EVALUATING TRADE-OFFS IN AN ECOSYSTEM-BASED FISHERY MANAGEMENT PARADIGM: AN EXPLORATION THROUGH ANALYSIS OF THE ATLANTIC BUTTERFISH AND LONGFIN SQUID FISHERIES

By
Keith Carlisle

Anthony Rogers

Jiaxi Wang

Dr. Martin D. Smith, Adviser

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ABSTRACT

The Mid-Atlantic Fishery Management Council, our client for this masters project, is evaluating how best to transition from a primarily single-species management approach to an integrated multi-species management paradigm. In this connection, we explore how economic considerations may be incorporated into an integrated multi-species management approach by focusing on two closely associated stocks managed by the Council: longfin squid and Atlantic butterfish.

We take several different approaches in our analysis of the two fisheries, our ultimate objectives being (i) to characterize the behavior of the fleets based upon historical landings data and geospatial analysis; and (ii) to provide the Council with insight into the potential impact of management constraints and ecosystem interactions on economic benefits in the fisheries. To illustrate potential impacts to economic benefits, we develop a two-species bioeconomic model and derive optimal harvest levels for the stocks, taking into account varying degrees of management constraints and ecosystem interactions.

Based upon our analysis of landings data, we found that the Council's allocation of the longfin squid landings quota among trimester management periods is no longer representative of actual landings in the fishery throughout the year. As a result, there is potential that the fishery may be forced to close prematurely in the summer months, thereby reducing economic benefits to participants who are highly dependent on revenues from the fishery. We also found, based upon our geospatial analysis of butterfish landings and butterfish bycatch in the longfin squid fishery, that a statistically significant correlation exists between the distance to shore from the point of catch and the butterfish bycatch rate.

With respect to the model, we explored the importance of three parameters not generally included in a single-species model: predation, bycatch by fishermen, and benefits to the longfin squid population of additional butterfish. We found that all three have potential economic impacts. We also found that the amount of the total allowable catch of butterfish allocated to a bycatch cap imposed on the longfin squid fishery is higher than necessary to prevent early closure of the longfin squid fishery and could result in lost revenues in the butterfish fishery.

Table of Contents

1. Introduction

The Mid-Atlantic Fishery Management Council (hereafter, the Council), our client for this masters project, is in the process of evaluating how best to integrate additional ecosystem considerations into its management of marine fisheries.[1] This effort is part of an envisaged longer-term transition by the Council from a primarily single-species management approach to an integrated multi-species or ecosystem-based fisheries management paradigm. In this connection, the Council proposed that we explore how the management of two closely associated fisheries, the Atlantic butterfish (*Peprilus triacanthus*) fishery and the longfin squid (*Loligo pealei*) fishery, could better incorporate economic considerations.[2]

Although our primary focus concerns the effects of management constraints and ecosystem interactions on economic benefits in the two fisheries, given the client-based nature of this project, we are also interested in identifying other characteristics of the fisheries that may have implications for management. We therefore analyzed historical landings and price data to characterize the fisheries and identify recent trends, and we conducted a geospatial analysis of landings and bycatch to determine whether there are any spatial patterns or phenomena that should be considered by the Council. In order to explore the effects of management constraints and ecosystem interactions on economic rents, we developed a two-

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[1] The Magnuson-Stevens Fishery Conservation and Management Act defines the term "fishery" as "(A) one or more stocks of fish which can be treated as a unit for purposes of conservation and management and which are identified on the basis of geographical, scientific, technical, recreational, and economic characteristics; and (B) any fishing for such stocks." 16 U.S.C. §1802(13).

[2] A potential source of confusion is that multiple, sometimes unrelated, species of fish are commonly referred to simply as "butterfish" in the seafood industry, although we are aware of only a single species (*Peprilus triacanthus*) that goes by the name "Atlantic butterfish." Other species commonly called "butterfish" include *Poronotus triacanthus* (also known as silver pomfret and Pacific Pompano) and *Seriola rivoliana* (also known as Punnarameen). The longfin squid (*Loligo pealei*), on the other hand, has multiple common names, including long-finned squid, the longfin inshore squid, the Boston squid, and the loligo squid.

species bioeconomic optimization model and derived optimal harvest paths under varying levels of harvest constraints and ecosystem interactions. With regard to ecosystem interactions, we considered both a technical interaction (bycatch by fishermen) and a species interaction (predation). Our aim with the model is to provide the Council with a conceptual framework for evaluating the economic tradeoffs associated with multi-species fisheries management. As a byproduct of our analysis, we also highlight areas where further research may be warranted to better understand the ecosystem interactions that affect optimal fisheries management.

2. The Fisheries and Management Context

Atlantic butterfish and longfin squid overlap temporally and spatially and are often caught by the same mixed-fisheries vessels in the mid-Atlantic and southern New England regions. The economics and incentives of the two fisheries are quite different, however. The Atlantic butterfish fishery once enjoyed a strong overseas market in Japan, but the directed fishery essentially disappeared after 2001 due, at least in part, to an apparent decline in butterfish abundance and economic conditions in Japan (MAFMC Butterfish AP Informational Document 2012). The fishery for longfin squid, however, has remained active over the last decade, with strong demand for the species stemming from its reputation as a premium calamari squid. Vessels targeting longfin squid generally use small-mesh otter trawls, and they frequently encounter Atlantic butterfish as bycatch. In most cases, the butterfish are discarded rather than landed by the vessels.

In terms of management, Atlantic butterfish remain under a rebuilding plan as a result of a 2004 stock assessment that found the stock to be overfished. This finding initially resulted in a constrained landings quota, and beginning in 2011, a cap on butterfish bycatch in the longfin squid fishery (referred to as the “mortality cap”). The details of the mortality cap are described in section 3.5.1, but a consequence of the cap is closure of the longfin squid fishery for the remainder of any management period in which the mortality cap threshold is reached. Given the relative importance of the longfin squid fishery, the Council has allocated most of the allowable biological catch (ABC) of Atlantic butterfish to the mortality cap in an effort to avoid premature closure of the longfin squid fishery.

Significantly, there are now indications that Atlantic butterfish are more abundant than previously estimated. Indeed, the 2005 Atlantic butterfish stock assessment that resulted in the stock rebuilding plan was recently invalidated, and the stock status was declared “unknown,” pending a new assessment at the end of 2013. With this development, the Council is evaluating how best to manage the two fisheries, and in particular, how to allocate increases in the ABC for Atlantic butterfish. We understand that the Council has two primary objectives in this regard: (i) allocate a sufficient quantity of the butterfish ABC to the mortality cap to avoid premature closure of the longfin squid fishery; and (ii) increase, to the extent possible, the landings quota for butterfish to allow rebuilding of the directed fishery.

In 2012, the Council initially doubled the prior year’s ABC for butterfish to 3,622 metric tons (mt) before making a late-season increase to 4,200 mt over concerns that unexpectedly high butterfish bycatch threatened to close the longfin squid fishery.[3] Of the 4,200 mt, 3,165 mt was allocated to the bycatch cap, while only 872 mt was allocated to the butterfish landings quota. The 872 mt quota represented an increase of 57 percent above the 500 mt quota in effect from 2008 through 2011, however. This year, the Council once again doubled the butterfish ABC to 8,400 mt, but unlike in the previous two years, a significant portion of the increase was allocated to the landings quota to allow for a directed butterfish fishery.

Current butterfish regulations provide for a 2,570 mt landings quota and a mortality cap of 3,884 mt. While this allocation may meet the dual objectives of allowing rebuilding of the Atlantic butterfish fishery without unnecessarily impacting the longfin squid fishery, it is not clear whether it is likely to result in the optimal management of the two fisheries from an economic standpoint. We explore this question, along with the implications of accounting for ecosystem interactions in optimal fisheries management, in section 6 below. We also analyze historical landings data from the longfin squid fishery in section 4 and geospatial patterns in the Atlantic butterfish fishery in section 5 in order to more fully characterize the two fisheries. First, however, we provide background information in the following section concerning (i) the life history characteristics of longfin squid and Atlantic Butterfish; (ii) the commercial fisheries for the two species; (iii) federal fisheries management; (iv) the transition to ecosystem-based fishery management; and (v) present management of Atlantic butterfish and longfin squid fisheries.

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[3] In 2011, there was also a small increase in the butterfish ABC from 1,500 mt to 1,811 mt. The entirety of the increase was allocated to the bycatch cap, however, and the butterfish landings quota remained at 500 mt where it had been since 2008.

3. Background

3.1 Life History Characteristics for Longfin Squid and Atlantic Butterfish

3.1.1 Longfin Squid. The longfin squid is a schooling pelagic invertebrate that is distributed from Newfoundland down to the Gulf of Venezuela (Jacobson 2005). It only occurs in commercially exploitable concentrations, however, from Georges Bank to Cape Hatteras off the Atlantic coast of the U.S (Jacobson 2005). The longfin squid is also a fast-growing and short-lived species. It has a maximum lifespan of less than one year, and although it is capable of attaining a mantle length of between 40 to 50 centimeters, most reach no more than 30 centimeters in length (Jacobson 2005).

From late fall through mid-spring, when inshore waters are coldest, the longfin squid is found in deep offshore waters along the edge of the continental shelf in the Mid-Atlantic Bight and southern New England (Jacobson 2005). In the late spring when inshore waters begin to warm, it migrates to shallow coastal waters before returning back offshore again in the late fall (Macy and Brodziak 2001). The species is believed to spawn more or less throughout the year, although there are seasonal and geographic peaks that vary from year-to-year (Jacobson 2005; Macy and Brodziak 2001; Hatfield and Cadrin 2002). Larvae and juvenile longfin squid live in the upper water column, while adults generally live just above mud or mud/sand substrate of the continental shelf and upper continental slope (Jacobson 2005).

Active cephalopods like longfin squid have one of the highest metabolic rates among all animal species on account of their energetically inefficient mode of locomotion, jet propulsion (Pimentel et al. 2012). Indeed, the metabolic demand of a squid is several times greater than the metabolic demand of an equally sized fast-swimming fish (Pimentel et al. 2012). This means that the longfin squid is a voracious feeder, and its diet includes not only other squid and crustaceans but also larval and juvenile finfish (Hunsicker and Essington 2006; Hunsicker and Essington 2008). From an ecological standpoint, longfin squid occupy a key role in Northwest Atlantic food webs. As both juveniles and adults, they are an important prey species for toothed whales, sea birds and a number of fish species, including commercially important species like Atlantic cod, flounder and hake (Hunsicker and Essington 2006). As adults, however, they also consume many of those same fish species in their larval or juveniles stages (Hunsicker and Essington 2006). Thus, their role in the ecosystem is both important and complex.

3.1.2 Atlantic Butterfish. The Atlantic butterfish is a small, short-lived, pelagic species with an average length of 15 to 23 centimeters and a maximum lifespan of about three years (Cross et al. 1999). It is a schooling planktivore that ranges from Newfoundland to the Atlantic and Gulf coasts of Florida, but it generally occurs in exploitable concentrations from the Gulf of Maine to Cape Hatteras (Cross et al. 1999). Like longfin squid, the Atlantic butterfish exhibits seasonal migrations. It spends the late fall and winter months in deep offshore waters along the continental shelf edge before migrating in the late spring to shallower inshore waters to spawn (Cross et al. 1999). During the summer months, the species remains inshore and is may be found in looser aggregations near the surface (Cross et al. 1999).

The Atlantic butterfish is also an important forage fish in the highly productive Northwest Atlantic ecosystem. It serves as prey for many species, including protected species like pilot whales and common dolphins, as well as commercially important species like haddock, silver hake, monkfish, and swordfish (MAFMC Butterfish AP Informational Document 2012). As discussed in the following section, Atlantic butterfish is also consumed by longfin squid, which has implications for management of the two species under an ecosystem-based fishery management paradigm.

3.1.3 Interactions Between Longfin Squid and Atlantic Butterfish. As previously noted, longfin squid and Atlantic butterfish co-occur both spatially and temporally throughout the year. As a result, it is nearly impossible to conduct directed fishing for longfin squid without also incidentally catching Atlantic butterfish (Hendrickson 2011. As described in section 5 below, butterfish bycatch rates are fairly high in the longfin squid fishery, and in 2012 approximately 87 percent of all butterfish caught on longfin squid fishing trips were discarded (*see* 50 CFR part 648). In addition, the survival rate for discarded butterfish is likely extremely low on account of the lengthy tow durations in the longfin squid fishery (Hendrickson 2011). Thus, butterfish mortality resulting from incidental catch by the longfin squid fishery may be quite significant.

In addition to this technical or fishery interaction, there are almost certainly predator-prey interactions between the two species in the ecosystem. As noted in section 3.1.1, longfin squid have very high energetic demands, and their diet includes larval and juvenile finfish. In this regard, researchers have estimated, based upon studies of longfin squid stomach contents and gastric evacuation rates, that fish may exceed 50 percent of the longfin squid diet by weight (Maurer and Bowman 1985) and that individual longfin squid likely consume between 8 and 11.5 percent of their bodyweight in fish each day (Hunsicker and Essington 2008). In a 2006 study by Hunsicker and Essington, the size of fish found to have been ingested by longfin squid ranged from 8 to 172 mm, with an average length of 58 mm (Hunsicker and Essington 2006). It is important to note that there is seasonal variation in the extent to which longfin squid consume fish. In the same 2006 study, Hunsicker and Essington found that larger longfin squid exhibit higher rates of piscivory than smaller squid, but that longfin squid are piscivorous at smaller sizes in the winter and spring when the rate of piscivory is highest and the number of vulnerable prey species is greatest (Hunsicker and Essington 2006).

Based upon the likely size range of longfin squid prey, Atlantic butterfish could be vulnerable to longfin squid predation for much of their expected lifespan. At 2+ years of age, for example, Atlantic butterfish average approximately 170 mm in length (Cross et al. 1999). This means that even at early maturity, butterfish remain within the size range (albeit at the high end) of suitable prey size for longfin squid found by Hunsicker and Essington. In addition, there is considerable overlap in the occurrence of Atlantic butterfish and longfin squid throughout the year, with both species migrating in the spring to inshore waters before migrating back out to deeper waters along the continental shelf break in the fall (Cross et al. 1999). Studies have also found a high degree of overlap in both temperature and depth preferences for the two species (Hendrickson 2011). The Atlantic butterfish would therefore seem to be an ideal prey candidate for longfin squid based upon the two species’ life history characteristics.

While there is suggestion in the literature that longfin squid prey upon Atlantic butterfish (see e.g. Cross et al. 1999), it is not possible, based upon existing studies, to estimate with any degree of certainty the extent of such predation. In a paper describing the diets of fish and squid species in the Northwest Atlantic based upon several decades of sampling surveys, Smith and Link found that unidentified (i.e., well-digested) cephalopods and unidentified fish constituted the overwhelming majority of the longfin squid's dietary components (Smith and Link 2010). They noted that the large amounts of well-digested and unidentifiable prey in the squid's diet were attributable to the high degree of prey mastication by the species (Smith and Link 2010).

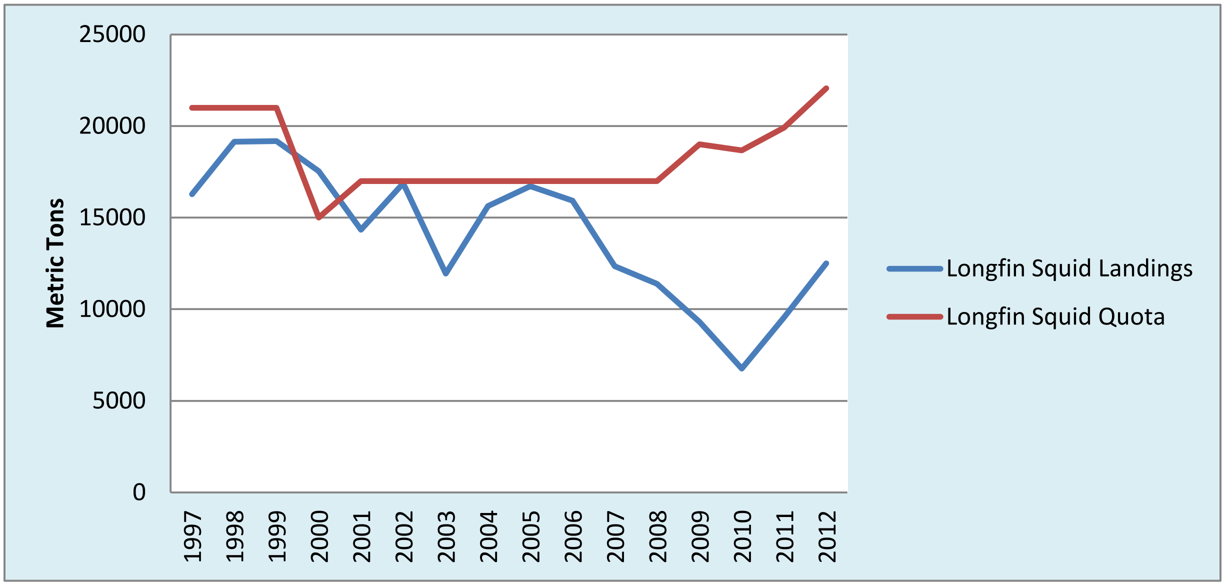
In all likelihood, Atlantic butterfish would not need to constitute a significant portion of the longfin squid diet for the squid to exert top-down pressure on the butterfish stock. In this regard, Hunsicker and Essington estimated that, based upon an annual biomass of butterfish recruits of 16,250 mt, only 5 to 9 percent of the longfin squid diet in a <u>single</u> <u>season</u> would need to consist of Atlantic butterfish for squid consumption to equal the estimated annual recruitment of butterfish (Hunsicker and Essington 2008). Thus, there is potential for longfin squid to exert trophodynamic control on the recruitment success of the Atlantic butterfish stock.

