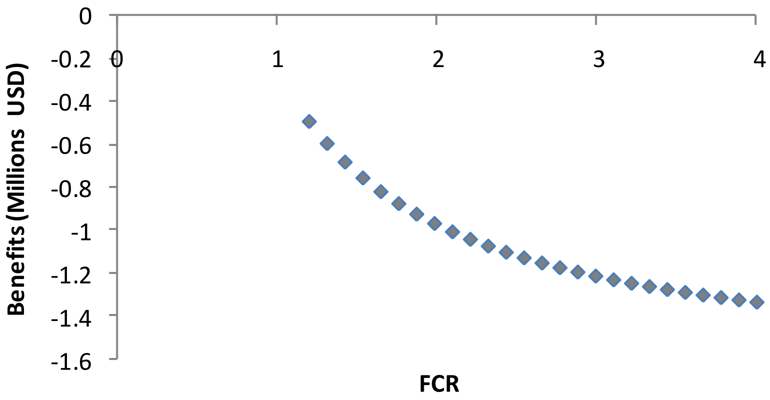

Figure 6: Net benefits associated with a range of dolphinfish FCRs.

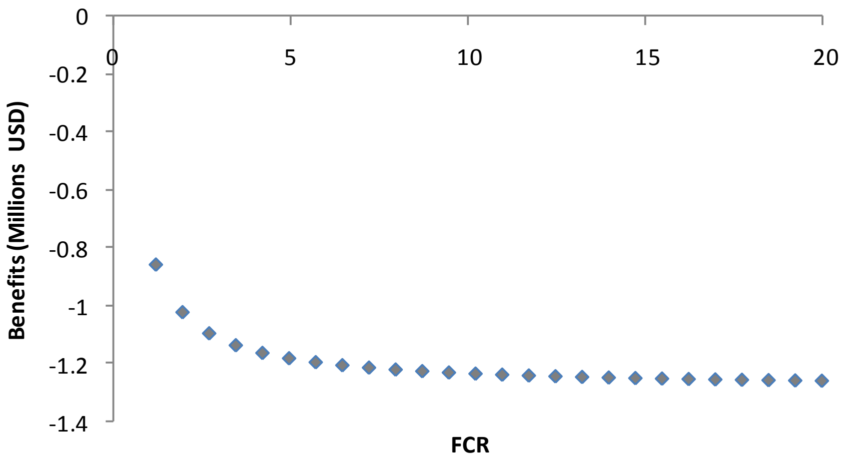

Figure 7: Net benefits associated with a range of other commercial fish species FCRs.

The net benefits become positive with a decrease in the price of flyingfish. This suggests that at these lower prices, it is more feasible to harvest the higher priced predator species (Figure 8). It can be seen in Figures 9 & 10 that increased prices of the predators result in the net benefits becoming less negative. However, prices above these showed here are unrealistic, therefore even with the reduced harvest of flyingfish, the net benefits would still be negative.

The number of iceboat trips and per trip iceboat harvest costs were the only additional variables for which sensitivity analyses indicated possible positive net benefits associated with reduced harvest of flyingfish (Figure 11 & 12).

