## Abstract

Spiny dogfish (*Squalus acanthias*) is one of the most abundant species in the Northwest Atlantic however; the stocks collapsed in the late 1990s and were declared overfished April 3, 1998 by the Atlantic States Marine Fisheries Commission. Spiny dogfish have recently been declared recovered well ahead of the 15 to 20 year recovery time estimated by Atlantic States Marine Fisheries Commission, resulting in the methods of the Northeast Fishery Science Center's trawl survey to be questioned. Gillnets are widely used for fishing operations and assessments. This project was undertaken to determine the feasibility and estimate parameters for using gillnets to estimate abundances. The goals of this study were to determine the percentage of spiny dogfish vertically distributed above the fishing height of the NEFSC calibrated trawl survey and determine the catchability of spiny dogfish in a gillnet. The catchability of spiny dogfish in a gillnet was determined by multi-pass depletion sampling inside a corral net. The maximum efficiency was 8.6% with a 95% confidence interval of 5.8% to 11.3% during a 10 minute soak time. The minimum catch efficiency was 1.6% with a 95% confidence interval of 0.9% to 2.2%. Recalculated population estimates from a previous study using gillnets produced estimates between $3.87 \times 10^6$ and $9.09 \times 10^6$ metric tons of mature females, depending on the method of estimating catch efficiency used for coastal North Carolina waters. Catch efficiency was not affected by dogfish being tagged; tagged dogfish are captured at the same rate as untagged. A vertically elongated gillnet was used to estimate that the NEFSC is missing a minimum of 21.8 % (SD = 25.1%, Variance = 6.3) of the dogfish vertically suspended in the water column depending on water depth. The findings of this study indicate

that a large number of spiny dogfish may not be adequately sampled by the NEFSC calibrated trawl survey and supplemental sampling methods should be considered.

# Gillnet Calibration for Spiny Dogfish Abundance Assessment

A Thesis

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Masters of Science

by

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# Chapter 1: Introduction

## Fishery Background

The spiny dogfish (*Squalus acanthias)* is one of the most abundant demersal species in the Northwest Atlantic (NEFSC, 1994) and has been harvested commercially for more than 100 years (Ketchen, 1986). Commercial landings peaked in 1974 with 24,700 mt, declined to lower levels of 6,300 mt, then increased to a record high of 28,200 mt in 1996 (Sosebee and Rago, 2006). The spiny dogfish stock collapsed in the late 1990s due to overfishing (ASMFC, 2002). Commercial fisheries target large mature females, consequently creating a stock consisting of sexually immature females (Register et al., 2006).

On April 3, 1998, the National Marine Fisheries Service (NMFS) declared the stock overfished (ASMFC, 2002). Currently spiny dogfish stocks have recovered, thus resulting in higher commercial quotas (ASMFC, 2009). In the 2010/2011 fishing season the Atlantic States Marine Fisheries Commission (ASMFC) set the commercial quota at 6,795 mt (ASMFC, 2010); the 2011/2012 and the 2012/2013 fishing seasons commercial quotas were set at 9,060 and 13,590 mt, respectively (ASMFC, 2010; ASMFC, 2011). The ASMFC Spiny Dogfish Technical Committee and MAFMC's Monitoring Committee recommended a quota of 16,535 mt for the 2012/2013 fishing season, but concern from the fishing industry about the 75% increase in quota resulted in setting a lower quota of 13,590 mt (ASMFC, 2011). Members of the fishing industry felt the lack of cutting houses in conjunction with a large quota increase would cause a drastic decrease in prices. These quotas are a significant increase over the 1,812 metric ton quota set in place by the 1998 Fishery Management Plan (FMP). Under the original plan, trip limits were 136 and 272 kg depending on fishing period. Currently states have the ability to set their own trip limits to maximize the season and market price as needed by fishermen (ASMFC, 2011).