3.2 The Fisheries for Longfin Squid and Atlantic Butterfish

3.2.1 The Longfin Squid Fishery.

The longfin squid fishery dates back to at least 1928, and until 1966, it was entirely a domestic fishery that took place seasonally when the squid were in shallow, inshore waters (MAFMC MSB Staff ABC White Paper 2011). In 1967, foreign fishing fleets began harvesting longfin squid offshore, and from 1967 to 1984, foreign landings dominated the fishery with a peak of 37,600 mt in 1973 (MAFMC MSB Staff ABC White Paper 2011). Following the enactment of the Magnuson-Stevens Fishery Conservation and Management Act in 1976, the U.S. began gradually phasing out foreign fishing, and by 1990, the longfin squid fishery was entirely a domestic fishery (MAFMC MSB Staff ABC White Paper 2011). Domestic landings of longfin squid peaked in 1989 at 23,700 mt, and since 1998, landings have generally been restricted by quotas. As illustrated in Figure 1 below, however, landings have been well below the quota for the past five years for reasons that are not entirely clear.

Figure 1. Longfin Squid Landings and Quota, 1997 – 2012



Source: generated from the Commercial Fisheries Database Service landings data; quota from NFSC (2011)

The vessels in the longfin squid fishery range from Massachusetts to North Carolina, with the greatest amount of longfin squid typically landed in Rhode Island and New York.[4] These vessels primarily use bottom otter trawls with a small mesh to prosecute the fishery.[5]

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[4] Longfin squid landings at Point Judith, Rhode Island and Montauk, New York constituted 40% and 16%, respectively, of total longfin squid landings in 2010. Those same two ports also constituted 31% and 22% of the total butterfish landed in 2010. *See* Addendum to the Environmental Assessment for 2012 Atlantic Mackerel, Squid, and Butterfish Specifications and Management Measures (2012). Available at http://www.nero.noaa.gov/nero/regs/frdoc/12/12SMB2012SpecsEA.pdf

[5] Although bottom trawling can alter benthic habitat and destroy sensitive ecosystems, the mud and sand habitats occupied by longfin squid and butterfish are believed to be fairly resilient to trawling. These trawls can, however, incidentally catch marine mammals, large pelagics, and a number of finfish. Total discards of all species by longfin squid fishermen constitute about 42% of the total amount of longfin squid kept. *See* NOAA Fishwatch U.S. Seafood

This type of gear consists of a large, cone-shaped net that is towed along the bottom from the stern of the vessel. The mouth of net is kept open horizontally by two planks (the "otter boards").[6] In addition to catching longfin squid, vessels making hauls with this gear also catch other species living on or near the bottom, such as silver hake, scup and Atlantic butterfish.

In terms of the species' commercial value, longfin squid is harvested primarily for human consumption. In fact, it is considered by many to be the best squid for calamari, and it is prized globally for its flavor, tenderness and consistency.[7] Not surprisingly, it commands a premium in the marketplace, and is the most expensive squid sold in the U.S. In 2011, for example, the average ex-vessel price for longfin squid was $1.18 per pound. In the same year, the other major squid species harvested on the east coast, Ilex squid, averaged $.46 per pound, while the major squid species harvested on the west coast, California Market Squid, averaged $.25 per pound.[8] Longfin squid is sold both domestically and internationally, with exports going to European and Asian markets.

3.2.2 <u>The Atlantic Butterfish Fishery</u>. Atlantic butterfish have been harvested off the U.S. Atlantic coast since the late 1800s, and until 1963, it was entirely a domestic fishery. Starting in 1963, foreign fleets began targeting butterfish in the months when the species was offshore along the continental shelf edge (Cross et al. 1999). Annual landings of butterfish

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Facts: Longfin Squid. Available online at http://www.fishwatch.gov/seafood_profiles/species/squid/species_pages/longfin_squid.htm.

[6] A description and illustration of bottom otter trawl gear can be found on the website of the Food and Agriculture Organization of the United Nations at: http://www.fao.org/fishery/geartype/306/en.

[7] This information is based upon website content from Stavis Seafoods, a U.S. seafood distributor. Available online at http://www.seafoodexperts.net/tag/fresh-seafood/page/2/.

[8] Prices obtained from the NMFS Monthly Commercial Landings Statistics website, searching the average annual price in 2011 for each species for "all states." Available online at http://www.st.nmfs.noaa.gov/pls/webpls/FT_HELP.SPECIES.

peaked in 1973 at 19,500 mt, and as with the longfin squid fishery, the passage of the Magnuson-Stevens Conservation and Management Act in 1976 began the gradual elimination of foreign fleets from the fishery (Cross et al. 1999). From 1977 to 1987, the last year in which the fishery included foreign fleets, annual landings averaged 6,500 mt. (Cross et al. 1999). During this period, the Japanese spent large sums of money importing butterfish to Japan, where it was dried, lightly salted and consumed as a breakfast food (Lee 2012). The Japanese butterfish market eventually collapsed in the 1990s, however, due, at least in part, to dwindling catches of high-quality butterfish[9] and economic conditions in Japan (MAFMC Butterfish AP Informational Document 2012).

As illustrated in Figure 2 below, from 1987 through 2001, total annual butterfish landings were generally in the 2,000 – 4,000 mt range, with somewhat larger harvests in 1993 and 2001. Following 2001, the directed fishery for butterfish essentially disappeared. In 2011, for example, only 38 vessels caught 10,000 pounds or more of butterfish, whereas in 1984, with a strong Japanese market and a higher quota, there were 113 vessels that caught 10,000 pounds or more of butterfish (MAFMC Butterfish AP Informational Document 2012).

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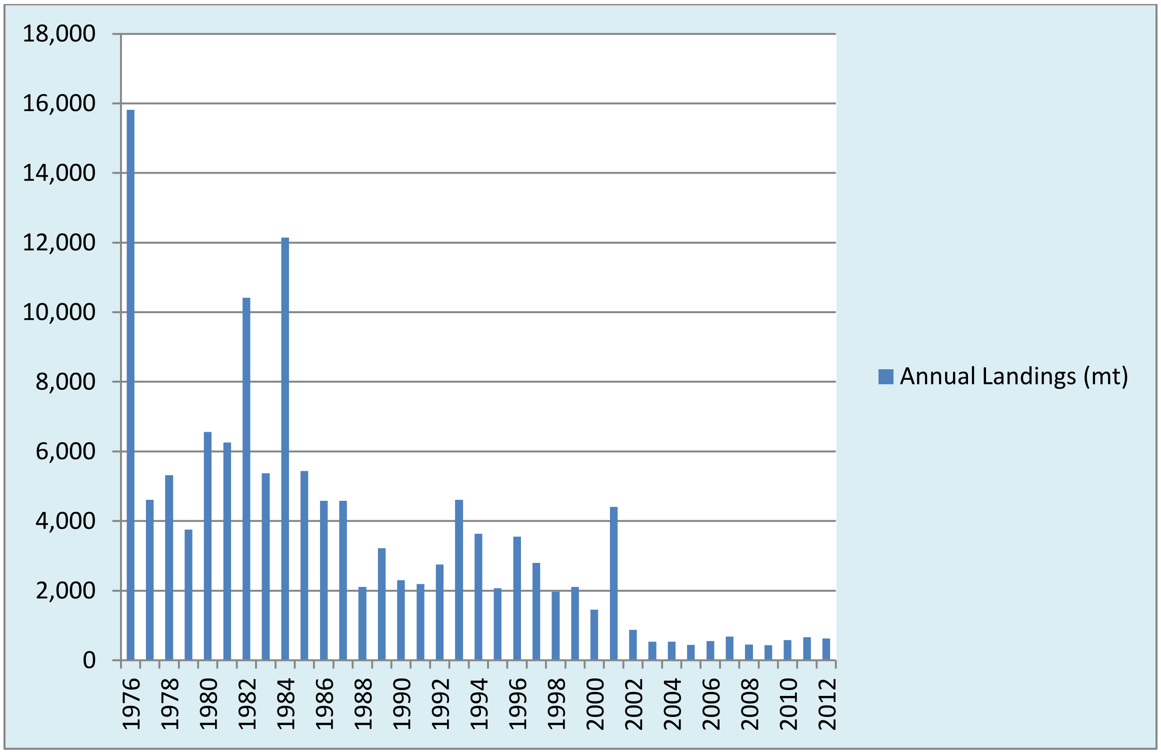
[9] Japanese fish buyers have apparently been very specific with U.S. suppliers about the quality of butterfish they expect; they prefer large fish that are high in fat with no food in the stomachs. This has important implications for the timing of the harvest – the butterfish need to be caught at the end of fall migration when they have stopped eating and are full of winter fat (Lee 2012).

Figure 2. Total Annual Butterfish Landings (mt), 1976 – 2012



Following a stock assessment in 2004, the status of the Atlantic butterfish stock was classified as "overfished" in 2005, and the stock has been under a rebuilding plan ever since (MAFMC and NMFS 2008). The cause of the decline is not very well understood, but it is believed to be related to environmental processes and low recruitment rather than overfishing (MAFMC OFL/ABC Recommendations 2012). In the last two years, however, the butterfish population appears to be rebounding, and in 2012 the National Marine Fisheries Service changed the status of butterfish from "overfished" to "unknown," pending the findings of a stock assessment to be conducted in 2013.

Although whole Atlantic butterfish continue to be sold in niche markets in the U.S., most butterfish catches are discarded on account of relatively weak demand. The ex-vessel price of butterfish has generally fluctuated between $.40 and .80 per pound over the last five years, but there are unsubstantiated reports that high quality butterfish may have fetched as high as $2 per pound in the 1980s when there was a strong Japanese market (Lee 2012). Advocates of a higher butterfish landings quota contend that the formerly profitable butterfish market in Japan could be reestablished if the landings quota is increased substantially to allow for the export of butterfish in sufficient numbers and of sufficient size to satisfy distributors and processors.[10] This could reasonably be expected to result in higher ex vessel prices for butterfish, which in turn could result in more landings of butterfish by the longfin squid fishery. To that end, the Council has begun easing the restrictions on the fishery given the apparent improved health of the stock.

3.3 Legal and Institutional Framework for Federal Fisheries Management in the U.S.

3.3.1 Magnuson-Stevens Fishery Conservation and Management Act.

The Magnuson-Sevens Fishery Conservation and Management Act (hereafter, Magnuson-Stevens) is the primary law governing fisheries management in federal waters, which generally range from 3 to 200 nautical miles offshore (16 U.S.C. §§ 1801-1884). When it was enacted in 1976, the Act was primarily intended to assist with the development of the domestic fishing industry through the gradual phasing out of foreign fishing fleets (Macpherson 2001; Hooks and Baylor 2009). Although it included conservation goals, Magnuson-Stevens placed greater emphasis on

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[10] A large fishing enterprise that formerly supplied butterfish to the Japanese market provided a letter to the Council (distributed at a May, 2012 meeting of the Council's Scientific and Statistical Committee) from its former butterfish distributor in Japan. In the letter, the distributor claims that the U.S. lost its market for butterfish in Japan due to inconsistent supplies, irregular prices and small fish size. The distributor further states that without a substantial increase in the U.S. butterfish landings quota, it would be unable to convince the small Japanese processing companies to switch their production from other species back to butterfish. Letter from Transpac, Ltd. to Seafreeze Ltd. dated April 30, 2012 *available at* http://www.mafmc.org/meeting_materials/SSC/2012-05/Monsen1-Transpac-Butterfish-letter.pdf.

utilization of fishery resources (Macpherson 2001). Over the years, however, Magnuson-Stevens evolved into a law that is focused on *sustainably* using the nation's fishery resources and rebuilding overfished stocks (Macpherson 2001). The 1996 Magnuson-Stevens amendments, for example, had three primary goals: ending overfishing, minimizing bycatch and increasing habitat protection (Hooks and Baylor 2009). It required, among other things, that fishery management plans (FMPs) include conservation measures that, to the extent practicable, minimize bycatch. Amendments to the Act in 2006 further required that annual catch limits (ACLs) be established for overfished stocks by 2010 and for nearly all other stocks by 2011 (16 U.S.C. § 1853(a)(15)).[11]

In its present form, Magnuson-Stevens contains seven express purposes. Perhaps the most fundamental of these purposes is "to provide for the preparation and implementation of fishery management plans that will achieve and maintain the optimum yield from each fishery" (16 U.S.C. §1801 (b)(4)). The term "optimum yield," is of great significance, as it describes the theoretical harvest level that federal fisheries managers are directed to target. This consequential term is defined by Magnuson-Stevens to mean "the amount of fish which -

> (A) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems;
>
> (B) is prescribed on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant social, economic, or ecological factor; and

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[11] ACLs must be based upon fisheries managers' calculations of ABC, and according to later-adopted National Standard 1, must be reduced by the scientific and management uncertainties in the fishery. Stocks that have annual life cycles, such as longfin squid, are exempt from the ACL requirement. Atlantic butterfish, though short-lived, are not an annual species and are therefore subject to ACL requirements.

(C) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery." (16 U.S.C. § 1802(33)).

Thus, the term "optimum yield," encompasses multiple, sometimes conflicting, objectives, including food production, conservation and recreation. Significantly, the 1996 amendments to Magnuson-Stevens amended the definition of "optimum yield" to clarify that it be prescribed on the basis of maximum sustainable yield (MSY), but *reduced* (rather than modified) by any relevant social, economic or ecological factors.[12] The biologically determined MSY is therefore an upper limit for optimum yield determinations and cannot be exceeded to achieve short-term economic or social objectives.

3.3.2 The National Marine Fisheries Service and the Regional Councils. The institutions with primary rule-making and management authority over federal marine fisheries are the regional fishery management councils (of which there are eight) and the National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Administration (NOAA) under the U.S. Department of Commerce. The regional council system was designed to allow regional participation in the governance of federally managed fisheries by industry representatives, experts and others with a stake in fishery management (Matulich 2007). To that end, Magnuson-Stevens grants a tremendous amount of authority to the regional councils, whose members are nominated by state governors, by giving them the primary responsibility for initiating, developing and amending FMPs for each fishery in a council's jurisdiction that requires management (Matulich 2007).

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[12] The term "maximum sustainable yield" has no statutory definition but is defined by NOAA in its Fisheries Strategic Plan as "… the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions." Available online at http://www.nmfs.noaa.gov/om2/glossary.html.

In the case of the Mid-Atlantic Fishery Management Council, it is comprised of members from New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia and North Carolina. Although the Atlantic butterfish and longfin squid fisheries extend beyond this region into southern New England, the entire fishery for each species is managed by the Council, as Magnuson-Stevens gives every regional council the authority to prepare a management plan for a fishery's entire range when it extends beyond a council's geographic scope (Macpherson 2001).

Magnuson-Stevens also grants regional councils the authority to propose regulations to implement FMPs (Matulich 2007). FMPs generally include specific management measures, such as fishing seasons, trip limits, landing quotas and gear restrictions, and are based upon advice from each Council's Scientific and Statistical Committee (SSC), which sets the upper ceiling on ABC. FMPs must also comply with national standards set forth in Magnuson-Stevens, including the requirement that they achieve and sustain optimum yield (16 U.S.C. §1851 (a)(1)). Another national standard of particular relevance to this masters project states that FMPs must, to the extent practicable, consider efficiency in the utilization of fishery resources, although they may not have economic allocation as their sole purpose (16 U.S.C. § 1851(a)(5)).

FMPs are subject to review and approval by the Secretary of Commerce (delegated to NMFS), but the review is limited by statute to ensuring that the FMP or any proposed regulation complies with Magnuson-Stevens or any other applicable law (Matulich 2007). Once NMFS approves an FMP, it promulgates regulations that give force of law to the policies and management measures set forth in the FMP. Importantly, the regional councils and NMFS are required to use open public processes (e.g., public notice of proposed regulations and a public comment period) in the development and amendment of FMPs, thereby ensuring that stakeholders have a voice in federal fisheries management. The management approach reflected in FMPs primarily focuses on single stocks,[13] although as discussed below, the regional councils are beginning to take steps toward achieving a more integrated multi-species management approach.

3.4 Ecosystem-Based Management and Application to Fisheries

3.4.1 Ecosystem-Based Management. A great deal has been written about the need to transition from single-species or single-sector resources management to a more holistic ecosystem-based management paradigm in order to sustain the long-term provisioning capacity of marine and terrestrial ecosystems. Indeed, ecosystem-based management, sometimes referred to as the ecosystem approach, has emerged in the last three decades as a favored paradigm for managing human activities that utilize or impact living resources. The first global convention to adopt ecosystem-based management was the 1980 Convention for the Conservation of Antarctic Marine Living Resources (Wang 2004). Subsequently, the Rio Declaration accepted at the 1992 United Nations Conference on Environment and Development (known as the Rio Earth Summit) called on nations to use the ecosystem approach to conserve, protect and restore the health and integrity of the Earth (UNEP Rio Declaration 1992). The Convention on Biological Diversity, which also emerged from the Rio Earth Summit, adopted ecosystem-based management as the framework for implementing and achieving its objectives

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[13] Magnuson-Stevens defines a "stock of fish" as "… a species, subspecies, geographical grouping, or other category of fish capable of management as a unit." 16 U.S.C.§1802(42). The entire populations of longfin squid and Atlantic butterfish off the U.S. Atlantic coast are managed as single stocks.

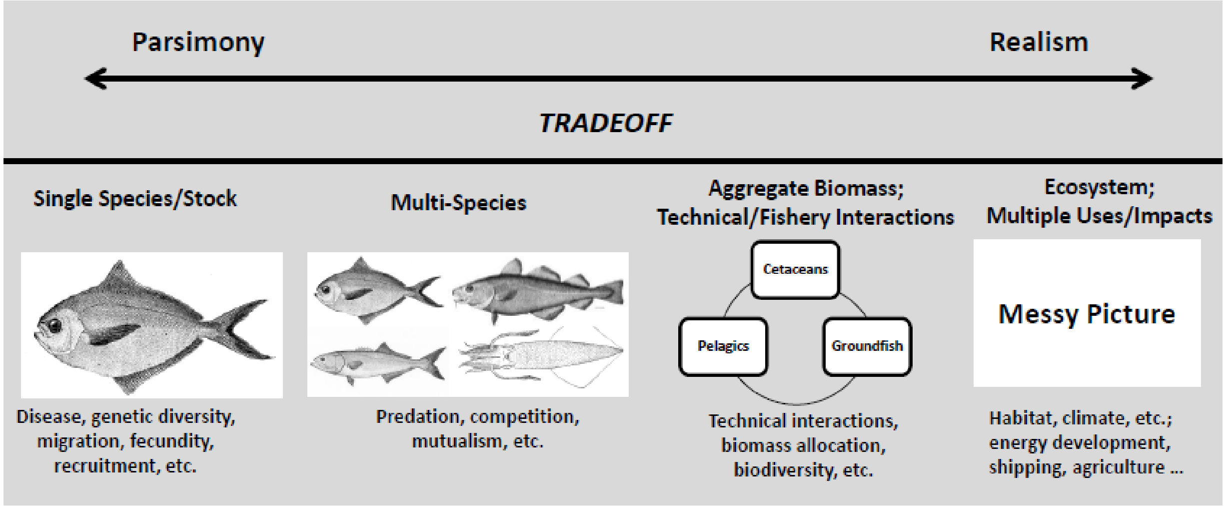
(UNEP CBD 1992). More recently, representatives at the 2012 Rio+20 Convention reaffirmed international support for ecosystem-based management and added a commitment in the outcome document to apply ecosystem-based management in managing activities that impact the marine environment (UNEP 2012).