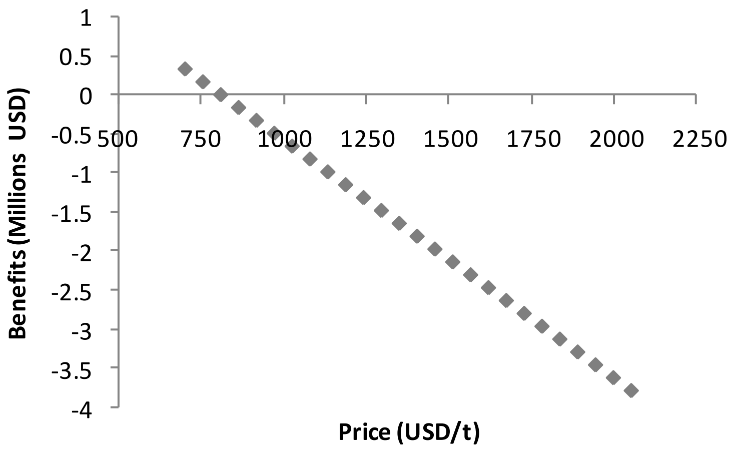

Figure 8: Net benefits associated with a range of prices for flyingfish

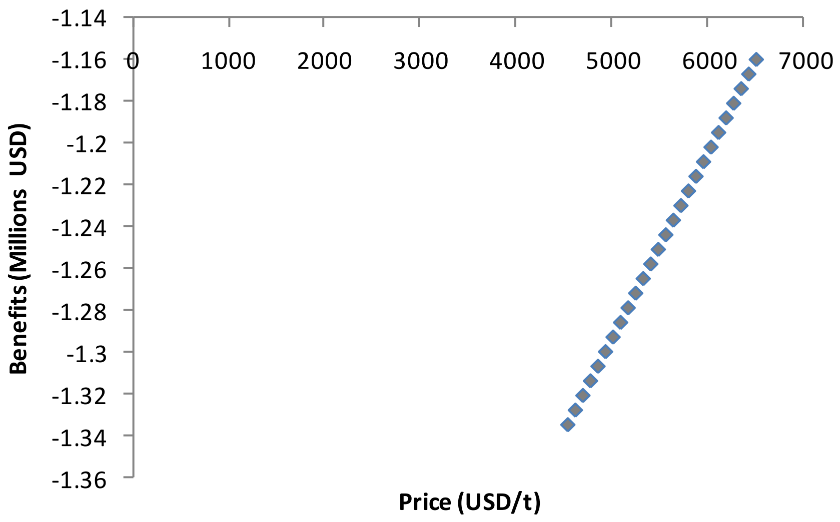

Figure 9: Net benefits associated with a range of prices for dolphinfish

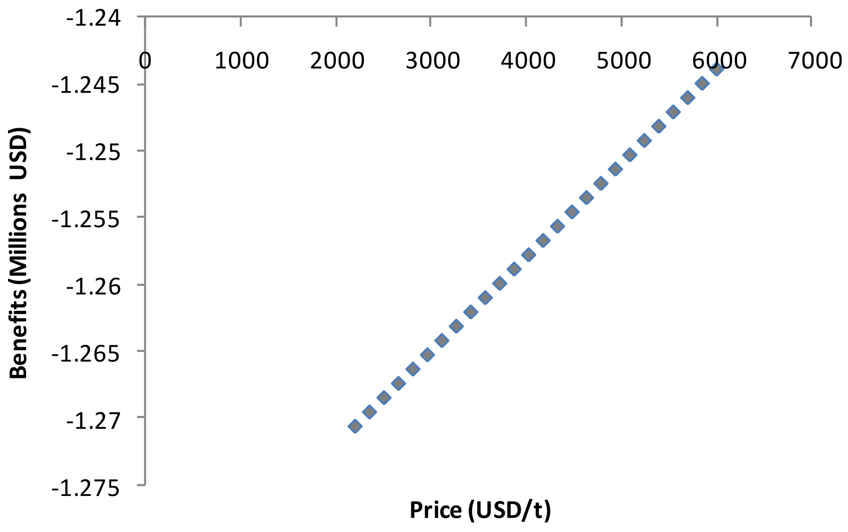

Figure 10: Net benefits associated with a range of prices for other commercial fish species.

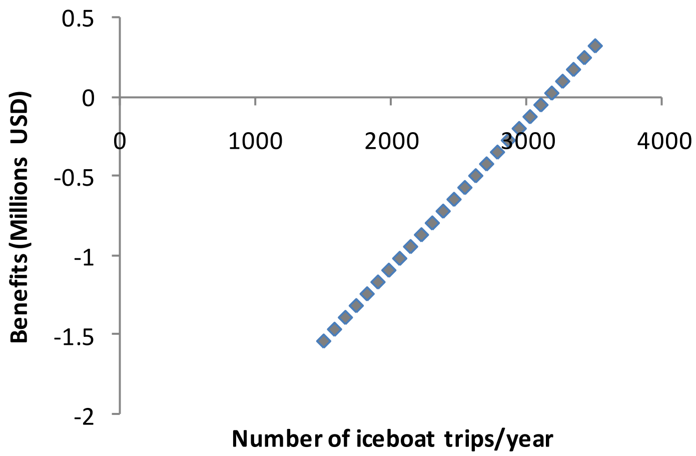

Figure 11: Net benefits associated with a range of number of iceboat trips per year