**Management**

Since implementation, the federal stock restoration plan for spiny dogfish as dictated by the Magnuson Fishery Conservation Act has become highly controversial. Both fishermen and scientists are questioning the effectiveness of the methods used to evaluate populations (Campana et al, 2008). Commercial and recreational fisherman believe that the population recovered and expandied at rates greater than the projected by NMFS Northeast Fisheries Science Center (NEFSC).

Spiny dogfish are currently managed by several different state, regional, and federal agencies and councils, including North Carolina Division of Marine Fisheries (NCDMF), Mid-Atlantic Fisheries Management Council (MAFMC), NMFS, Northeast Fisheries Management Council (NEFMC), and Atlantic States Marine Fisheries Commission (ASMFC). The NEFSC surveys the US East Coast stock in the spring and fall each year using a calibrated trawl survey to estimate the spiny dogfish population size (Rago and Sosebee, 2006), and these population estimates are used by ASMFC for management decisions. While quotas and stock assessments are managed at the federal level, the North Carolina Division of Marine Fisheries (NCDMF) manages the fishery at the state level by setting trip limits and monitoring the quota to ensure that North Carolina fisherman do not exceed their allotted limit (ASMFC, 2009;2011). The declaration of the spiny dogfish stock being overfished led to the development of a fisheries management plan (FMP) by the ASMFC. The spiny dogfish FMP was accepted in 1999 by the NMFS and implemented into action in 2000 (ASMFC, 2002). The purpose of this management plan was to reduce overfishing and fishing mortality and to design and implement management regulations, which could be used by management councils and state fisheries (ASMFC, 2002).

Regulations were kept at a minimum while setting forth uniform regulations for all states to keep impacts to other fisheries at a minimum. The goal of these objectives was to preserve the overall biodiversity and function of the ecosystem (ASMFC, 2002).

In November of 2005, Addendum I to the ASMFC spiny dogfish fishery management plan was adopted to address the problem of annual total allowable landings (TALs) being set only for one year, which made it hard for industry and fisherman to make long term investments. Under this addendum, the ASMFC Management Board can now adopt up to five years of TALs during any one year which allows fisherman to set plans and industry to adopt long-term marketing plans (ASMFC, 2005).

Addendum II was introduced to address concerns about the northern coastal states (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and Delaware) having the first opportunity to harvest fish. At that time, the fishing year began on May 1$^{st}$ during which most spiny dogfish had migrated northward. However, unlike the southern coastal states (Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida), spiny dogfish remain off the northern states for much of the year thereby allowing fisherman to harvest most of the quota before dogfish arrive in more southern states in the fall (ASMFC, 2008). Addendum II set forth three different management areas to manage the coastwide quota, with the quota distributed as follows: Northern Region 58% (comprising nine states), Southern Region 26% (comprising five states), and North Carolina 16% (ASMFC, 2008). This rectified the problem of northern states harvesting more than their historical catches.

Maryland and Virginia sought to separate from the regional allocation under which they were managed. This was addressed through Addendum III to the Spiny Dogfish Fishery Management Plan. Under Addendum II the allocations were Maine through Connecticut (five states) receiving 58%, New York through Virginia 26% (six states), and North Carolina 16%. Under Addendum III the allocations changed to Maine through Connecticut (five states) receiving 58%, New York 2.7%, New Jersey 7.6%, Delaware 0.9%, Maryland 5.9%, Virginia 10.8%, and North Carolina 14.0% (ASMFC, 2011). This was to allow states to manage their fishery to maximize it through adjusting trip limits and harvest seasons without fear that their allocation would be taken by more northern states as the stock migrated southward (ASMFC, 2011).

**Life History**

The spiny dogfish is typically found in coastal waters from Newfoundland to Georgia but also has been reported from Greenland in the north to Florida and Cuba in the south. The spiny dogfish is a long-lived coastal shark species. Most females mature between the ages of 12 and 26 years with a mean age to maturity (50% of the population) of 17.0 years (Jones and Ugland, 2001). This species is very susceptible to overfishing because of a long reproductive cycle of up to 24 months, which is the longest gestation period of any living vertebrate (Nammack et al., 1985). Eggs are fertilized internally: the male claspers are inserted into the female cloaca and sperm is released fertilizing those eggs >40 mm in diameter (Jones and Ugland, 2011). The spiny dogfish is an oviviparous species; eggs hatch within the uterus, and development continues internally without placental connection with the mother (Jones and Geen, 1977; Jones and Ugland, 2001; Sosebee, 2005).