In the U.S., the privately funded Pew Oceans Commission and the U.S. Commission on Ocean Policy each endorsed ecosystem-based management (Pew Oceans Commission 2003; U.S. Commission on Ocean Policy 2004), and the Obama Administration adopted ecosystem-based management as a foundational principle in its proposed National Ocean Policy (76 Federal Register 14392011). Ecosystem-based management also enjoys broad support in academia. In fact, more than 200 scientists and policy experts at U.S. academic institutions endorsed ecosystem-based management in a Scientific Consensus Statement released in 2005 (McLeod, et al. 2005).

Despite the popularity of ecosystem-based management, the meaning of the term – particularly in a practical or applied sense – can be elusive. As described by Jane Lubchenco, former NOAA Administrator, ecosystem-based management represents a shift from a highly focused, single species or short-term sectoral approach to a more comprehensive, longer-term, place-based approach (Lubchenco 1994). Underlying this approach is the idea that long-term use and enjoyment of natural resources requires the maintenance of healthy and intact ecosystems. In practice, this would entail consideration of the cumulative impacts of multiple uses and sectors on ecosystem functioning and the complex interactions between different ecosystem components, which in turn would necessitate intersectoral cooperation, planning and management based upon sound science. In the U.S., given that our legal and regulatory framework remains focused on individual sectors or resource uses, true ecosystem-based management is still many years away. In certain sectors such as marine fisheries, however, managers are starting to make progress by gradually incorporating more ecosystem considerations into resource management.

3.4.2 The Transition to Ecosystem-Based Fisheries Management. Ecosystem-Based Fisheries Management (EBFM) represents an extension of ecosystem-based management principles to the fisheries context. Link et al. define *full implementation* of EBFM as follows: "… that governance, management, science and institutional system that takes into account all of the systemic, environmental, inter-specific, inter-fleet, and multivariate and-or cumulative facets beyond a typical single-species approach …" (Link et al. 2011). It thus constitutes an integrated multi-species, multi-fleet approach informed by sound natural and social science. Moreover, as represented on Figure 3 below, adapted from Link (2002), EBFM need not be thought of as an "all or nothing" proposition; rather, there is a gradient of possibilities between single-stock management and a completely integrated ecosystem approach. Of course, the benefit of added realism represented by EBFM brings with it the downside of significant data requirements (and resource requirements) and also possibly the introduction of greater uncertainty into the management process.

Figure 3. Adapted from Link (2002)



As noted in section 3.3.1 above, Magnuson-Stevens has been amended since its passage to require that certain ecosystem considerations, such as identification of essential fish habitat and reduction of bycatch, be addressed by fishery managers. In addition, when Congress reauthorized Magnuson-Stevens in 1996, it requested that NMFS convene a panel of experts to: (i) assess the extent to which ecosystem principles are applied in fisheries research and management; and (ii) recommend how best to integrate ecosystem principles into future fisheries management and research (Fluharty et al. 1998). In response, NMFS created the National Marine Fisheries Service Ecosystem Principles Advisory Panel (hereafter, the Panel), which recommended, among other things, that the regional councils be required to adopt Fisheries Ecosystem Plans (FEPs) (Fluharty et al. 1998). The Panel further suggested that FEPs include provisions like a conceptual food web model for target species and a description of how removals relate to biomass, trophic structure and other ecosystem indicators (Fluharty 1998). Based upon this recommendation, in 2004 Congress instructed the Council and three other regional fishery management councils to develop guidelines on incorporating ecosystem considerations into fisheries management (MAFMC 2006).[14] To that end, the Council has solicited stakeholder input concerning EBFM and has begun to develop guidance to facilitate a gradual transition from a single-species management approach to a more integrated EBFM approach.

Despite the current trend towards EBFM, certain elements of Magnuson-Stevens are still very much focused on single-stock management. Most notably, National Standard 1 states that the conservation and management measures in an FMP must achieve "the optimum yield from each fishery" on a continuing basis (16 U.S.C. § 1851(a)(1) emphasis added). It is extremely unlikely, however, that the biomass of each commercially fished species in an ecosystem could be maintained at MSY or OY levels simultaneously given the interconnectedness of species in an ecosystem (Gamble and Link 2009). National Standard 1 would therefore seem to be incompatible with EBFM, and it highlights the sometimes contradictory nature of legal mandates or directives for federal fisheries management.

3.5 Management of the Longfin Squid and Atlantic Butterfish Fisheries

3.5.1 Management of the Longfin Squid Fishery. Since 1983, longfin squid has been managed together with Atlantic butterfish, Atlantic mackerel and Ilex squid under a single FMP (MAFMC 2010).[15] The stated objectives of the Mackerel-Squid-Butterfish FMP are to:

(i) enhance the probability of successful recruitment to the fisheries;

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[14] *MAFMC – Evolution Towards an Ecosystem Approach to Fisheries (EAF).* Mid-Atlantic Fishery Management Council in cooperation with the National Marine Fisheries Service. (2006).

[15] The original FMPs for Atlantic butterfish and longfin squid were adopted by the Council in 1978 and approved by NMFS in 1979. At that time, the two stocks were managed under separate plans, but a merged Atlantic mackerel, squid (both longfin and Ilex squid), and butterfish plan was implemented by emergency interim regulation in 1983 and continues to this day, though it has been amended multiple times (MAFMC 2010).

(ii) promote the growth of the U.S. commercial fishery, including the fishery for export;

(iii) provide the greatest degree of freedom and flexibility to all harvesters of these resources to the extent consistent with other FMP objectives;

(iv) provide marine recreational fishing opportunities;

(v) increase the understanding of the conditions of the stocks and fisheries; and

(vi) minimize harvesting conflicts among U.S. commercial, recreational and foreign fishermen.

The fisheries managed under the Mackerel-Squid-Butterfish (MSB) FMP operate pursuant to a permit program that stipulates permissible levels of harvest. There are two categories of permits that apply to the harvest of both longfin squid and Atlantic butterfish: (i) the incidental squid/butterfish permit (known as the SMB 3 permit), and (ii) the limited access squid/butterfish permit (known as the SMB 1 permit). The major difference between the two permits is that SMB 3 incidental permits impose trip limits for longfin squid (2,500 pounds) and Atlantic butterfish (600 pounds), whereas the limited access SMB 1 permits impose no trip limits on longfin squid so long as the fishery remains open and a more permissive trip limit schedule for Atlantic butterfish (discussed in section 3.5.2 below). As of January 1, 2012, NMFS had issued 1,686 incidental SMB 3 permits and 345 limited access SMB 1 permits.[16]

Each year the Council sets an annual landings quota for longfin squid, and in recent years the quota has generally been one-half of estimated MSY (MAFMC OFL/ABC Recommendations 2012). The annual quota for longfin squid is further divided into trimester allocations to ensure that fishing mortality is spread throughout the year and that the fishery

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[16] A more detailed description of the permitting requirements can be found online at: http://www.nero.noaa.gov/sustainable/species/msb/.

can operate year-round (MAFMC 2010). At present, 43 percent of the quota is allocated to trimester I (January through April); 17 percent is allocated to trimester II (May through August); and 40 percent is allocated to trimester III (September through December).[17] For 2013, the total landings quota is 22,049 mt, allocated as follows: (i) 9,481 mt to trimester I; (ii) 3,748 mt to trimester II; and (iii) 8,820 mt to trimester III (NMFS 2013). In the event the fishery reaches 90 percent of a trimester's quota allocation (or 95 percent in the final two weeks of trimesters 1 or 2, or 95 percent of the total annual quota in trimester III), the fishery is closed for the remainder of the trimester (NMFS 2013).

In addition to the landings quota, the longfin squid fishery has been subject to a cap on butterfish bycatch (the mortality cap) since 2011. Like the landings quota, the total mortality cap for the year is allocated among management trimesters, and the longfin squid fishery closes for the remainder of any trimester in which the applicable closure threshold is reached.[18] The cap operates in near-real time, and estimates of butterfish caught by longfin squid fishermen are extrapolated from observer data collected from a relatively small percentage of the fishery. For purposes of the calculation, only when vessels land more than 2,500 pounds of longfin squid on a single trip does their catch of butterfish count against the mortality cap. Prior to 2013, both discards and landings of butterfish were counted against the cap once the 2,500 pound longfin squid trip threshold was exceeded. In 2013, however, the mortality cap was

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[17] The trimester system started in 2000, but from 2001 to 2006, management was quarterly. In 2007, management of longfin squid returned to the present trimester system. *See* National Marine Fisheries Service (2012) Addendum to the Environmental Assessment for 2012 Atlantic Mackerel, Squid, and Butterfish Specifications and Management Measures. Available at http://www.nero.noaa.gov/nero/regs/frdoc/12/12SMB2012SpecsEA.pdf.

[18] For 2013, the allocation of the mortality cap is as follows: trimester I – 65%; trimester II – 3.3%; Trimester III – 31.7%. *See* Methodology for the 2013 Butterfish Mortality Cap for the Longfin Squid Fishery, available online at http://www.nero.noaa.gov/regs/frdoc/13/13smb2013specsbmcmethodology.pdf.

converted to a discards cap, meaning that any butterfish that are landed in the longfin squid fishery are not counted against the mortality cap.[19]

In 2011 and 2012, the Council allocated 75 percent of the butterfish ABC to the mortality cap (3,165 mt in 2012). Interestingly, the longfin squid fishery experienced a high amount of estimated butterfish bycatch in the summer of 2012 (as well as higher than usual longfin squid landings), and there was concern in the fishery that the season might be forced to close early if the same levels were to continue for the remainder of the year. Based upon the Council's recommendation, NMFS raised the 2012 butterfish ABC from 3,622 mt to 4,200 mt (with a resulting increase in the mortality cap) to avoid early closure of the longfin squid fishery. The Council justified the recommendation on the basis that both butterfish and longfin squid appeared to be relatively abundant and that the increase of butterfish ABC would avoid financial hardship on the fishermen without jeopardizing either stock. This decision came on the heels of an earlier decision in June to raise the 2013 butterfish ABC to 8,400 mt based upon recent data indicating increased butterfish abundance.[20]

For 2013, 3,884 mt of butterfish was allocated to the mortality cap, which amounts to 46 percent of the 8,400 mt butterfish ABC (50 CFR Part 648). Most of the balance of the butterfish ABC was allocated to the butterfish landings quota (NMFS 2013). Under current management specifications, the longfin squid fishery will close in 2013 (i) for the remainder of

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[19] The mortality cap changed from a catch cap to a discards cap in a final rule issued by NMFS March 5, 2013 (50 CFR Part 648). In the process, NMFS reduced the mortality cap allocation by 13% (from 4,477 mt to 3,884 mt), reasoning that in 2012 when the mortality cap as a catch cap, 13% of the butterfish caught in the longfin squid fishery was retained.

[20] *See* the following MAFMC press release for details on the 2012 decision to raise the butterfish ABC: Council Recommends Higher Butterfish Catch for Remainder of 2012. September 19, 2012. Available online at http://www.mafmc.org/press/2012/pr12_20_Butterfish_ABC.pdf.

trimester I if it reaches 90 percent of the trimester I mortality cap allocation; (ii) for the remainder of trimester II if it reaches 75 percent of the total mortality cap for 2013; and (iii) for the remainder of trimester III if it reaches 90 percent of the total mortality cap for 2013 (NMFS 2013).

In addition to utilizing a landings quota and a butterfish mortality cap to manage the longfin squid fishery, the Council also imposes a minimum mesh size requirement to reduce bycatch. The minimum mesh required for trimester II is slightly smaller than is required for trimesters I and III, most likely reflecting ecological considerations resulting from the migration of the stock and the fishery to inshore waters during the summer.

For management purposes, the status of longfin squid is currently “unknown” with respect to mortality rates and “not overfished” with respect to stock size (MAFMC OFL/ABC Recommendations 2012). There is, however, considerable intra-annual and inter-annual variability with respect to longfin squid landings. All of this variability, combined with the longfin squid’s very short lifespan, means that there is very high uncertainty about what MSY might be in a given year (MAFMC OFL/ABC Recommendations 2012).

3.5.2 Management of the Atlantic Butterfish Fishery.

As discussed in section 3.5.1 above, the Atlantic butterfish fishery operates under a permit program with permits issued for incidental harvest and for limited access to the fishery. Management measures for the fishery consist primarily of an annual landings quota (also referred to as domestic annual harvest or DAH), the mortality cap applicable to the longfin squid fishery, trip limits, and gear restrictions (NMFS 2013). The Council’s SSC sets the ABC for butterfish each year, and the Council then determines how much of the ABC to allocate to the landings quota, how much to reserve for expected discarding in fisheries other than the longfin squid fishery, and how much to allocate to the mortality cap for the longfin squid fishery (MAFMC OFL/ABC Recommendations 2012).

Under the rebuilding plan for Atlantic butterfish that the Council implemented in 2005, the annual landings quota was maintained at a very low level through 2012 (between 495 and 872 mt). For this year, however, with evidence that butterfish are more abundant, the Council increased the butterfish ABC to 8,400 mt and the landings quota to 2,570 mt to allow for rebuilding of the directed butterfish fishery (NMFS 2013).[21] On account of the higher landings quota and the potential for a directed butterfish fishery, the Council devised a new three-phase butterfish management system for 2013 applicable to limited access permit holders (NMFS 2013).[22] The three-phase system essentially utilizes increasingly lower trip limit restrictions (the size of which is generally higher for vessels using a mesh size greater than three inches) for each successive management phase (NMFS 2013). Transition from one phase to the next is triggered when a specified percentage of the butterfish landings quota has been attained. The threshold percentage for this purpose varies by month (NMFS 2013). By way of example, limited access permit holders utilizing a greater-than-three-inch mesh have no trip limits in phase one, a 5,000-pound trip limit in phase two, and a 500-pound trip limit in phase three as the fishery approaches the annual landings quota limit (NMFS 2013). A potential and unintended consequence of the low trip limit in phase three is that it may encourage butterfish discards when mixed-fisheries vessels unexpectedly (and unintentionally) reach the trip limit.

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[21] The ABC for butterfish has generally been set at a precautionary 50% of estimated MSY.

[22] As noted in section 3.5.1, incidental permit holders are subject to a 600 mt trip limit in all three trimesters.

4. Analysis of Landings Data to Characterize the Fisheries

For purposes of this masters project, the Council and the Northeast Fisheries Science Center provided us access to data from the Commercial Fisheries Database Service (formerly known as the Dealer Weigh-Out Database). Records in the database include information on all species landed on a particular trip (e.g., weight and ex-vessel prices), as well as information concerning the gear and the vessel. The data comes from seafood dealers, who are legally required to report all landings transactions to NMFS. The dataset provided to us consists of all commercial landings in the Mid-Atlantic and New England regions from 1996 through September 18, 2012. Thus, the most recent year for which we had full-year data was 2011. We were, however, able to obtain price and landings information for the remainder of 2012 using NOAA's online Monthly Commercial Landings Statistics service.[23] Although it is not possible to relate this information to specific vessels or trips, the data was useful for purposes of determining full-year 2012 landings trends and price averages.

By analyzing the landings and price data using Stata statistical software, we were able to more fully characterize the fisheries and the behavior of the fleets. In particular, we used the data to develop a more complete picture of total landings and revenues by vessels in the longfin squid and Atlantic butterfish fisheries and to identify long-term and seasonal trends in the longfin squid fishery. As this relates to EBFM, comparative multi-fleet economic and behavioral analysis is critical to the success of an integrated ecosystem approach (Gasalla et al.

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[23] The Monthly Commercial Landings Statistics service may be found online at: http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/monthly-landings/index.

2010). By identifying and understanding the choices made by participants in the relevant fisheries, managers can better assess and predict a sector's performance, the performance of management, and the likely impacts of fishing on the ecosystem.

4.1 Inshore and Offshore Participation in the Longfin Squid Fishery.

One of the first questions we sought to answer through analysis of the landings data was whether there exist distinct inshore and offshore groups of participants in the longfin squid fishery. In our conservations with Council staff, we were told that the summer longfin squid fishery (i.e., the inshore fishery) likely brings in participants who are not active in the fishery during the offshore months. If this is the case, this characteristic of the fishery is important to understand because it has implications for the trimester management system. In particular, if a large segment of the inshore longfin squid fishery (by proxy, the trimester II fishery) does not participate in the offshore fishery, the Council should consider whether increasing the trimester II quota allocation (currently 17%) is warranted in order to ensure equitable access to the resource. Also relevant to this determination is the overall level of fishery participation in trimester II and the degree of dependence by the inshore fishery participants on revenues from longfin squid.