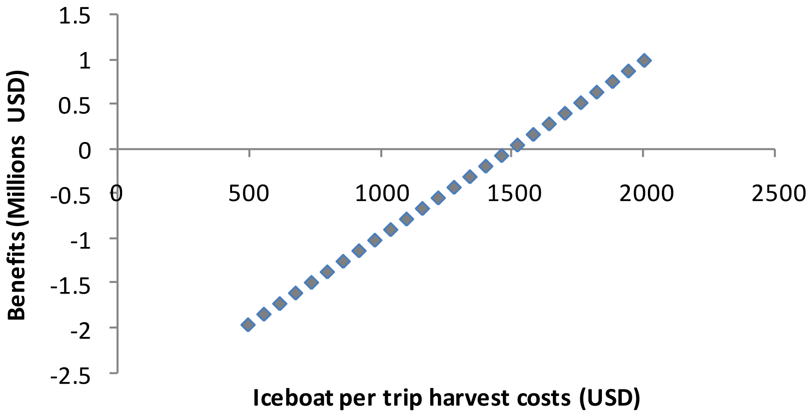

Figure 12: Net benefits associated with a range of per trip harvest costs for iceboats

5.1.1 Stochastic Assessment

In order to account for all the uncertainties in the model, a stochastic simulation consisting of 1000 iterations was done using the simulation software Simetar©. The standard deviations applied in the simulation are provided in Table 6. The standard deviations were estimated from ranges found in the data sources for different variables/parameters. All variables were assumed to be normally distributed. Figure 13 shows considerable variation in the net benefits. However, most of the outcomes are negative. Only 1.7% of the outcomes are positive, which indicates that although the uncertainty in the variables/parameter estimates is taken into account it is highly unlikely that the true net benefits are positive. This further supports the conclusion from the original estimate and the sensitivity analysis.

Table 6: Standard deviations of the biological and economic variables/parameters

Variables	**Value**	**Standard deviation**
Mean Food Conversion Ratios (grams of wet weight food/gram of live weight gain)		
Dolphinfish	3.24	1
Yellowfin tuna	18.2	6
Average Eastern Caribbean Prices 2001-2005 (USD/t)		
Flyingfish	$ 1220/t	100
Dolphinfish	$ 5420/t	200
Other commercial fish species	$ 4090/t	200
Average Trip and Harvest Data (t) 2001-2005		
No. of trips (dayboats)	2311	231
No. of trips (iceboats)	1805	181
Flyingfish harvest (dayboats)	218 t	22
Flyingfish harvest (iceboats)	945 t	94
Annual and Per Trip Harvest Cost Data (USD)		
Annual harvest costs (dayboats)	$ 47,132	7070
Annual harvest costs (iceboats)	$ 155,544	23,332
Per trip harvest costs dayboats (fuel,oil,food)	$ 140	21
Per trip harvest costs iceboats (fuel, oil, food, ice)	$ 858	129