Immature and smaller dogfish tend to be pelagic predators. After sexual maturity, diets shift to demersal and benthic species (Bangley, 2011). Dogfish are opportunistic feeders; their prey selection is based on abundance of prey rather than preference (Alonso et al., 2002). Bangley (2011) found that an ontogenetic dietary shift occurs at 600 – 650 mm total length (TL) when larger mature dogfish shift to a cooler, lower salinity, and shallower habitat. Dogfish may also have dietary differences based on sex, with females preferring teleost fishes and males preferring crustaceans (Bangley, 2011).

**Habitat**

Spiny dogfish school by size until they reach maturity, and afterwards they school by size and sex (Templeman, 1944; Jones and Geen, 1977; Silva and Ross, 1993; Rago et al., 1994; NOAA, 1999; Alonso et al., 2002). Dogfish located on the Scotian Shelf are found in bottom water temperatures ranging from 0°C to 12°C, but they tend to prefer 6-11°C. In North Carolina aggregations of spiny dogfish were found in temperatures of 10.4°C to 15.7°C south of Cape Hatteras (Rulifson and Moore, 2009). Dogfish inhabit a wide range of depths, being found at depths of 0 to 350 m, but more frequently found from 50 to 200 m (Campana et al., 2008). Spiny dogfish habitat selection (depth and salinity) varies by shark size and sex. Males occupy significantly deeper, higher salinity waters than females (Templeman, 1944; Jones and Geen, 1977; Silva and Ross, 1993; Rago et al., 1994; NOAA, 1999; Alonso et al., 2002). Mature female dogfish greater than 800 mm TL dogfish occupy near-shore, shallower, lower salinity waters than smaller dogfish (Shepherd et al., 2002). This makes it possible for singling out and exploiting the larger mature females. Females are targeted by the commercial fishing industry because they are the largest and easiest to obtain since they are located near inlets in shallower lower salinity areas. Larger females are the preference of the processing plants, because they yield more product with less effort (Register, 2007).

Spiny dogfish populations also exist in coastal waters in the Northeast Pacific, Japan, New Zealand, Argentina, and Europe in addition to the population in the Northwest Atlantic (Campana et al., 2008). While spiny dogfish are known to be a primarily demersal species inhabiting the waters along the continental shelf, there are some questions about habitat shift. Commercial and recreational fishermen are reporting abundances in areas south of Cape Hatteras, North Carolina a phenomenon that has not been previously reported. This is of particular concern due to spiny dogfish feeding habits (Bangley, 2011). The area currently sampled by the NEFSC for population estimates does not extend south of Cape Hatteras, North Carolina due to the design of the Calibrated Trawl Survey (ASMFC, 2002; Register et al., 2006; Register, 2007). Currently commercial fishing operations for spiny dogfish are active south of Cape Lookout, North Carolina, which is approximately 113 km south of Cape Hatteras, North Carolina (Red Munden and John Willis, NCDMF, Morehead City, personal communication). Dogfish are also regularly observed up in the water column to the surface (Dewey Hemilright, NC Commercial Fisherman, personal communication). These observations lead some fishermen and scientists to believe that dogfish abundance in the areas sampled by the NEFSC's Calibrated Trawl Survey may not be increasing at the same rate as the overall population. Fisherman believe that spiny dogfish may not be as demersal as once thought and may have shifted their niches in pursuit of prey or pupping areas.

**Problem**

Recently the methodology and effectiveness of the NEFSC trawl survey has been questioned by scientists and fishermen alike (Campana et al., 2008). At the time this project was undertaken, the stock was considered recovered to the population targets as set by the Federal stock restoration plan; even so, the NMFS has now declared that the stock is not overfished, and overfishing is no longer occurring (ASMFC and MAFCS, 2006). Fishermen and scientists are seeing dogfish in numbers not seen before in recent memory, but the trawl survey population estimates are not corresponding with what is being observed, especially with regard to juvenile dogfish.