To determine the extent to which there are distinct inshore and offshore fisheries for longfin squid, we compiled lists of all vessels that landed 10 mt or more of longfin squid[24]

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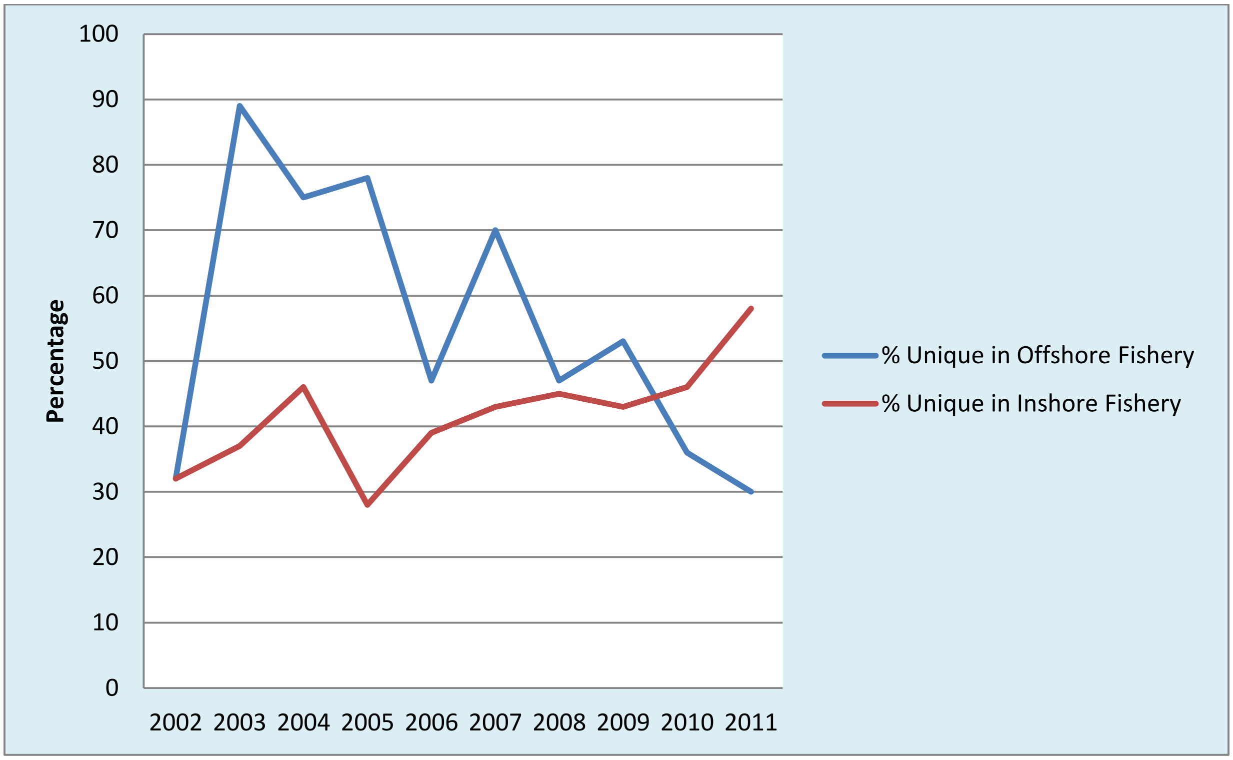
[24] We chose a cut-off of 10 mt in order to exclude vessels that were not active participants in the fishery (e.g., vessels that may have only incidentally landed longfin). Using the 10-mt cut-off, the highest number of vessels in any year participating during the offshore period was 124 (2002) and the lowest number was 60 (2011). The highest number of vessels in any year participating during the inshore period was 124 (2002) and the lowest number was 19 (2003).

during the inshore months (May through September)[25] and during the offshore months (January through April and October through December) for the years 2002 through 2011. We then calculated, for each year, the percentage of vessels that only participated in the fishery during the inshore months and the percentage of vessels that only participated in the fishery during the offshore months (referred to hereafter as the "percentage unique"). The results for this ten-year period are represented in Figure 4 below.

Figure 4. Longfin Squid Landers (> 10 mt), Percentage Unique Offshore and Inshore, 2002-2011



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[25] Although the month of September does not fall within the trimester II management period, we included it with the other trimester II months for purposes of this analysis because longfin squid remain inshore during the month of September. There is variability from year-to-year in terms of the exact timing of the longfin squid inshore/offshore migration, which appears to be tied to water temperature (Jacobson 2005). Accordingly, the inshore and offshore months we chose for the ten-year period of analysis is an imperfect approximation of the inshore and offshore fisheries. It likely *underrepresents* the degree of distinctness of the inshore and offshore fisheries, as longfin squid may remain inshore well into late fall (Jacobson 2005). As a result, there may be vessels fishing inshore for longfin squid through the months of October and November in some years, but who are assumed in our analysis to be participating in both in the inshore and offshore longfin squid fisheries.

During the period 2002 through 2011, the percentage unique to the inshore fishery ranges from 28 percent to 58 percent, with a mean of 42 percent. The percentage unique to the offshore fishery ranges from 30 percent to 89 percent, with a mean of 56 percent. Thus, while there is significant overlap between the inshore and offshore participants in the longfin squid fishery, there is a substantial element that only participates during the inshore or offshore months, but not both.

The percentage unique is influenced by disparities or imbalances in the numbers of vessels in participating in the inshore versus offshore months in a particular year. In 2002, for example, the same number of vessels (124) landed more than 10 mt of longfin squid in the inshore period as in the offshore period, resulting in the same percentage unique (32 percent) for each period. In the following year, however, 113 vessels landed more than 10 mt of longfin squid in the offshore period, while only 19 vessels landed more than 10 mt of squid in the inshore period. This resulted in 89 percent of the offshore period being unique and 37 percent of the inshore period being unique. It is therefore important for purposes of interpreting the percentage unique in any period to consider the corresponding number of vessels, as provided in Table 1 below.

Table 1. Percentage Unique and Number of Vessels, 2002 – 2011

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of Offshore Participants/ Percentage Unique	124 32%	113 89%	113 75%	106 78%	108 47%	91 70%	90 47%	79 53%	67 36%	60 30%
Number of Inshore Participants/ Percentage Unique	124 32%	19 37%	52 46%	32 28%	93 39%	47 43%	89 45%	83 43%	80 46%	100 58%

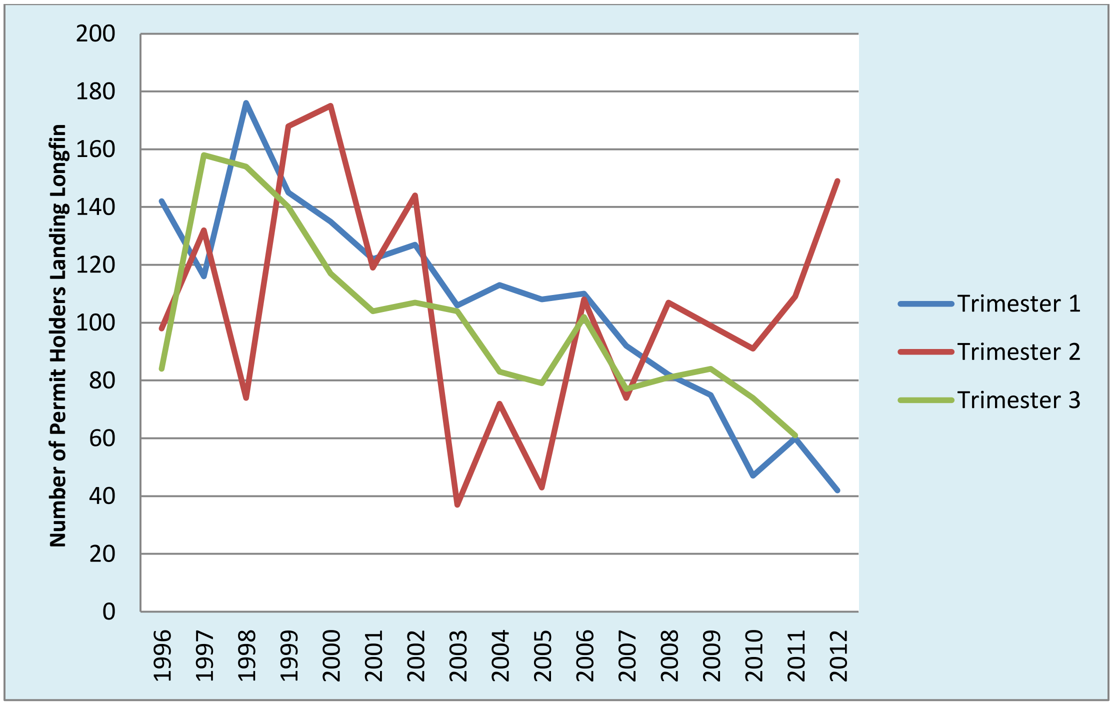
Given that there are sizable constituents of the fishery who only participate during the inshore season or offshore season, achieving a representative allocation of the landings quota among the three trimesters is arguably more important than it would be if participants generally participated in the fishery year-round. For a number of participants in the fishery, annual access to the resource may be limited to a single trimester's quota allocation. This is especially true for the inshore-only participants whose window of fishing opportunity falls primarily in trimester II. We therefore set about trying to determine how representative the current longfin squid quota allocation is of participation and landings in the fishery.

4.2 Longfin Squid Landings and Fishery Participation by Trimester

As noted in section 3.5.1, the 2013 landings quota of 22,049 mt for longfin squid has been allocated as follows: (i) 9,481 mt to trimester I (43 percent of quota); (ii) 3,748 mt to trimester II (17 percent of quota); and (iii) 8,820 mt to trimester III (40 percent of quota) (NMFS 2013). In order to assess whether this allocation is representative of actual landings and participation in the fishery, we determined the number of vessels that participated in the longfin squid fishery in each trimester and the total amount of longfin squid landed in each trimester over a period of years. For this purpose, we were interested not only in seeing the trimester composition of the most recent year, but also whether there were any discernible trends over a longer time frame. We therefore plotted out trimester landings and participation for all years in the data that was provided to us (1996 through the second trimester of 2012).

For purposes of this analysis, we defined "participant" broadly to include any vessel that landed any amount of longfin squid in a trimester. Figure 5 below illustrates trimester participation in the longfin squid fishery from 1996 through the second trimester of 2012.

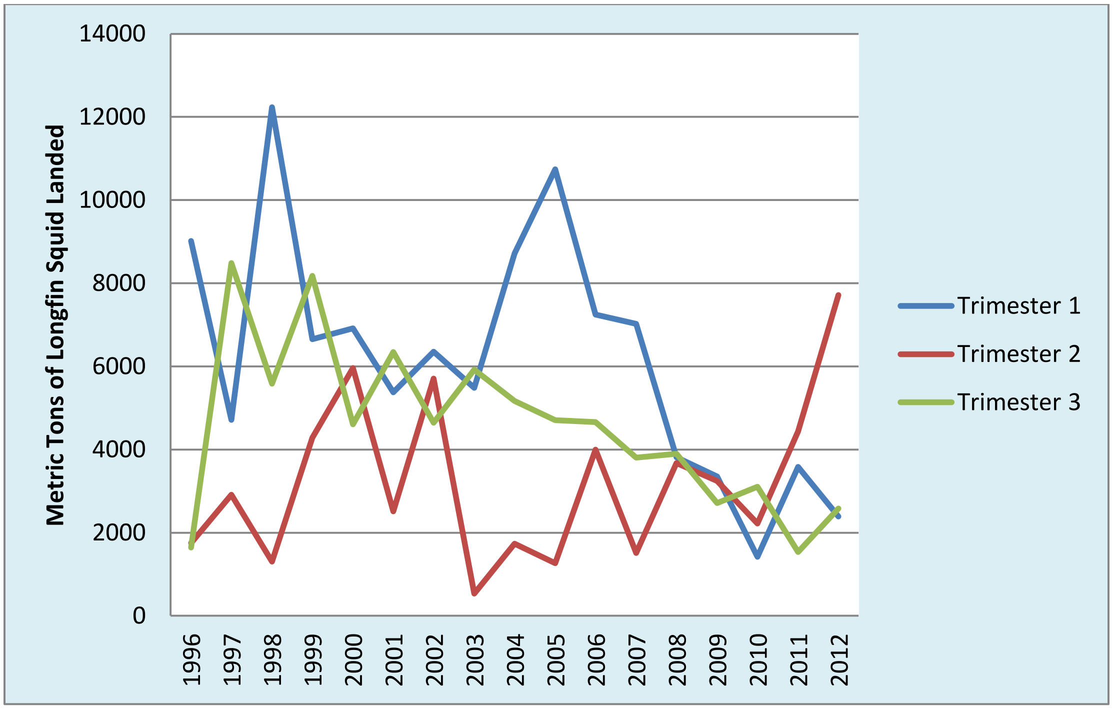
Figure 5. Number of Permit Holders Landing Longfin Squid by Trimester, 1996 - 2010



The most obvious characteristic that emerges is the clear, downward trend in participation in trimesters I and III that begins in 1998 and continues through 2012. In 1998, for example, 176 vessels landed longfin squid in trimester I, whereas in 2012, only 42 vessels landed longfin squid in trimester I. Participation in trimester II has been more variable, though there has been a fairly sharp increase in trimester II participation since 2010. If we consider only 2011 (the most recent year for which we have full-year data), participation in trimester II constituted 48 percent of the total, whereas trimesters I and III each constituted 26 percent of the total. Purely from the standpoint of fishery participation, then, the 2013 quota allocation is not representative of the longfin squid fishery in recent years. Indeed, the last year that participation was nearly the same as the current quota allocation was 2003, when trimester II accounted for 15 percent of total participation and trimesters I and II each accounted for 42.5 percent of total participation.

Participation, however, is not the only characteristic of the fishery relevant to quota allocation. More important, perhaps, are actual landings of longfin squid by trimester, which are illustrated in Figure 6 below.

Figure 6. Longfin Squid Landings (mt) by Trimester, 1996 - 2012



In this case, while the overall decline in trimester III participation is generally reflected in the mostly downward trend in landings for trimester III since 1999, the same is not true for trimester I. Although trimester I participation declined over the period 1998 through 2012, there was a spike in trimester I landings from 2003 to 2005, followed by a fairly sharp decline in trimester I landings from 2005 to 2010. Trimester II landings have been quite variable over this time frame, with a sharp increase in landings since 2010. The overall percentage of annual landings in each trimester since 2010 is shown on Table 2 below.

Table 2. Percentage of Landings by Trimester, 2010 - 2012

Year	Trimester I % of Total Landings	Trimester II % of Total Landings	Trimester III % of Total Landings
2010	21%	33%	46%
2011	38%	46%	16%
2012	19%	61%	20%

Based upon our findings, it is apparent that the current allocation of the longfin squid quota is not representative of actual landings and participation in the fishery in recent years. In particular, an allocation of only 17 percent of the quota to trimester II significantly underrepresents recent trimester II landings and participation. Events from this past summer illustrate the potential consequence of underallocating quota to trimester II. In 2012, 9,555 mt of the longfin squid quota were allocated to trimester I while 3,777 mt were allocated to trimester II. By our calculation, only 2,393 mt of longfin squid were landed in trimester I, leaving 7,162 mt of quota unused in trimester I. Under the longfin squid management plan, if there is a quota underage of at least 25 percent in a trimester, 50 percent of the unused quota can be rolled over to the following trimester, but in no event can the following trimester's quota be increased by more than 50 percent. As a result, although there was a significant amount of unused quota from trimester I, the trimester II quota could only be increased by 50 percent, or 1,889 mt in this case. Taking the roll-over of unused quota from trimester I into account, the total quota for trimester II was 5,666 mt. Participation and landings in trimester II ended up being extremely high, however, and the trimester II fishery was forced to close on July 10 after reaching the closure threshold.[26] In trimester III, only 2,583 mt of longfin squid were landed against a quota of 8,888 mt, with the result that for the year, only 57 percent of the 2012 longfin squid quota was utilized. This represents a potentially significant amount of foregone economic benefits to the fishery.

This year's allocation of the longfin squid quota is nearly identical to the allocation in 2012, so early closure of the longfin squid fishery remains a threat if trimester II participation and landings are once again high. With this in mind, we wanted to get a better sense of the relative importance of revenues from longfin squid for the most active participants in the trimester II fishery. To the extent the trimester II participants are heavily dependent on revenues from longfin squid, this suggests that reallocation of more longfin squid to the trimester II quota should be a higher priority.

4.3 Relative Significance of Revenues from Longfin Squid Landings

To gauge the importance of longfin squid revenues to the most active participants in the fishery, we selected 2011 for our analysis because it was the most recent year for which we had full-year data. Because we wanted to analyze revenues for the most active participants in the

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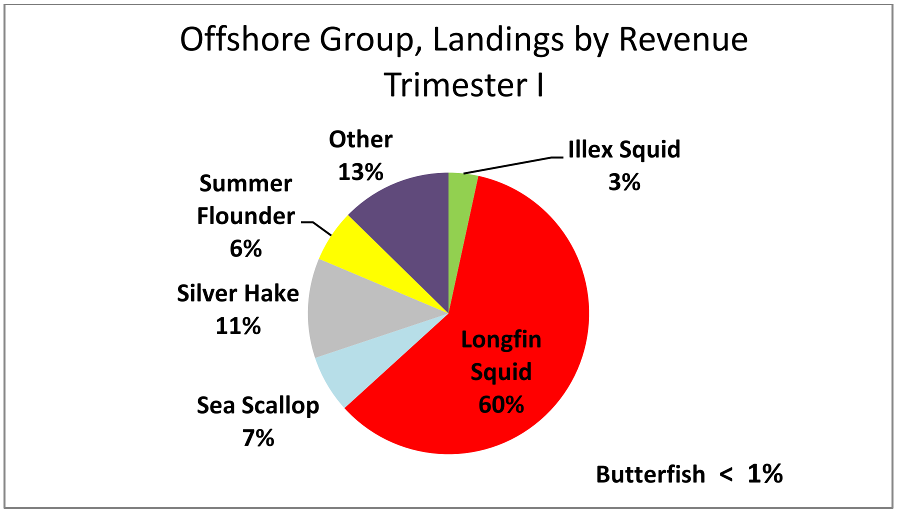
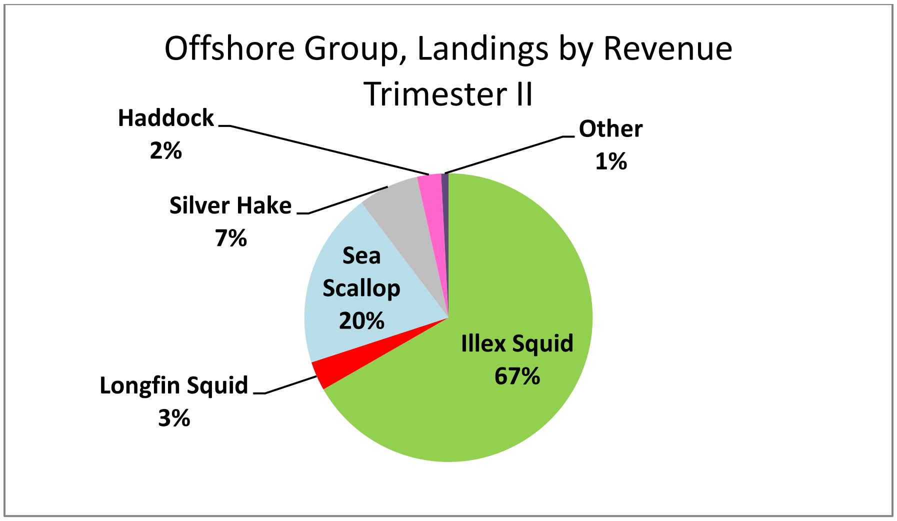
[26] According to our calculation, a total of 7,712 mt of longfin squid were ultimately landed in trimester II, a total that is well above the 5,666 mt quota. This is likely explained by the fact that vessels in state waters continued to land longfin squid throughout the summer, and holders of incidental and limited access permits were allowed to land up to 2,500 pounds of longfin squid per trip in federal waters after the July 10 closure.