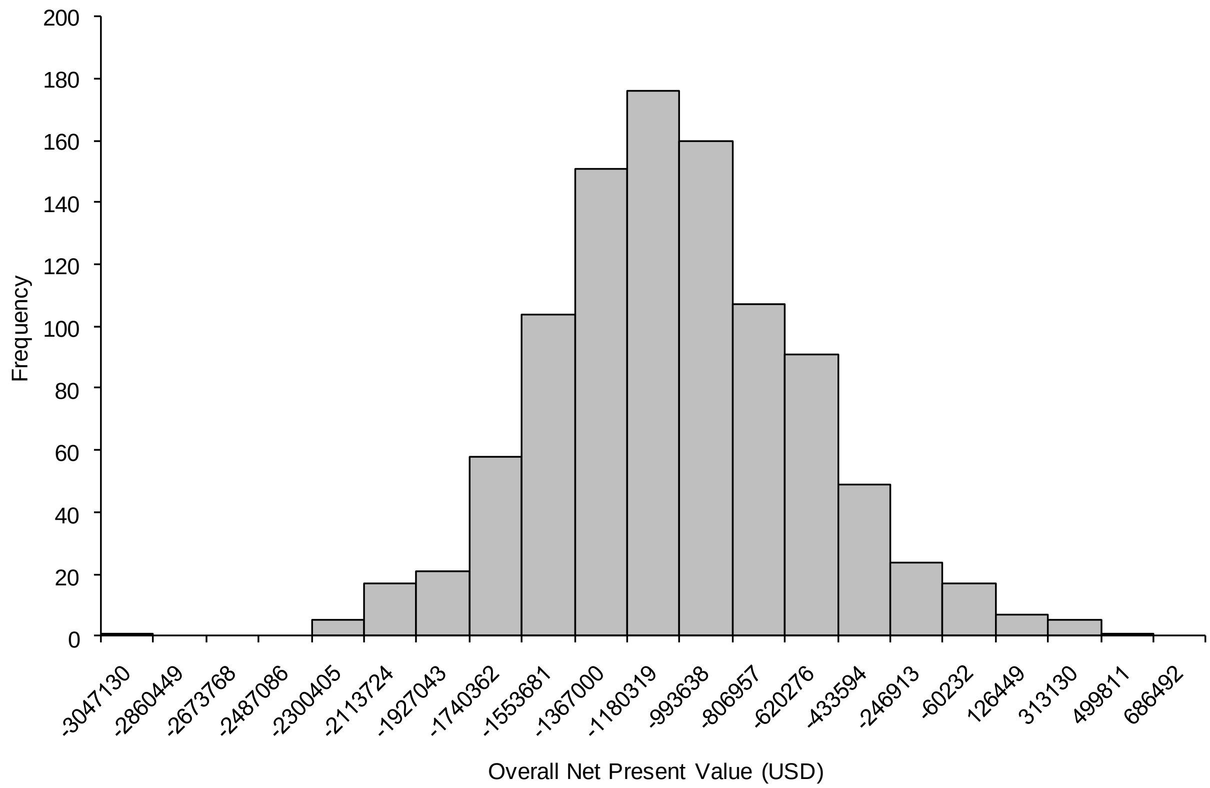

Figure 13: A histogram of the simulation showing the mean net benefits and its distribution.

6 DISCUSSION

Increasing the economic returns obtained from fisheries is one of the main aims of fisheries management, and it must be based on a thorough understanding of the economics of the fishing activity and measurement of the relevant economic parameters (Arnason *et al.* 2003). The biological parameters must also be taken into consideration and studies in boreal ecosystems done by Hannesson (1983), Flaaten (1989), Sumaila (1997), Eggert (1998), and Flaaten (1998) indicate that in some predator-prey relationships where the prey species are considered low value and the predator species are considered high value, increased economic returns could be obtained by reducing harvest of the prey and instead harvesting the prey indirectly through increased predator harvest.

The current study does not come to this conclusion; as this does not seem to be the case with the predator-prey relationships between flyingfish and other large pelagics in the tropical ecosystem. This bioeconomic model explores the benefits associated with the two harvesting strategies of flyingfish and investigates the effects of changes of biological and economic parameters on the net benefits. The results of the model indicate that reducing the flyingfish harvest would not increase the value of the multi-species pelagic fishery in the eastern Caribbean and therefore does not represent optimal management. Instead the direct harvesting of flyingfish, as currently practised is more beneficial.

Despite its low ex-vessel price, the high abundance and catchability due to its spawning behaviour has allowed the flyingfish to become an important fishery species. In addition to these aspects, the flyingfish processing sector is very important in terms of the value-added benefits, and the employment provided. Special skills are needed to de-bone flyingfish and this is one of the main reasons why other islands do not recognize as much value-added benefits as Barbados where it is a traditional skill. The use of a filleting machine to increase the value-added benefits in the other islands should therefore be considered and would provide a shift from the sale of whole (low valued) flyingfish to de-boned fillets (high value).

The estimated overall value of the flyingfish fishery in the eastern Caribbean is $5.5 million US (Oxenford *et al.* 2007) and the most recent landings estimate for 2007 is 2512 t (Medley *et al.* 2009). As mentioned before, there is a strong economic link among flyingfish, dolphinfish and other regional large pelagics as they are caught on the same trips. Interestingly, studies of the Barbados longline fleet by Walcott *et al*. (2009) also highlight the importance of this flyinfish–dolphinfish fishery which accounts for 25% of the longline landings, with flyingifsh accounting for 15% and dolphinfish accounting for 10%. Even though these species are not the main targets of the longliners, short trips are conducted in order to provide funds for the longer trips which target the large oceanic pelagics; or flyingfish may be targeted near the end of the trip. There is also a major technical link with flyingfish as some of the longline fisheries utilize it as bait.