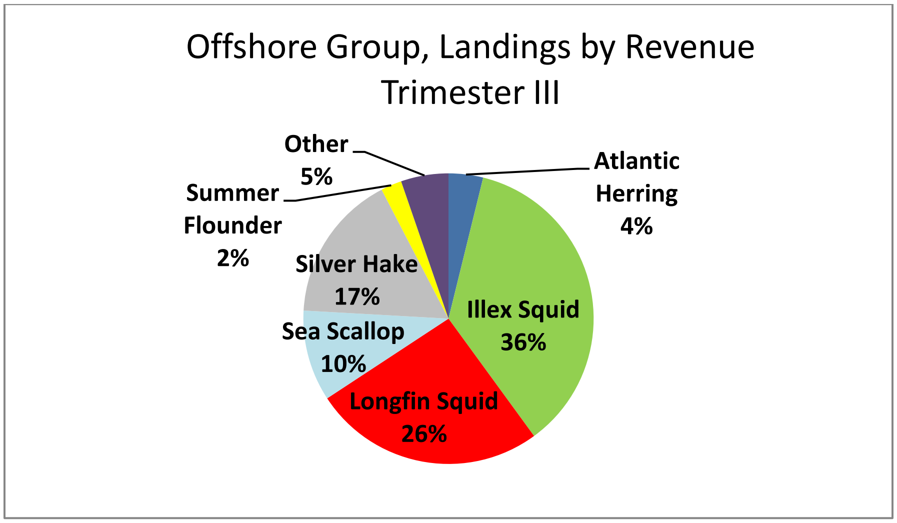
fishery, we chose to focus on the top 20 landers of longfin squid (by weight) in each of the three trimesters. Not surprisingly, there was considerable overlap between the top landers in trimesters I and III (primarily the offshore season), with 13 out of 20 vessels appearing on both top-20 lists. Only four of the top landers from trimester II were top landers in trimester I or IIII, however. We therefore created two separate lists of landers for purposes of our analysis: (i) a list of the top trimester II landers, excluding the four who were also top landers in trimester I or III (total number = 16); and (ii) a list of the top landers from trimesters I and III combined, also excluding the four who were top landers in trimester II (total number = 23). We then determined the total weight of all species landed by each group in each trimester of 2011, and we calculated the revenues attributable to landings of each species.

Starting with the top landers from the combined trimesters I and III list (referred to hereafter as the “offshore group”), the three charts in Figure 7 below illustrate the composition of revenues by species that the group landed in each trimester of 2011.

Figure 7. Offshore Group: 2011 Landings by Revenue



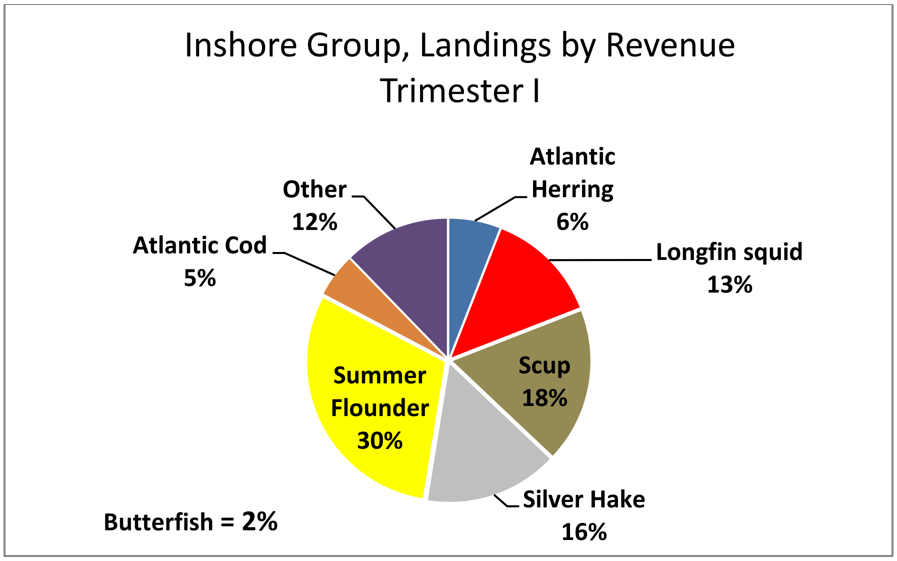


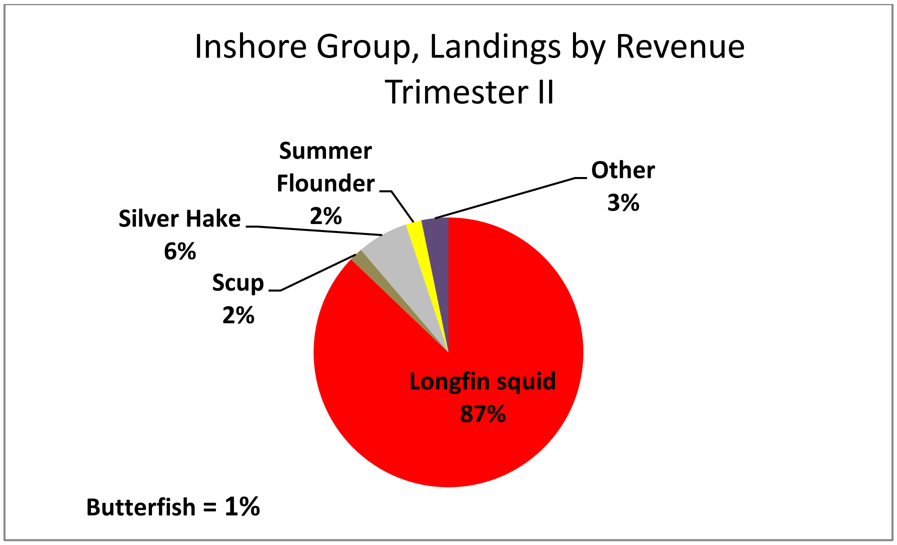


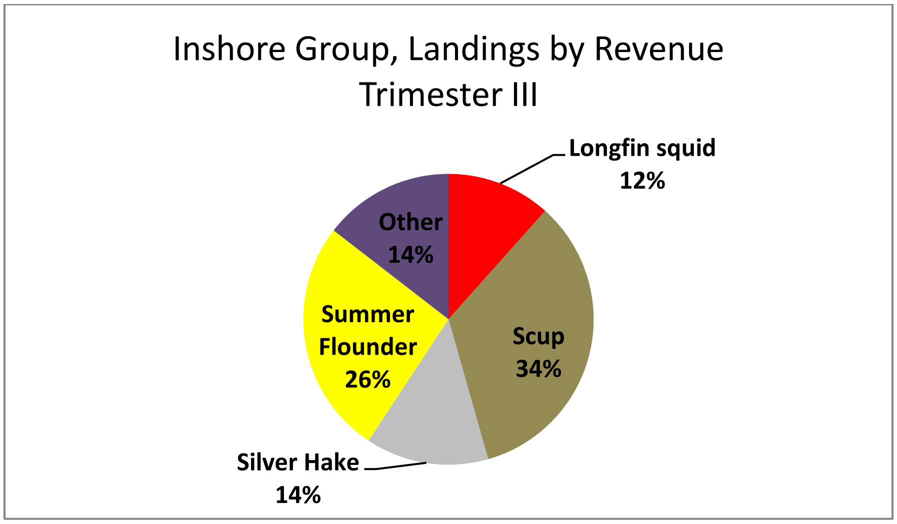
As represented by the red areas on the above charts, revenues from longfin squid constituted 60 percent and 26 percent of the offshore group's total revenues in trimesters I and III, respectively. Trimester II, however, is a completely different picture. Revenues from longfin squid constituted a relatively negligible three percent of the group's trimester II revenues. Although we expected longfin squid revenues to be a lower percentage of this group's trimester II revenues given that none of them were among the top-20 trimester II landers, we were surprised at just how small a percentage longfin squid revenues actually was in this period. It seems that the majority of the offshore group participants switched to the Ilex squid fishery in the summer and early fall months. It would therefore appear that the offshore group would not be greatly affected by an early closure of the longfin squid fishery in trimester II – at least insofar as 2011 is generally representative of the behavior of the most active participants in trimesters I and III of the longfin squid fishery.

We also conducted the same analysis for the top landers of longfin squid in trimester II (referred to hereafter as the "inshore group"). The results are illustrated on the charts below in Figure 8.

Figure 8. Inshore Group: 2011 Landings by Revenue







For the inshore group, revenues from longfin squid in trimesters I and III constituted 13 and 12 percent of trimester revenues, respectively. Landings of scup, silver hake and summer flounder all accounted for a greater share of the inshore group's revenues during the offshore months. In trimester II, however, the inshore group was extremely reliant on revenues from longfin squid. Longfin squid accounted for 87 percent of the group's total revenues in trimester II, dwarfing revenues received from any other fishery. In fact, the inshore group's revenues from longfin squid constituted nearly half (46 percent) of the group's total revenues in 2011. By comparison, the offshore group's revenues from longfin squid constituted 22 percent of the group's total revenues in 2011. The inshore group's high level of dependence on longfin squid revenues from trimester II landings means that this group has an extremely strong stake in the fishery remaining open throughout trimester II. All of our findings therefore suggest that the Council should consider allocating significantly more of the longfin squid quota to trimester II to ensure that participants have continued access to the fishery and to prevent the loss of economic benefits in the fishery.

4.4 Landings of Atlantic Butterfish in Other Fisheries

In the case of Atlantic butterfish, the directed fishery has been essentially non-existent for over a decade. As already noted, the Council significantly increased the butterfish landings quota for 2013 in an effort to allow rebuilding of the directed fishery. It is therefore not particularly useful to analyze recent historical landings data for purposes of evaluating the present management specifications. We were interested, however, in learning which fisheries were responsible for landing the most butterfish in the most recent year for which we had full-year data, 2011. We felt that this type of analysis might provide the Council with some indication of the types of fishery participants that stand to benefit most from the increased butterfish landings quota.

Similar to our methods for the longfin squid fishery, we identified the top-20 landers of Atlantic butterfish in trimesters I, II and III of 2011. Because there was so little butterfish landed in 2011, some of the participants on our top-20 lists landed fairly small amounts of butterfish (less than 5 mt). We then determined the total weight and revenues attributable to all species landed in each trimester by the top-20 landers from that trimester. Our findings are summarized in Table 3 below.

Table 3. Top 20 Landers of Atlantic Butterfish in Trimesters I, II and III of 2011: Landings Composition by Weight and Revenues

Species	Trimester I Top Landers: % of Trimester 1 Landings by Weight	Trimester I Top Landers: % of Trimester 1 Revenues	Trimester II Top Landers: % of Trimester 2 Landings by Weight	Trimester II Top Landers: % of Trimester 2 Revenues	Trimester III Top Landers: % of Trimester 3 Landings by Weight	Trimester III Top Landers: % of Trimester 3 Revenues	Trimesters Aggregated: % of 2011 Landings by Weight	Trimesters Aggregated: % of 2011 Revenues
Atlantic Butterfish	2%	1%	4%	4%	3%	3%	4%	4%
Longfin Squid	21%	27%	27%	42%	5%	9%	20%	30%
Silver Hake	18%	12%	44%	37%	14%	13%	32%	27%
Scup	10%	6%	6%	4%	52%	40%	21%	15%
Summer Flounder	4%	9%	2%	4%	8%	24%	4%	11%
Other	45%	45%	17%	9%	18%	11%	19%	13%

As is readily apparent, Atlantic butterfish constituted a fairly insignificant source of revenue among the vessels that were the top landers of butterfish in 2011 (4 percent by both weight and revenues for the year). Interestingly, although these vessels earned more revenue from longfin squid than from any other fishery for the entire year (30 percent), there were two other species that constituted a larger share of the landings by weight: silver hake (32 percent) and scup (21 percent). Presumably, these vessels were incidentally catching Atlantic butterfish rather than actively targeting the species. It is therefore problematic to predict, based upon incidental landings in 2011, the types of fishery participants that are likely to actively target and land (rather than discard) Atlantic butterfish in 2013. Accordingly, a similar analysis based upon full-year 2013 landings data could be helpful for purposes of characterizing and predicting the behavior of participants in the Atlantic butterfish fishery.

5. <u>Geospatial Analysis of Observer Data</u>

In addition to providing us access to the Commercial Fisheries Database Service, the Council and the Northeast Fisheries Science Center allowed us access to data from the Fisheries Observer Program (hereafter referred to as "the observer data"). The observer data represents a small subset of all trips and is collected by an independent onboard observer. This data is supplemental to any data reported to NMFS by the vessel operators or seafood dealers. Like the landings data, records in the database include information on all species landed on a particular trip (e.g., weight and ex-vessel prices). However, the data is considerably more extensive in the level of detail provided on many other factors, such as vessel information; day/month/hour/minute of each individual haul; time and length of haul; gear type used; and – most relevant to our geospatial analysis – latitudinal and longitudinal coordinates of each haul. The observer dataset, then, is both highly reliable and particularly detailed.

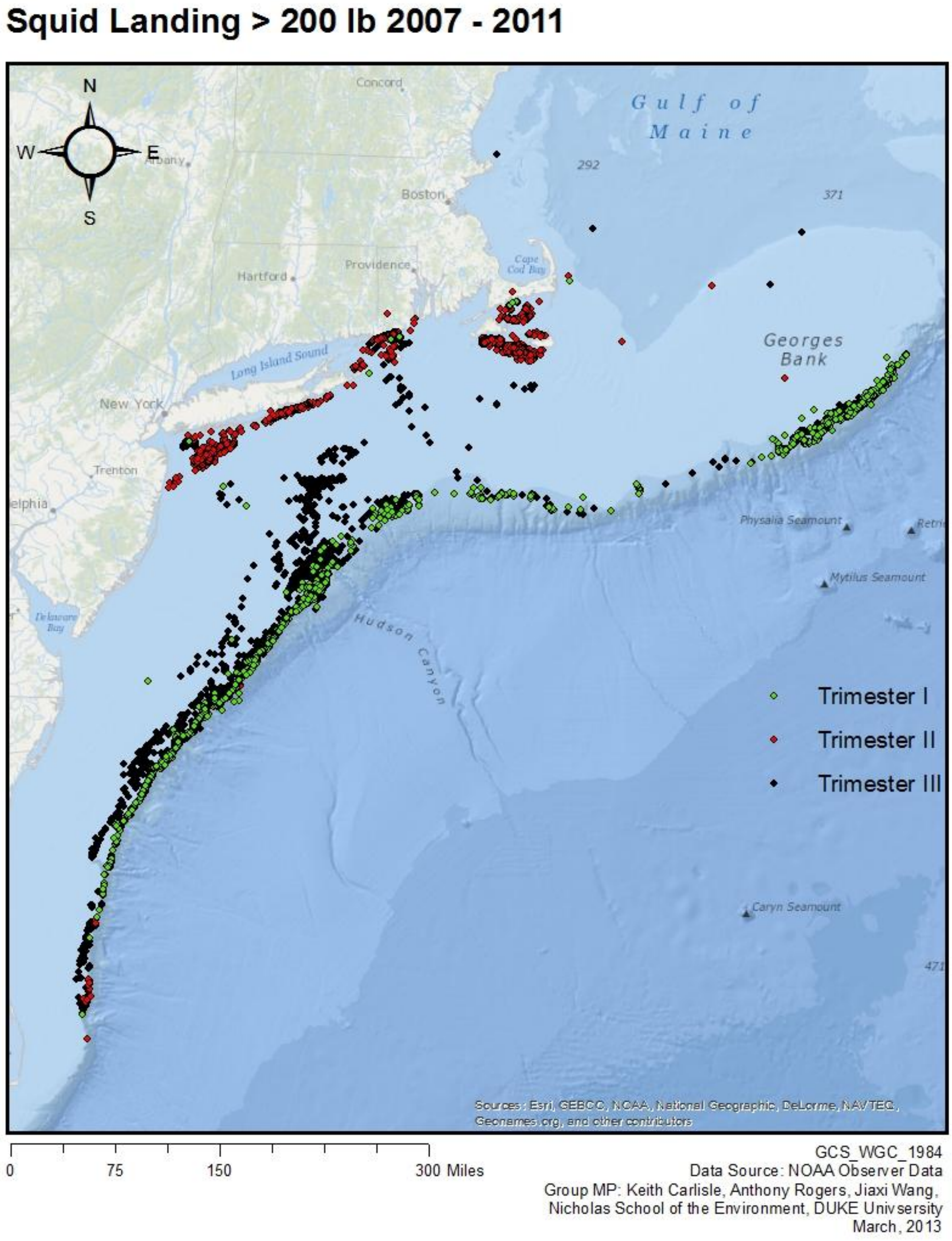
The dataset provided to us consists of all observed landings in the Mid-Atlantic and New England regions from 1999 through the end of 2011. This dataset represents approximately 11 percent of the total landings within the same timeframe. We utilized the dataset in order to, among other things, conduct a geospatial analysis of Atlantic butterfish landings and bycatch in the longfin squid fishery. The benefits of geospatial analysis in this project are essentially twofold. First, it allows us to visually explore and depict in an intuitive fashion the geographic areas where both landings and bycatch have occurred. Second, it allows us to explore the relationships between butterfish bycatch and spatial or geographic characteristics, such as distance from shore.

To get a better sense of the fishery's recent behavior, we constrained our geospatial analysis to include only the last 5 years, 2007-2011. Of these 5 years, there are 13,786 observations in the entire dataset that relate to longfin squid and butterfish, and of those, only 5,406 are trips where more than 2,500 mt of longfin squid were landed (i.e. the current threshold the Council uses for its bycatch calculation).

We once again analyzed the data provided to us using Stata statistical software. Using the latitudinal and longitudinal coordinates, we then imported the spatial data into ArcGIS and constructed a point layer map. Each point on a map therefore represents the location of a single haul. The spatial range of the data is entirely within the Exclusive Economic Zone of the United States, off of the Atlantic coast between 35.5N to 41.9N and 75.9W to 66.3W.

Our first two maps characterize the seasonal patterns of the longfin squid fishery and butterfish bycatch. Figure 9 shows where more than 200 pounds of longfin squid were landed from 2007 to 2011, split by trimester. Figure 10 shows where more than 200 pounds of butterfish were landed from 2007 to 2011, again split by trimester. In each map, we can clearly see that the seasonal landings follow the species' migratory patterns, as there is a distinct split between offshore harvest in trimester I along the continental slope and inshore harvest in trimester II. The transitional nature of September and October make the split a little less distinct in trimester III, although in aggregate the majority of landings in trimester III are also offshore.

Figure 9. Squid Landings > 200 Pounds, 2007-2011



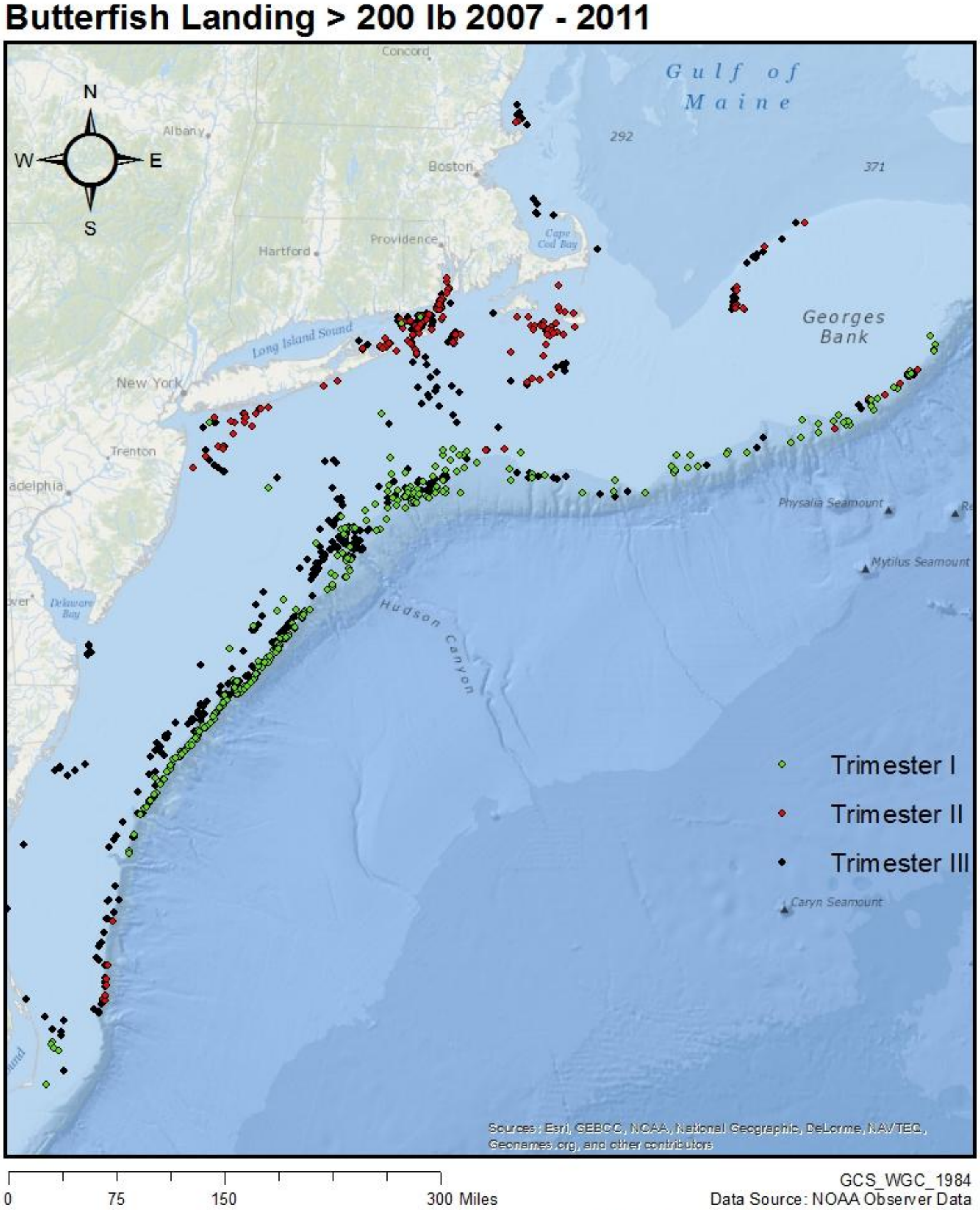
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors

Data Source: NOAA Observer Data

Group MP: Keith Carlisle, Anthony Rogers, Jiaxi Wang, Nicholas School of the Environment, DUKE Univsersity

March, 2013

Figure 10. Butterfish Landings >200 Pounds, 2007-2011



GCS_WGC_1984
Data Source: NOAA Observer Data
Group MP: Keith Carlisle, Anthony Rogers, Jiaxi Wang,
Nicholas School of the Environment, DUKE Univsersity
March, 2013

To analyze butterfish bycatch, we also plotted the bycatch rate of each haul on the map. Figure 11 illustrates the locations of butterfish bycatch in 2011. Because the Council utilizes the observer data when calculating the published butterfish bycatch rate, we sought to calculate these rates using the same methodology for this part of our analysis. Therefore, we define butterfish bycatch rate here as the weight of butterfish caught in a haul divided by the total haul weight, only including those trips where more than 2,500 pounds of longfin squid were landed. Each point falls into one of five different ranges of bycatch rates that we defined for purposes of this analysis.

A simple inspection of the map fails to reveal anything approaching a distinct pattern in spatial bycatch distribution. There is considerable noise throughout the data, although we note that there appear to be three separate clusters: one cluster close to the coast, a second cluster offshore along the continental slope edge, and a third cluster far offshore to the east of Georges Bank.

To explore whether the rate of bycatch is related to the distance between the point of catch and the shore, we calculated the distance to shore for each haul. To do this, we utilized a Medium Resolution Digital Vector U.S. Shoreline shapefile for the contiguous United States as a polygon layer within ArcGIS.[27] Our algorithm calculates the shortest distance between each point and the US east shoreline polygon. In other words, the distance to shore here means the

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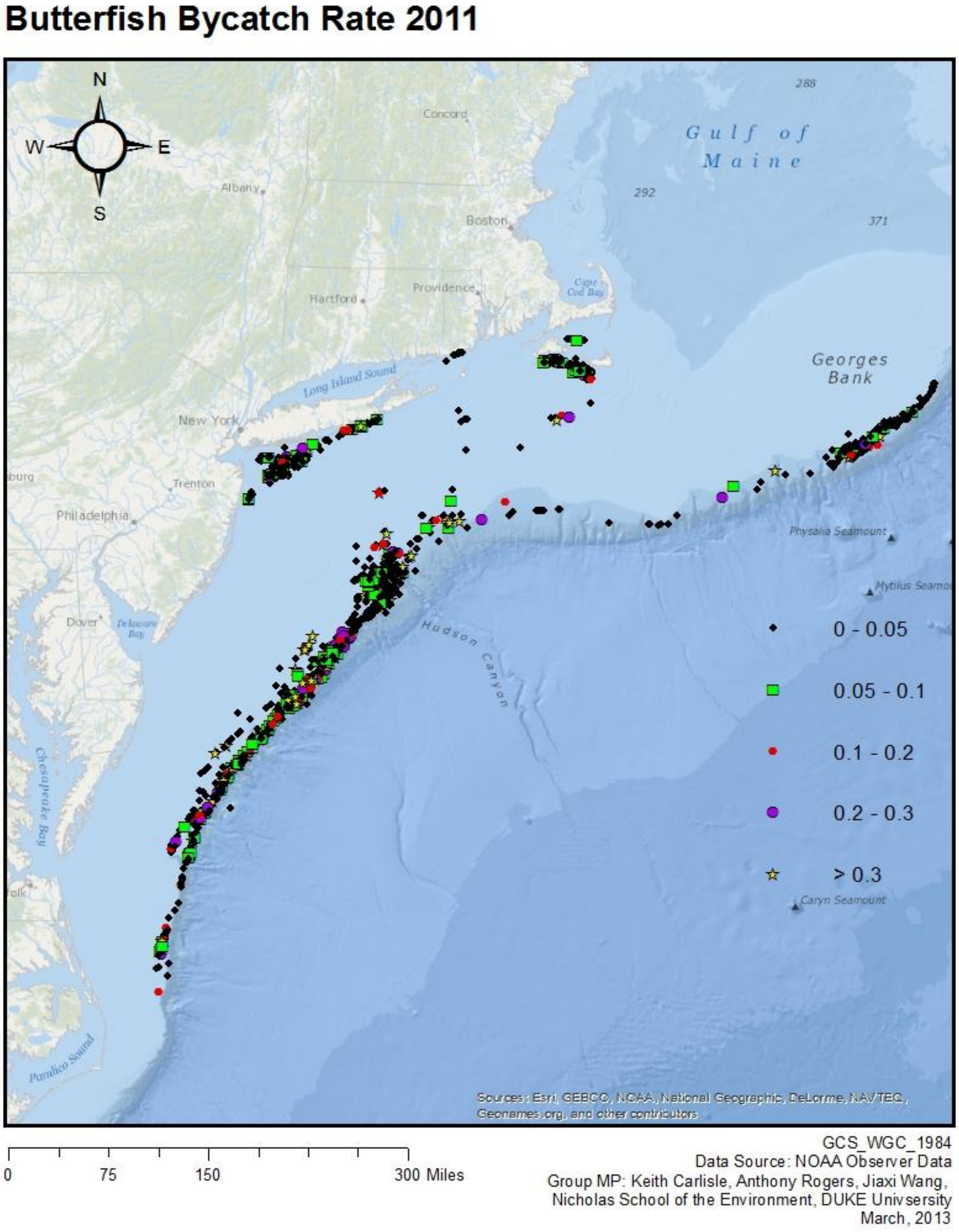
[27] National Oceanic and Atmospheric Administration, National Ocean Service (NOS), NOS80K - Medium Resolution Digital Vector U.S. Shoreline shapefile for the contiguous United States: NOAA/NOS/ORCA/SEA, Silver Spring, MD. Available at <http://coastalmap.marine.usgs.gov/GISdata/basemaps/coastlines/nos80k/nos80k.zip>

distance from each haul to the nearest point on land. We then plotted the bycatch rate for each distance to shore, the result of which can be seen in Figure 12.

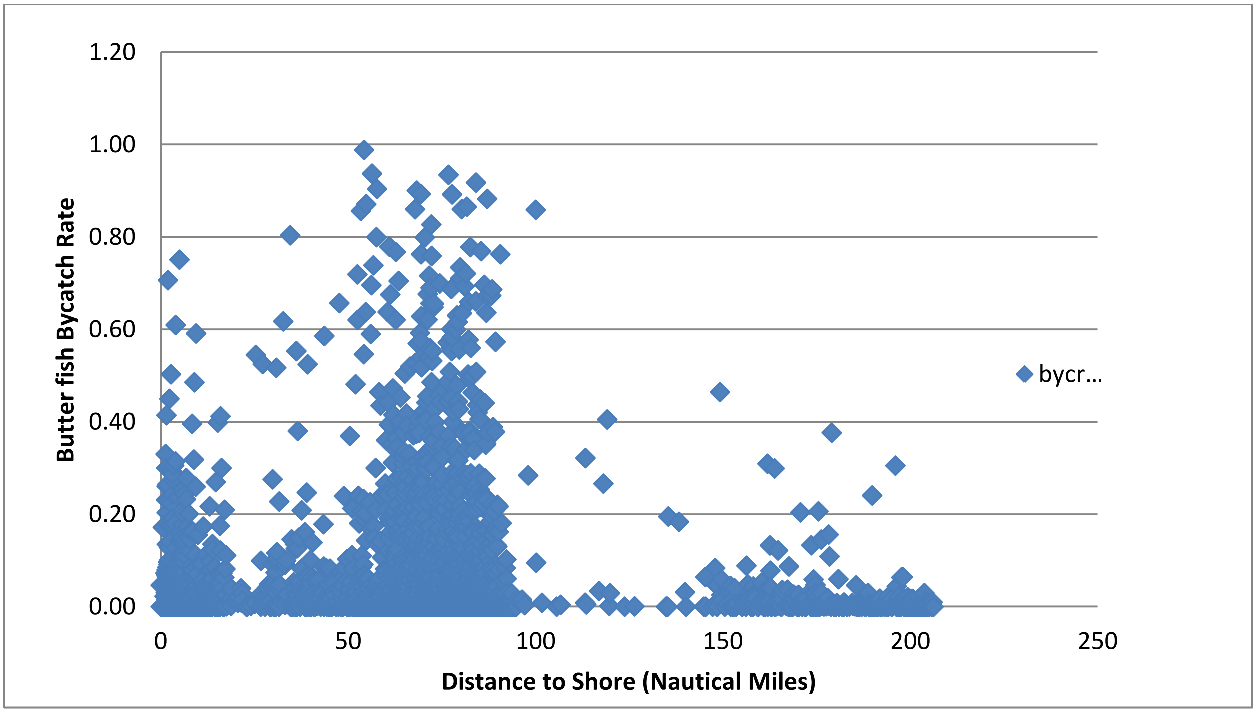
Figure 11. Spatial Distribution of Butterfish Bycatch Rates in 2011



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors

GCS_WGC_1984
Data Source: NOAA Observer Data
Group MP: Keith Carlisle, Anthony Rogers, Jiaxi Wang,
Nicholas School of the Environment, DUKE Univsersity
March, 2013

Figure 12. Distribution of Butterfish Bycatch Rates Across Distance to Shore



Again, we see considerable noise in the results. However, we once again note a slight trend, in this case that the higher bycatch rates appear to fall somewhere in the middle. Table 4 shows the results of splitting the data into three distance-to-shore categories: less than 20 nautical miles, 20-100 nautical miles, and more than 100 nautical miles. We then calculated the mean bycatch rate for each category. These categories approximately coincide with the three distinct clusters noted in Figure 11. Interestingly, the mean bycatch rate in the 20-100 nautical mile category is 0.062, almost three times the rate found in either of the other two categories.

Table 4. Mean Bycatch Rate by Distance to Shore

Distance (nautical miles)	Mean bycatch Rate
< 20	0.023
20 - 100	0.062
> 100	0.016

Hypothesizing that the approximate shape of the distribution in Figure 12 is that of a parabola, we ran a simple regression of bycatch using both distance to shore and a distance to shore squared term. The results of this regression can be found in Table 5. Both distance and distance squared are highly significant and have the expected signs. The regression predicts a maximum average bycatch rate of 0.0624, which is found at a distance of 88 nautical miles. The low r^2 value, however, suggests there are a considerable amount of omitted variables accounting for the variation in bycatch rate besides distance to shore. Unfortunately a more rigorous statistical analysis in this area was outside the scope of this project, and as such we cannot say whether distance to shore had a direct causal influence on the bycatch rate. We would therefore recommend to the Council that this relationship be explored further in the future. For now, we at least feel confident that we have identified that a statistically significant correlation exists between distance to shore and the bycatch rate.

Table 5. Distance to Shore Regression Results

Variable	Coefficient	P-value	Standard Error
distance	0.00093580	0	0.00006560
distance^2	-0.00000531	0	0.00000033
constant	0.02121440	0	0.00177090
			$r^2 = 0.03$

6. Integrated Bioeconomic Modeling of the Fisheries

6.1 The Bioeconomic Model

To explore the effects of management constraints and ecosystem interactions on benefits to the fisheries, we developed a bioeconomic model that illustrates what we would expect to see if the combined longfin squid and butterfish sectors followed an optimal harvest strategy path. It should be noted that "optimal" in this context strictly refers to fishery rents – we do not here take into account factors not captured in commercial value, such as employment, distributional issues, and other ecosystem considerations. To do this, the model incorporates price information for both species to maximize economic rents from harvest, while also modeling the changes to each respective stock.

Standard constrained optimal control models in fisheries management seek to maximize the total value from the harvest of a fish stock. "Total value" in this case is the total revenue from harvest – that is, the amount landed multiplied by the price received – minus the costs of harvest. Common costs include expended fuel for a fishing vessel and wages for the fishermen onboard. These benefits are then discounted over time, so that the net present value of the income received in the fishery may be maximized. The objective function for our model is therefore

$$\underset{h_y + h_x}{max} \int_{t=0}^{\infty} e^{-\delta t} \left[\left(P_{y(t)} - C_{y(t)}\right)h_{y(t)} + \left(P_{x(t)} - C_{x(t)}\right)h_{x(t)}\right]dt \tag{1}$$

where the x subscript denotes butterfish, the y subscript denotes longfin squid, h denotes the harvest of a species, P denotes the price of a species, C denotes the cost of harvesting a species, t denotes time, and δ denotes the discount rate.