The limitations of this model include:

- The use of data from 2001-2005;
- The use of economic data from only one country representing two fleet types;
- The fact that predation mortalities may change over time due to many factors including environmental conditions, and species abundance.

A stochastic simulation of the model was conducted to address these sources of uncertainty. The simulation results confirm the outcome of the initial analysis. This adds substantial robustness to the results.

It should be noted that the model results presented here may be revised in the future as updated data become available; however at present, they are indicative of the economic importance of the flyingfish fishery.

Economic objectives are focused on maximizing the net economic benefits from the utilization of the fishery resources for the society and can be contrary to the biological management objectives, which do not include economic benefits and costs of fisheries. Therefore, a caveat of this model is that even though the economic benefits associated with the harvest of flyingfish are great, the significant trophic linkages should be recognized and the precautionary approach taken for harvest levels that may result in the catch trigger point of 5000 t being exceeded.

7 CONCLUSION AND RECOMMENDATIONS

The model is applied to the question of whether direct harvest of flyingfish or indirect harvest is more profitable. The conclusion is clear; direct harvest is the better management strategy. The results also support the importance of incorporating biological and economic factors into management analyses.

Many of the fisheries in the eastern Caribbean provide employment through commercial fishing, the fisheries processing sector, recreational fishing and tourism. Fish is also an excellent protein source and has an important role in the region's food security. As a result of this heavy dependence, the majority of coastal resources are fully or overexploited, while the demand for fish products continues to increase.

Fisheries management has to address these issues and should be based on research. It is therefore necessary to improve the collection of biological; catch and effort; and social and economic data especially for the commercially important species. This research can then lead to the formulation of efficient management policies. It must also be noted that in order for fisheries management to be successful, monitoring and enforcement of these policies are required; however these activities are usually inadequate due to limited human and financial resources within the Caribbean region.

Good fisheries management can generate significant economic rents. These rents constitute capital that is available for investment in other industries and thereby the foundation of development. As such, optimal management of fisheries is an important issue for governments to address.

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Appendix 1: Vessel and gear characteristics by country for the flyingfish fishery (FAO, 2002a).

Indicator	Barbados	Grenada	Dominica	St. Lucia	St. Vincent and the Grenadines	Trinidad and Tobago
Vessel	• Day boats (6-12m) • Ice boats (12-14m) • Longliners (12-27m)	• Semi-industrial iceboats (10-15m) • Pirogue with cabin (PC) (8.5-10m) • Open pirogue (OP) (4-5m)	• Canoes • Keel boats • Fibreglass boats • Length: 5-8m	• Canoes • Fibreglass pirogues • Shaloops • Length: 5-9 m	• Double enders • Pirogues • Length: 5-8m	• Dayboats/open pirogues (7-9m) • Iceboats (6-12m)
Engine	• 50-200 HP(dayboats) • 150-215 HP(iceboats) • 220- 470 HP(longliners)	• Diesel inboard: 70-350 HP(iceboats) • Outboard: 2x65-85 HP(PC) • Outboard:14-25 HP(OP)	• Outboard 25-48 HP	• Outboard 40-115 HP	• Outboard 40-85 HP	• Gasoline outboard: 40-75 HP • Diesel inboard: 72-335HP
Gear	• Gillnets (3-5 m long, 2-4 m deep) • Dipnet	• Gillnet (30m) • Surface longline • Dipnet	• Dip nets • Gillnets • Hook & line	• Dipnet • Surface Handlines • Surface gillnets	• Gillnets • Hook & line • Dipnet	• Gillnets (4-7 m long, 2-2.5 m deep) • Dipnets • H ook & line

Appendix 2: Social and economic indicators of the importance of flyingfish to the eastern Caribbean. Adapted from Ferreira (2002a). New data from: [1] Medley *et al*. (2009), [2] C. Parker, Barbados Fisheries Division (pers. comm.) (FAO, 2009a).

Indicators	**Barbados[2]**	**Dominica**	**Grenada**	**Martinique**	**St. Lucia**	**St. Vincent & the Grenadines**	**Tobago**
Contribution of flyingfish fishery to national employment	1,100 fishers 450 persons in flyingfish post-harvest sector. 550 non-fisher vessel owners. 7 fish processing plants	615 fishers (31% of total fishers). 54 non-fisher boat owners Many wives of fishers in post-harvest sector. 1 fish processing plant	423 fishers (estimate) Many non-fisher boat owners	A few hundred fishers	915 fishers	2,500 fishers (none target flyingfish) 500 vendors, processors, etc.	228 fishers 200 persons in processing 4 major & 3 minor processing plants. Many cottage processing industries.
Number of boats in the flyingfish fishery	408	544	163	Not available	305	300 (none target flyingfish)	127
Composition of flyingfish fishery fleets	240 day boats 168 ice boats	197 canoes 308 keel boats 39 fibreglass boats	60 ice boats 55 cabin pirogues 48 open pirogues	Not available	163 canoes 122 pirogues 20 shaloops	-	126 pirogues 1 ice-boat
% of total fishing fleet landing flyingfish	43	57	Not available	Not available	32	60	18
investment in flyingfish harvest sector (USD)	Not available	2.44 million	5.63 million	Not available	5.65 million	Not available	Not available
Total estimated flyingfish catch (tonnes) [1]	1288 (2007 estimate)	36.1 (2007 estimate)	385.1 (most of this for bait)	370 (2007 estimate)	46 (2007 estimate)	1 (2007 estimate)	210 (2008 estimate)

Flyingfish as % of total fish landings	62 (1998-2007 average)	3	< 1	11.3 (1987 estimate)	4	< 1	75
Price of flyingfish **(USD/kg)**	0.83 - 1.61 (wholesale)	0.81-1.85	0.81 (wholesale) 1.63 (retail) 1.85 (processed)	1.50 – 7.00 (wholesale)	1.63 – 2.03 (retail)	-	0.69 (wholesale)
Value of flyingfish production (USD)	2,000,000 (wholesale) 20,000,000 (Value added) (1998-2007 average)	87,076	270,000	1,000,000 – 3,000,000 (1987 estimate)	136,054	-	61,986 (ex-vessel) 123,971 (retail) (1990-1991 estimate)
Contribution of fisheries to national economy (% GDP)	0.4 (2005 estimate)	1.8 (1999 estimate)	1.4 (1999 estimate)	Not available	1.16% (1999 estimate)	2	0.2 (1998 estimate)
Export flyingfish	Yes	No	Yes	No	No	No	Not available
Value of flyingfish exports (US$)	52,500 (2000-2006 average)	-	2,407	_	-	-	
Import flyingfish	Yes	No	Yes	Not available	Yes	Yes	Yes
Value of flyingfish imports (US$)	34,500 (1999 estimate)	-	Not available	-	101,501 (1999 estimate)	4,037	215,600 (1999 estimate)

Appendix 3: LAPE functional groups and species which account for predation mortality on flyingfish (Mohammed *et al.* 2008a).

Functional Group	**Common Name**	**Scientific Name**	**Predation Mortality on Flyingfish (yr^{-1})**
Dolphinfish	Common dolphinfish	*Coryphaena hippurus*	1.151
Swordfish	Swordfish`	*Xiphias gladius*	0.001
Other billfishes	Atlantic blue marlin	*Makaira nigricans*	0.004
	Atlantic white marlin	*Tetrapturus albidus*	
	Atlantic sailfish	*Istiophorus platypterus*	
	Black marlin	*Makaira indica*	
	Longbill spearfish	*Tetrapturus pfluegeri*	
Yellowfin tuna	Yellowfin tuna	*Thunnus albacares*	0.006
Skipjack tuna	Skipjack tuna	*Katsuwonus pelamis*	0.041
Bigeye	Bigeye	*Thunnus obesus*	0.028
Blackfin tuna	Blackfin tuna	*Thunnus atlanticus*	0.018
Mackerels	Serra Spanish mackerel	*Scomberomorous brasiliensis*	0.154
	King mackerel	*S. cavalla*	
	Cero mackerel	*S. regalis*	
	Spanish mackerel	*S. maculatus*	
Wahoo	Wahoo	*Acanthocybium solandri*	0.006
Coastal Predators	Keeltail needlefish	*Platybelone argalus argalus*	0.523
	Redfin needlefish	*Strongylura notata notata*	
	Agujon needlefish	*Tylosurus acus acus*	
	Atlantic needlefish	*Strongylura marina*	
	Blue runner	*Caranx crysos*	
	Black jack	*Caranx lugubris*	
	Hound needlefish	*Tylosurus crocodilus*	
	Crevalle jack	*Caranx hippos*	
	Bar jack	*Caranx ruber*	
	African pompano	*Alectis ciliaris*	
	Yellowtail amberjack	*Seriola lalandi*	
	Rainbow runner	*Elegatis bipinnulata*	
	Leatherjacks	*Oligoplites* spp.	
	Amberfish	*Seriola dumerili*	
	Great barracuda	*Sphyraena barracuda*	
	Guachanche barracuda	*Sphyraena guachancho*	
	Pompano	*Trachinotus carolinus*	
	Sennet	*Sphyraena picudila*	
	Common snook	*Centropomus undecimalis*	
	Yellowtail snapper	*Ocyurus chrysurus*	
	Tripletails (Lobotidae)	*Lobotidae*	
	Bermuda sea chub	*Kyphosus sectatrix*	
	Palometa pompano	*Trachinotus goodei*	
	Permit	*Trachinotus falcatus*	
Seabirds	Black-capped petrel	*Pterdroma hasitata*	0.005
	Brown pelican	*Pelacanus occidentalis*	
	Cayenne tern	*Sterna eurygnatha*	
	Common tern	*Sterna hirundo*	
	Gull-billed tern	*Galechelidon nilotica*	
	Royal tern	*Sterna maxima*	
	Least tern	*Sterna antillarum*	
	Sandwich tern	*Sterna sandvicensis*	
	Roseate tern	*Sterna dougalli*	