The state equation for each species keeps track of the change in stock over time. A key difference between this model and a standard dynamic optimization model, however, is the inclusion of technical and biological interactions between the two species that link each of their state equations. In the context of this model, the technical interaction modeled is the aforementioned butterfish bycatch rate as longfin squid are harvested, while the biological interactions modeled include both predation and any additional benefits to longfin squid of a larger butterfish stock. Therefore our state equations for butterfish and longfin squid are, respectively,

$$\dot{x} = F(x) - \alpha y_t - \theta h_{y(t)} - h_{x(t)} \tag{2}$$

$$\dot{y} = G(y) + \beta x_t - h_{y(t)} \tag{3}$$

where x once again denotes butterfish, y again denotes longfin squid, F(x) and G(y) denote net biological growth functions of the stocks, h denotes harvest, α denotes predation, θ denotes bycatch, and β denotes added benefits of additional butterfish left in the ocean ("butterfish amenity").

Utilizing [2] and [3] to model the growth of each species separately builds on the work done by Ragozin and Brown (1985) and Wilen and Brown (1986). Specifically, both papers adapt Hanneson's (1983) predator-prey work to build models where the populations of a predator and prey species are split into two separate equations, but linked by an interaction variable. These models separate the ecological interactions of the two species from other background growth processes. Smith and Crowder (2011) observe that there are two advantages to such an approach: 1) the use of the intrinsic growth rate (see [5] below) can account for any reproductive speed of adjustment that the predation parameter may not capture; and 2) the carrying capacity parameter (again, see [5] below) can account for any environmental limits that may exist besides the availability of the prey.

Our goal in optimally managing both fisheries collectively, then, is to maximize (1), subject to (2) and (3). To accomplish this task, we discretized our objective and state equations and then utilized the nonlinear optimization routines in Microsoft Excel's Solver program. This function runs multiple iterations until it finds the highest possible value of a particular cell (our total profit cell) by changing the values of other cells (in this case, the fishing effort cells). Each of these effort cells subsequently interact with cells populated by other parameters and continue to cascade forward, ultimately linking the chosen level of effort with the resulting total profit. In this way, Solver finds the amount of fishing effort that results in the maximum present value total profit, subject to the parameters and constraints imposed upon it.

6.2 Model Parameterization

Populating the model with appropriate values required drawing estimates from a variety of sources and calculations. For ease of calculation, we approximated the infinite time horizon using a discrete time calculation for each parameter.

Price information for (1) was collected from the Commercial Fisheries Database Service. We initially calculated an average price per pound for each species in each trimester of 2011, which was both the most recent full year of data available and the only year under the butterfish discard cap regulations in our dataset, making it a good proxy for prices going forward. However, there were concerns that, all else being equal, the trimester with the highest price may drive the behavior of the model, so we also ran each modeled scenario with a single average price for each species for the 2011 year. We did not consider endogenizing price; rather, we assumed market prices to be given. These prices are reflected in Table 6 below. Cost information for use in (1) was unfortunately unavailable. To compensate for this shortcoming, we endeavored to run each simulation under a variety of cost assumptions to ensure that our trends were robust to different cost scenarios. We also assumed a constant real discount rate of 3%, so $\delta = 0.03$. As a consequence of choosing such a low rate, the gains in the model are potentially overstated, but identifying qualitative differences is made more straightforward. We therefore acknowledge the limitations of this choice, and again point out that the intent of this model is to be illustrative, not predictive.

Table 6. Butterfish and Longfin Squid

2011 Average Prices

Average Price for Butterfish in 2011	
Trimester 1	0.92
Trimester 2	0.78
Trimester 3	0.84
Year average	0.82
Average Price for Longfin Squid in 2011	
Trimester 1	1.58
Trimester 2	1.21
Trimester 3	1.41
Year average	1.33

Direct harvest of each species in (1), as well as (2) and (3), is calculated using the first equation in the classical Gordon-Schaefer two-equation model

$$H_t = \mathrm{qE_tX_t} \tag{4}$$

where H_t denotes the harvest at time period t, q denotes the catchability coefficient (that is, how much fish is removed from a single unit of effort), E_t denotes the fishing effort, and X_t denotes the stock size (Schaefer 1954). As we previously mentioned, our model maximizes the total profit of the fisheries over time only by iterating on the level of E_t chosen in each period. (In other words, E_t for each fishery is the only variable in our model that Solver can manipulate, to reflect human choice. The rest of the interactions modeled are exogenous to human behavior, except when impacted by the level of harvest resulting from the chosen level of E_t.

Our initial stock of butterfish in Year 1 of the model is set to 88,800 mt, taken from the most recently available butterfish stock assessment (NFSC 2010). *F(x)* in (2) represents the butterfish stock growth rate. It is derived from the second equation of the classical Gordon-Schaefer model, which is given as

$$X_{t+1} = \mathrm{X_t} + \mathrm{rX_t}(1 - \frac{\mathrm{X_t}}{\mathrm{K}}) \tag{5}$$

where X_t denotes the butterfish stock, X_{t+1} denotes the growth of the stock in the next period, *r* is the intrinsic growth rate of the species, and *K* is the stock carrying capacity (Schaefer 1954). (It is important to note that the Gordon-Schaefer model typically subtracts the direct harvest of a species out as well. For the purpose of illustrating *F(x)*, however, we adapt it here to show only the growth portion, as we have already discussed harvest above.) The intrinsic growth rate, *r*, was estimated to be $r = 0.76$ in Gamble and Link (2009), where estimates of F_{MSY} for butterfish were doubled for use as inputs to *r* (Gamble and Link 2009). For the carrying capacity, *K*, we used the estimate from the most recently available butterfish stock assessment (149,100) (NFSC 2010).

Our initial stock of longfin squid in Year 1 of the model is set to 76,329 mt, which is the estimate in the most recently available longfin squid stock assessment (NFSC 2011). Because longfin squid are an annual species, we looked to Huang and Smith (2011) for a viable approach to modeling a species with such a short lifespan. Based upon Huang and Smith (2011), we regard the longfin squid stock recruitment as exogenous to the previous year's stock, less harvest, and each subsequent year begins with 90% of the carrying capacity, 84,819 mt, as identified in the most recent stock assessment (NFSC 2011). This flat value, then, takes the place of *G(y)* in (3) for each period.

Capturing the inshore and offshore migration of both species was an important consideration of our model. To accomplish this, each stock was split into two categories: one that tracked the percentage of the total stock (per species) that was inshore, and one that tracked the percentage of the total stock that was offshore. For the winter period (defined here as January-March), 90 percent of the total stock was offshore and 10 percent was inshore. For the summer period (July-September), the reverse was true: 90 percent of the stock was inshore, and 10 percent was offshore. We purposefully avoided allocating 100 percent of the stock to either inshore or offshore in any period to account for the likely variability in each stock's movement. In order to simulate the gradual, continuous shift from offshore to inshore in the first set of transitional months (that is, April-June), we utilized the following two equations

$$Y_{t\ (offshore)} = \frac{1}{2} + \frac{1}{2}\cos\left({}^{\pi t}/_{3}\right)\mathrm{Y_t} \tag{6}$$

$$Y_{t\ (inshore)} = [1 - (\frac{1}{2} + \frac{1}{2}\cos\left({}^{\pi t}/_{3}\right)]\,\mathrm{Y_t} \tag{7}$$

where $\mathrm{Y_{t(offshore)}}$ is the percentage of stock found offshore at time t and $\mathrm{Y_{t(inshore)}}$ is the percentage of the total stock found inshore at time t. When modeling the transitional period back to offshore (October-December), we again utilized (6) and (7), but in reverse: in these months, (6) refers to the inshore population, and (7) refers to the offshore population. The trigonometric functions in (7) and (8) approximate this seasonality.

6.3 The Predation Parameter

The second term in (2), αy_t, represents the predation of butterfish by longfin squid. α takes a value of ≥ 0, and y_t is the stock size of longfin squid at time t. Together, they represent the amount of butterfish consumed as a function of longfin squid stock size. While predation is not typically considered to cause persistent declines of fishery stocks, the combination of fishing pressure and predation can have significant effects on recruitment of prey populations (Gamble and Link 2009). Intuitively, this makes sense: all else being equal, as the amount of longfin squid in the environment increases, the species will consume more of everything in its diet, including butterfish.

Table 7. Initial Model Parameter Values

Parameter	Initial value
Butterfish intrinsic growth (r)	0.76
Longfin squid net growth (G(y))	76,329 (flat)
Butterfish carrying capacity (K)	149,100.00
Longfin squid carrying capacity (K)	84,819.00
Predation (α)	0.10
Bycatch coefficient (θ)	0.09
Butterfish amenity (β)	0

Figure 13. Effect of Increasing Predation Rate on Butterfish Landings

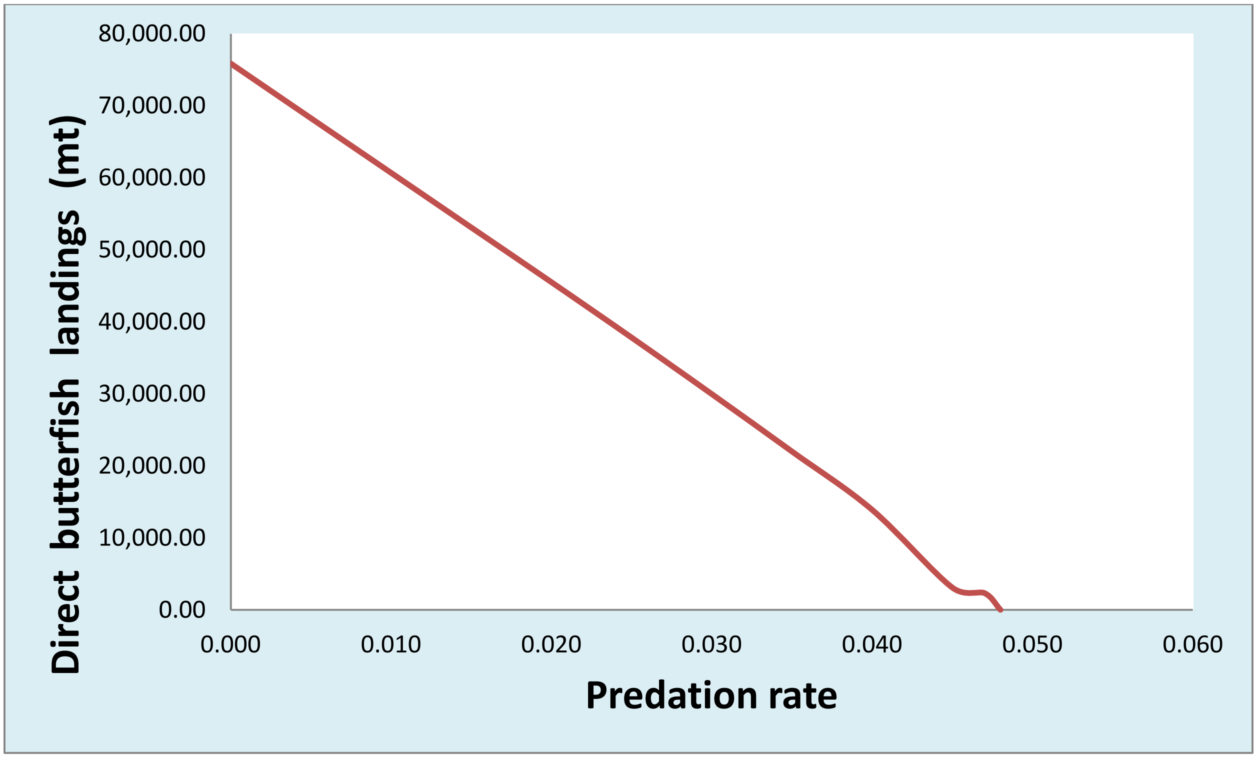


Table 7 shows the initial values used in running the first iterations of the model. Figure 13 displays the results of running multiple iterations of our model to explore the effect of the predation parameter. We ran the same scenario in our model several times, increasing the predation rate each time but holding all else constant. The increasing predation rate (α) is on the x-axis, and estimated direct butterfish landings are on the y-axis. Though we caution against drawing conclusive numbers from the output – this scenario, after all, disregards all other management constraints – once again the trend is intuitively easy to understand: as the rate of predation increases, there are less butterfish available for the fishery to harvest, and it is optimal to leave more butterfish as prey for its high-priced predator.

It is important to note, however, that marine ecosystems are extremely complex, and predator-prey relationships are not tightly coupled (Jennings et al. 2001). Both top-down and bottom-up effects shape species regimes, and the removal of predators by fishing does not result in the proliferation of their prey when bottom-up effects overwhelm top-down effects (Jennings et al. 2001). In fact, predators may provide stability to prey communities that are density dependent (Moustahfid 2010), and they may also provide other indirect benefits to their prey, such as consuming other predators and competitors of the prey (Pauly 2002). Therefore, simplistic pairwise evaluations or models of predator-prey relationships fail to capture the complex and dynamic nature of marine ecosystems (Link, et al. 2011).

As this relates to the interactions between longfin squid and Atlantic butterfish, it would clearly be incorrect to assume that a one-to-one relationship exists between squid and butterfish such that one could predict the impact to butterfish abundance solely by considering removals of longfin squid. Instead, developing an understanding of the impacts of butterfish-squid interactions requires understanding interactions among multiple predators and prey in the Northwest Atlantic. While such an exercise is necessarily data intensive and can be daunting, one does not need perfect knowledge of every process or interaction to manage fisheries from an ecosystem perspective (Link 2011). The strength of the model presented here, then, comes not from its predictive capabilities, but its capacity to illustrate potential tradeoffs between the two fisheries.

6.4 <u>The Bycatch Parameter</u>

The third term in (2), $\theta h_{y(t)}$, is the bycatch of butterfish as longfin squid is harvested. Once again, $\theta \geq 0$, and is a rate that is multiplied by the level of harvest of longfin squid at time t (that is, $h_{y(t)}$). As has already been discussed at length in this paper, bycatch is a central technical interaction linking longfin squid, butterfish, and harvest. It is important to point out that bycatch coupled with the predation parameter discussed above makes optimal management significantly more complicated, as predation implies that removing *more* longfin squid may benefit butterfish, but the very act of harvesting longfin squid may itself be detrimental to the butterfish population on account of the bycatch interaction.

For the purposes of this model, we utilized the observer data and calculated the average rate of butterfish bycatch whenever more than 2,500 pounds of longfin squid was landed. While 2,500 pounds is the same threshold used by the Council for purposes of the mortality cap, our methodology for calculating the bycatch rate differs slightly from the methodology employed by the Council. The published methodology calculates the amount of butterfish caught as a percentage of total species landed on trips where more than 2,500 pounds of longfin squid were landed. Because we are only modeling interactions between longfin squid and butterfish, however, we decided that a ratio of butterfish caught to squid landed was a more appropriate measure of bycatch for purposes of our analysis. We calculated this ratio to be approximately .09 in 2011, and therefore set $\theta = .09$ in our model. It is also worth noting that we use a constant for the bycatch rate, and we know that the rate varies dramatically across hauls. There may be systematic seasonal differences as well as differences attributable to different targeting behaviors and idiosyncratic vessel effects. At minimum, the statistical evidence suggests systematic differences in space. Thus, not all management measures affecting squid will necessarily have equal impacts on butterfish.

Figure 14. Butterfish Discard Cap and Estimated Effect on Longfin Squid Landings

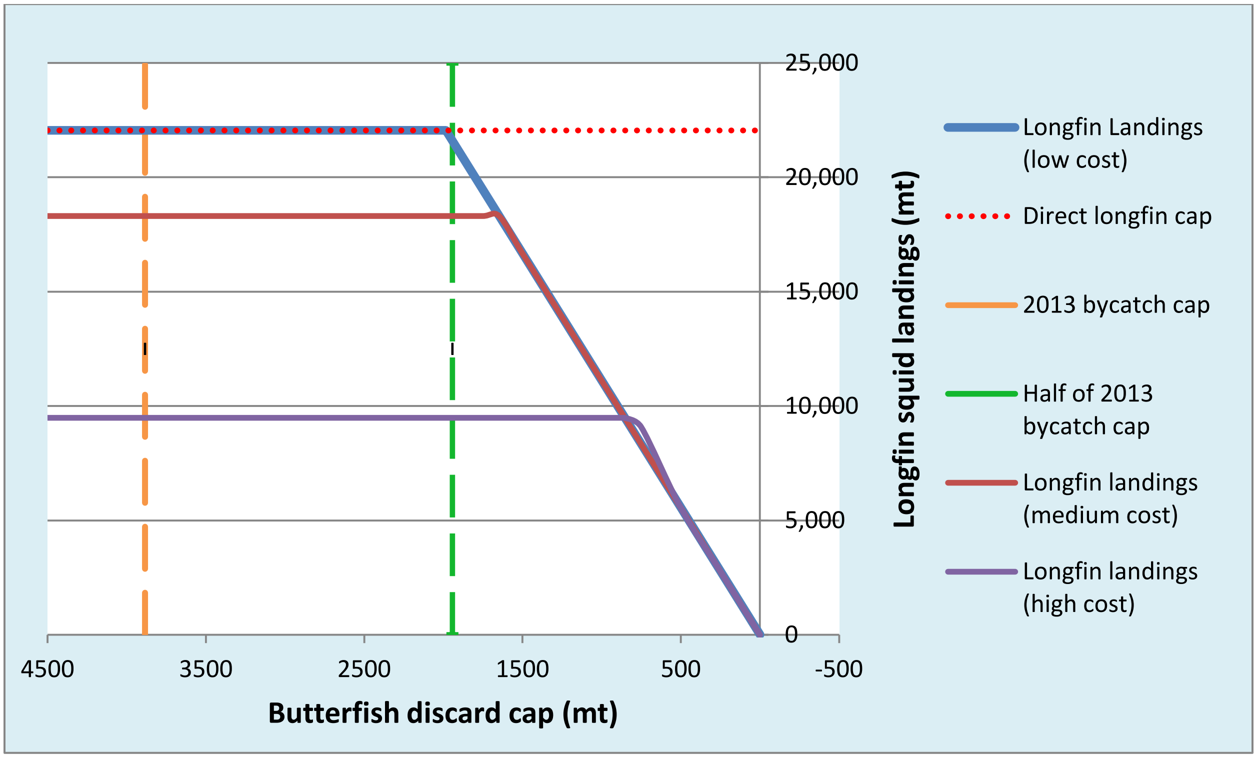


Figure 14 shows the estimated level of longfin squid that would be harvested under different butterfish mortality cap scenarios. The different mortality cap constraints (i.e. the bycatch constraint) are on the x-axis, and longfin squid landings are on the y-axis. The vertical dashed orange line on the left marks the current limit on butterfish bycatch imposed on the longfin fishery (50 CFR Part 648). The solid lines represent longfin squid landings as determined by the model. As mentioned previously, we ran the model under different cost scenarios to make sure the general trend was robust, so there are three trend lines included here for illustration: a low, medium, and high cost scenario.