	Bridled tern	*Sterna anaethetus*	
	Sooty tern	*Sterna fuscata*	
	Laughing gulls	*Larus atricilla*	
	Black noddy	*Anous minutus*	
	Masked booby	*Sula dactylatra*	
	Red-footed booby	*Sula sula*	
	Brown noddy	*Anous stolidus*	
	Red-billed tropicbird	*Phaethon aethereus*	
	White-tailed tropicbird	*Phaethon lepturus*	
	Audubon's shearwater	*Puffinus lherminieri*	
	Magnificent frigatebird	*Fregata magnificens*	
Large Mesopelagic Fish	Snake mackerel	*Gempylus serpens*	1.11
	Longnose lancetfish	*Alepisaurus ferox*	
	Oilfish	*Ruvettus pretiosus*	
	Atlantic pomfret	*Brama brama*	
Large squids	Onychoteuthidae and Architeuthidae Mantle Length > 50 cm		0.74

Appendix 4: Average catch (tonnes) of fish groups (2001-2005) (Mohammed *et al.* 2008b).

Functional Group	**Average catches taken by fleets which target flyingfish (t)**	**Average after removal of catches by beach seine, longliners and recreational fleet s (t)**
Dolphinfish	2197	2144.25
Swordfish	178	1.51
Other billfishes	410	27.83
Yellowfin tuna	1226	138.83
Skipjack tuna	222.6	84.20
Bigeye	26.6	1.77
Blackfin tuna	1409	1408.92
Mackerels	2877.4	2868.44
Wahoo	375.2	229.62
Coastal predators	578.6	374.51

Appendix 5: Average Eastern Caribbean fish prices (2001-2005) (Mohammed *et al.* 2008b).

Important Commercial Functional Groups	**Average price (USD/kg)**
Swordfish	$3.96
Billfishes	$4.22
Yellowfin tuna	$4.51
Skipjack tuna	$3.92
Bigeye tuna	$4.44
Blackfin tuna	$4.47
Mackerels	$3.65
Wahoo	$5.05
Coastal predators	$2.56
Dolphinfish	$5.42

Appendix 6: Estimate of fixed and operational costs for two fleets which target flyingfish and large pelagics (Ferreira, 2002a, FAO, 2009a).

Costs (USD)	**Dayboat**	**Iceboat**
Vessel and Engine	$27,500	$100,000
Gear cost /unit/year	$500	$2000
Average vessel and engine maintenance costs/unit/ year	$1000	$3000
Average insurance cost/unit/year	$1000	$2500
Average loan repayment cost/unit/year	$4150	$12,000
Average crew share/unit/year	$9563	$25,437
Gear repair/replacement, engine and hull repair costs/unit/year	$1496	$3932
Market fees/unit/year	$453	$978
Depreciation cost /year	$1330	$4839
Average fuel cost/unit/ trip	$100	$150
Average oil cost/unit/ trip	$25	$50
Average ice cost/unit/trip		$500
Average food cost/unit/trip	$15	$157.5