An important point to focus on in Figure 14 is that, under the current management scenario, longfin squid harvest does *not* appear to be constrained by the mortality cap. Rather, the landings in the low cost scenario are constrained by the longfin squid landings quota (as indicated by the red dashed line). In fact, if we continue to lower the mortality cap (moving to the right along the x-axis), we see that the longfin squid fishery is not constrained by the mortality cap until the cap reaches approximately 2,000 mt – nearly half the current allocation of butterfish to the mortality cap. If we look to the medium and high cost scenarios, we see the exact same trend – albeit with landings leveling out at a lower level due to higher costs, as expected. We can therefore see that with the current allocation of butterfish to the mortality cap, the longfin squid fishery is extremely unlikely to be closed on account of reaching the bycatch limit.[28] Again, we offer the caveat that we assume a constant bycatch rate in the model.

This finding is particularly important within the context of maximizing economic rents from the two fisheries combined. The butterfish buffer – i.e. the additional butterfish allocated to the mortality cap above the point where the bycatch cap is likely to be a factor – is approximately 1,900 mt in our low cost scenario (the scenario with the smallest buffer). If that 1,900 mt were instead allocated to the directed butterfish fishery, and if the additional butterfish allocation were landed and sold for $0.82 per pound (the 2011 average price per pound of butterfish), then the present buffer constitutes an additional $3,434,802 in revenues that is not being captured by the fishery. While some level of "butterfish insurance" is desirable to avoid early closure of the longfin squid fishery, the size of the buffer reflected in the 2013 management specification is quite large relative to the risk. There are of course caveats to this

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[28] The model does not take into account the fact that the mortality cap allotment is allocated among the three longfin squid management trimesters. However, the 2013 rules concerning closure of the longfin squid fishery on account of the mortality cap threshold allow the longfin squid fishery to remain open in trimester II until 75 percent of the total 2013 mortality cap is reached and to remain open in trimester III until 90 percent of the total 2013 mortality cap is reached (NMFS 2013). Based upon the closure rules, we believe that modeling the mortality cap as a single annual limit should not have a material impact on our findings from the model.

figure and our findings, including the assumption that the entire increase in the butterfish landings quota would be landed and also sold. As previously mentioned, demand for butterfish is relatively weak given that the market for the species in Japan no longer exists. Although it is very possible that the overseas market could be reestablished given a sufficiently high butterfish landings quota, it is unlikely that an additional allocation of 1,900 mt to the 2013 quota could be sold under present market conditions. It is more likely that capturing these foregone revenues in the butterfish fishery would occur over a period of years.[29]

6.5 The Butterfish Amenity Parameter

The second term in (3), βX_t, represents what we have deemed "butterfish amenity". This term captures the potentially beneficial effect of butterfish being left in the ecosystem for squid to consume. This effect may be thought of as the consequence of the predation parameter discussed above. In other words, this is the result of longfin squid consuming more butterfish, all else being equal. $\beta \geq 0$, and the entire effect is dependent on the total stock size of butterfish at time t.

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[29] See, e.g., the 2011 Squid-Mackerel-Butterfish Advisory Panel Fishery Performance Reports in which the Advisory Panel states that it would take several years to re-establish the butterfish market and that, as a result, landings would likely slowly increase if there were a larger quota. The reports are available at http://www.mafmc.org/fmp/msb_files/2012_Specs/2012_MSB_FPRs.pdf

Table 8. Model Results With and Without Predation and Butterfish Amenity

Set up	Butterfish harvested (mt)	% change	Longfin squid harvested (mt)	% change
Predation = 0, butterfish amenity = 0	68,023	-	131,455.00	-
Predation = 0.01, butterfish amenity = 0	61,124	-10.14	131,455.00	0
Predation = 0, butterfish amenity = 0.01	67,944	-0.12	132,215.03	0.58
Predation = 0.01, butterfish amenity = 0.01	61,038	-10.27	132,215.41	0.58

Table 8 shows the results of running the model – holding all else constant – for a two-year period under four scenarios: 1) with no predation or butterfish amenities included; 2) with just predation included; 3) with just butterfish amenities included; and 4) with both predation and butterfish amenities included. Once again, we caution that these results are illustrative, not predictive, but the trends are telling. The results indicate that without including the amenity parameter, the longfin squid fishery will harvest the same amount regardless of whether predation is included. Intuitively this makes sense, as the longfin squid is the more valuable of the two species in this model.

Once the amenity values are included, the total harvest of longfin squid increases, and the harvest of butterfish decreases. This is exactly as we would expect the butterfish amenity parameter to operate: there is now an additional incentive to reduce the landings of butterfish, as those individuals that would otherwise be harvested can instead be translated into additional value for the more valuable longfin squid fishery.

We must once again reiterate here, however, the caveats presented in the discussion of the predation parameter. The assumption that a one-to-one relationship exists between these two species is flawed, and it would be inappropriate to draw conclusions solely from the relationship modeled here. Further research is needed into the beneficial effects butterfish may have on the longfin squid population relative to further interactions with other predators and prey. Instead, the modeled relationship presented here serves to illustrate yet another potential relationship that could, in a more sophisticated model, have considerable implications for optimal management of the fisheries.

7. Conclusions

On account of the professional, client-based nature of this masters project, we have attempted to provide the Council with both practical management-related information (e.g., landings trends and geospatial patterns in the fisheries), as well as a more conceptual modeling framework to illustrate how economic benefits could be accounted for in an integrated, multi-species management paradigm. With respect to the former, perhaps our most important finding is that the present allocation of the longfin squid landings quota is no longer representative of seasonal participation and landings in the fishery. In particular, trimester II has become relatively more important in recent years with respect to both participation and landings of longfin squid, and the current quota allocation to trimester II (17 percent) could result in another early closure of the summer fishery and a loss of revenues. We acknowledge, however, that there is considerable seasonal and interannual variability in longfin squid landings when viewed over longer timeframes, which it makes it difficult to predict landings with any certainty. We therefore do not advocate adjusting the trimester II quota to reflect the percentage of last year's trimester II landings – at 61 percent, 2012 was an unusual year in comparison to the previous fifteen years. That said, since 2008, trimester II landings have represented at least one-third of total landings in the fishery, so a trimester II quota allotment that approaches one-third of the annual quota seems warranted. This is especially true given that we found a high level of dependence on the resource by active participants in the trimester II longfin squid fishery.

With the high level of inter-annual variability in seasonal landings of longfin squid and the recent increase in trimester II landings, an appropriate allocation strategy might be one which spreads the quota out fairly evenly among the trimesters to hedge against the risk of unanticipated high landings in any given trimester. It would make sense, however, to allocate a bit more of the quota to trimester I given that the other two trimesters have the possibility of benefiting from unused quota in the previous trimester. Thus, an ideal trimester allocation of the longfin squid quota might look something like: (i) 40 percent in trimester I; (ii) 30 percent in trimester II; and (iii) 30 percent in trimester III. In 2012, this would have resulted in an allocation of 6,615 mt to the trimester II quota and an additional roll-over of 3,213 mt from trimester I, for a total of 9828 mt of quota in trimester II. This could have been sufficient to prevent early closure of the fishery last summer given that 7,712 mt of longfin squid were ultimately landed in trimester II, with the fishery closing on July 10 but with landings continuing in state waters and in smaller amounts in federal waters (i.e., subject to a 2,500-pound trip limit).

Although we also analyzed landings data for the Atlantic butterfish fishery, our findings are limited on account of there having been no directed fishery for butterfish in over a decade. We gained more potentially useful insight regarding the butterfish fishery from our geospatial analysis of butterfish landings and bycatch in the longfin squid fishery. In this regard, we found that there is a statistically significant correlation between the butterfish bycatch rate and the distance to shore from the point of catch. In particular, we found that the butterfish bycatch rate in the longfin squid fishery was nearly three times higher in the zone that falls between 20 and 100 nautical miles from the shore (encompassing the intermediate and offshore areas of the longfin squid and butterfish distribution). At least one implication of this finding is that declining participation in the longfin squid fishery during the offshore months could result in both lower quantities and lower rates of butterfish bycatch. Further and more rigorous statistical analysis of this relationship is necessary to understand whether distance to shore has a direct causal relationship with the bycatch rate.

With respect to the model, we provided significant insight into some of the technical and biological relationships between longfin squid and butterfish that a single-species approach would not have taken into consideration. We found that the predator-prey dynamic of the two species can have both negative consequences for the butterfish population and positive benefits for the longfin squid population. Furthermore, we demonstrated how potential economic value was lost when these interactions were neglected. Perhaps most tellingly, we were able to show that the current butterfish allocation to the longfin squid fishery's bycatch mortality cap is making a substantial tradeoff between certainty and revenues generated by direct butterfish harvest.

There remain many more questions and several avenues for further research within these fisheries. While our work here has helped to characterize the nature of this fishery, we were unable to explore the causal factors that may be driving the change in focus to the inshore fishery. A more detailed statistical analysis of likely factors – such as increasing fuel prices – may shed some light on this behavior, especially if it is applied at the individual vessel level. Both the inshore-offshore migration and the distribution of the two species is largely driven by temperature, and understanding how climate change is likely to impact these movements – and, subsequently, fishing behavior – will be an increasingly important aspect of managing multiple fisheries simultaneously. Likewise, a more comprehensive bioeconomic model – one that includes both interactions between several species in the ecosystem and the technical aspects of fishing that link them together – may help to build a better understanding of the true scope of tradeoffs made in each individual fishery, and should provide further insight into the challenges of ecosystem-based management.

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References

Cross JN, et al. (1999) Essential Fish Habitat Source Document: Butterfish, Peprilus triacanthus, Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-145.

Fluharty D, et al. (1998) Ecosystem-Based Fishery Management: A Report to Congress by the Ecosystem Principles Advisory Panel. Available at http://www.nmfs.noaa.gov/sfa/EPAPrpt.pdf.

Gamble RJ, Link JS (2009) Analyzing the tradeoffs among ecological and fishing effects on an example fish community: A multispecies (fisheries) production model. 220 Ecological Modelling; p. 2570.

Gassala MA et al. (2010) A comparative multi-fleet analysis of socio-economic indicators for fishery management in SE Brazil. 87 Progress in Oceanography; p. 304.

Hannesson R (1983) Optimal harvesting of ecologically interdependent fish species. 10 Journal of Environmental Economics and Management; pp. 329–45.

Hendrickson LC (2011) Effects of a codend mesh size increase on size selectivity and catch rates in a small-mesh bottom trawl fishery for longfin inshore squid, Loligo pealei. 108 Fisheries Research; p. 42.

Hooks A, Baylor E (2009) Recent Developments: Natural Resources: Fishery Conservation and Management after Reauthorization of MSA. 39 Texas Environmental Law Journal; p. 193.

Huang L., Smith MD (2011) Management of an Annual Fishery in the Presence of Ecological Stress: The Case of Shrimp and Hypoxia. 79 Ecological Economics; p. 688.

Hunsicker ME, Essington TE (2006) Size-Structured Patterns of Piscivory of the Longfin Inshore Squid (*Loligo pealeii)* in the Mid-Atlantic Continental Shelf Ecosystem. 63 Canadian Journal of Fisheries and Aquatic Sciences 4; p. 754.

Hunsicker ME, Essington, TE (2008) Evaluating the Potential for Trophodynamic Control of Fish by the Longfin Inshore Squid (*Loligo pealeii*) in the Northwest Atlantic Ocean. 65 Canadian Journal of Fisheries and Aquatic Sciences; p. 2524.

Jacobson LD (2005) Essential Fish Habitat Source Document: Longfin Inshore Squid, Loligo pealeii, Life History and Habitat Characteristics, 2nd Ed. NOAA Technical Memorandum NMFS-NE-193.

Jennings S, Kaiser MJ, Reynolds JD (2001) Marine Fisheries Ecology. Oxford: Blackwell Science; 417 pp.

Lee JP (2012) Lee, J.P. A Fish that Built a Port. The Dented Bucket: a Fisherman's Blog. Posted March 26, 2012. Available at http://www.thedentedbucket.com/a-fish-that-built-a-port/.

Link JS (2002) What Does Ecosystem-Based Fisheries Management Mean? 4 Fisheries 27; p. 17.

Link JS, et al. (2011) Ecosystem-based Fisheries Management in the Northwest Atlantic. 12 Fish and Fisheries; p. 152.

Lubchenco J (1994) The scientific basis of ecosystem management: framing the context, language, and goals. In: Zinn J, Corn DL, editors. Ecosystem management: Status and potential: 103rd Congress, 2d Session, Committee Print: U.S. Government Printing Office, Superintendent of Documents; p. 33.

Macpherson M (2001) Integrating Ecosystem Management Approaches into Federal Fishery Management through the Magnuson-Stevens Fishery Conservation and Management Act. 6 Ocean and Coastal Law Journal; p. 1.

Matulich S et al. (2007) Policy Formulation versus Policy Implementation under the Magnuson-Stevens Fishery Conservation and Management Act: Insight from the North Pacific Crab Rationalization. 34 Boston College Environmental Affairs Law Review; p. 239.

Maurer RO, Bowman RE (1985) Food Consumption of Squids (*Illex illecebmsus* and *Loligo pealei*) off the Northeastern United States. Northwest Atlantic Fisheries Organization, Scientific Council Studies, No. 9; p. 117.

McLeod KL, Lubchenco J, Palumbi SR, Rosenberg AA (2005) Scientific Consensus Statement on Marine Ecosystem-Based Management. Available at http://doc.nprb.org/web/BSIERP/EBM%20scientific%20statement.pdf.

Mid-Atlantic Fishery Management Council in cooperation with the National Marine Fisheries Service (2006) MAFMC – Evolution Towards an Ecosystem Approach to Fisheries (EAF). Available at http://www.mafmc.org/fmp/Ecosystem%20Report/Ecosystem%20Report.pdf.

Mid-Atlantic Fishery Management Council in cooperation with the National Marine Fisheries Service (2008) Amendment 9 to the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan. Vol 1.

Mid-Atlantic Fishery Management Council (2010) 2011 Atlantic Mackerel, Loligo and Illex Squid and Butterfish Staff ABC White Paper.

Mid-Atlantic Fishery Management Council (2012) Butterfish AP Informational Document.

Mid-Atlantic Fishery Management Council (2012) 2013 Atlantic Mackerel, Ilex, Longfin Squid, and Butterfish (MSB) OFL/ABC Recommendations.

Moustahfid H, et al. (2010) Functional Feeding Responses of Piscivorous Fishes from the Northeast US Continental Shelf. 163 Oecologia; p. 1059.

National Marine Fisheries Service (2012) Addendum to the Environmental Assessment for 2012 Atlantic Mackerel, Squid, and Butterfish Specifications and Management Measures. Available at http://www.nero.noaa.gov/nero/regs/frdoc/12/12SMB2012SpecsEA.pdf.

Northeast Fisheries Science Center (2010) 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Summary Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-01; 41 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/nefsc/publications/

Northeast Fisheries Science Center (2011) 51st Northeast Regional Stock Assessment Workshop (51st SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 11-01; 70 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/nefsc/publications/

National Marine Fisheries Service (2013) Northeast Region Bulletin: 2013 Atlantic Mackerel, Squid, and Butterfish Specifications (Issued January 15, 2013).

Pauly D, et al. (2002) Towards Sustainability in World Fisheries. 418 Nature; p. 689.

Pew Oceans Commission (2004) America's Living Oceans: Charting a Course for Sea Change. Summary Report. Arlington, VA, USA.

Pimentel MS, et al (2012) Impact of Ocean Warming on the Early Ontogeny of Cephalopods: a Metabolic Approach. 159 Marine Biology; p. 2051.

Ragozin DL, Brown G (1985) Harvest policies and nonmarket valuation in a predator-prey system. 12 Journal of Environmental Econonomics and Management; pp. 155-168.

Schaefer MB (1954) Some Aspects of the Dynamics of Populations Important to the Management of Commercial Marine Fisheries. Bulletin of the Inter-American Tropical Tuna Commission 1:2; p. 26.

Smith BE, Link JS (2010) The Trophic Dynamics of 50 Finfish and 2 Squid Species on the northeast US Continental Shelf. NOAA Technical Memorandum NMFS-NE-216.

Smith MD, Crowder LB (2011) Valuing Ecosystem Services with Fishery Rents: A Lumped-Parameter Approach to Hypoxia in the Neuse River Estuary. 3 Sustainability; pp. 2229-2267.

United Nations Environment Programme (1992) Convention on Biological Diversity. The 1992 United Nations Conference on Environment and Development. Rio de Janeiro, Brazil.

United Nations Environment Programme (1992) Rio Declaration on Environment and Development. The 1992 United Nations Conference on Environment and Development. Rio de Janeiro, Brazil.

United Nations Environment Programme (2012) The Future We Want. Outcome Document from the 2012 United Nations Conference on Sustainable Development. Rio de Janeiro, Brazil.

U.S. Commission on Ocean Policy (2004) An ocean blueprint for the 21st century. Final report of the USA Commission on Ocean Policy to the President and Congress. Washington, DC, USA.

Wang H (2004) Ecosystem Management and Its Application to Large Marine Ecosystems: Science, Law, and Politics. 35 Ocean Development & International Law; p. 41.

Wilen J, Brown G (1986) Optimal recovery paths for perturbations of trophic level bioeconomic systems. 13 Journal of Environmental Economics and Management; pp. 225-234.