Spiny dogfish are commercially harvested by gillnets and longlines, and as bycatch in trawls (ASMFC, 2002). All harvesting techniques are biased due to construction techniques and method of operation (Rudstam et al., 1984; Engas and West, 1987; Petitgas, 2001). Trawl catches give biased estimates of fish stocks when they are compared to gillnets (Olin et al., 2009). Currently, NMFS estimates that a very small percentage of the population is located in inshore waters. However, the NMFS calibrated trawl survey used for spiny dogfish population estimates does not sample inshore state waters (Register, 2007). In addition, the trawl cannot be used in shallow or rough-bottom waters (Backiel and Welcomme, 1980; Hjellvik et al., 2001) like the continental shelf, Carolina hard bottoms (e.g. Wimble Shoals), or around wrecks, where dogfish typically congregate (Register, 2007).

An alternative gear is needed supplement to the NEFSC trawl and other trawl surveys to present a more accurate population estimate for spiny dogfish. Trawl catchability can be low for large individuals (Bethke et al., 1999); larger individuals of a species may be able to avoid a trawl but not gillnets (Richardson, 1956). Maneuverability and swimming ability of a species may also enable it to avoid or escape a trawl (Olin et al., 2009); thus under-estimating the abundance of larger individuals. The lack of sampling in inshore waters leaves out the portion of the population that is congregated in near-shore state waters, where much of commercial fishery is based (Register et al., 2006 and Register, 2007).

In winter of 2006, East Carolina University sampled from a commercial vessel and estimated that an overwintering population of 65,635.47 mt existed in North Carolina waters alone (Register et al., 2006), which represented 61.9 % of the NMFS population estimate for mature females. Register's (2007) study was conducted using a shortened gillnet 45.72 m long of several mesh sizes set as a dip in coastal waters at one mile intervals for 10-minute periods. However, because the sampling area of gillnet influence was unknown (i.e., not calibrated), Register (2007) used a sensitivity analysis (i.e., best guess) to derive the population estimates. The sensitivity analysis was constructed in order to show different population estimates based on 100% of the fish captured within four different areas of linear influence from the gillnet: 9.14 m, 22.86 m, 45.72 m, and 91.44 m. This resulted in ultra-conservative estimates. Two previous ECU studies funded by the North Carolina Fishery Resource Grant (FRG) program estimated spiny dogfish sex ratios in North Carolina state waters of 10.4:1 and 19.6:1 female to male ratios (Register, 2007) in contrast to the NMFS trawl survey, which produced a ratio of 1:14 females to males for all (state and federal waters) NC sampling locations (Rago, NMFS, personal communication). However, NEFSC data show that that females make up 75% of the population closer to shore, which is similar ECU results that mature females make up a high percentage of the population in near-shore waters not sampled by the NEFSC's Calibrated Trawl

Survey (Newman et al., 2000; Rulifson et al., 2002; Rulifson et al., 2005; Rulifson and Moore, 2009).

One of the big NMFS concerns is the lack of pup recruitment; pup abundance in the current sampling is lower than that of the early 1990s (Rago, NMFS, personal communication). NOAA (1999) suggested that juvenile spiny dogfish obtain a larger portion of their prey from the pelagic zone than adults. This suggests that juvenile dogfish are more pelagic than adults (Jones and Geen, 1977; Alonso et. al, 2002). Due to the sampling methods by the NEFSC, the juvenile portion of the population may be minimally sampled due to the low trawl height compared to water depth since they are thought to be more pelagic.

I undertook the study described herein to provide information on differences in spiny dogfish catchability between a calibrated trawl and uncalibrated gillnets. Specifically, I used two different studies to determine gillnet linear influence, and the distribution and abundance of spiny dogfish vertically in the water column. Results were then extrapolated to previous studies in order to provide better interpretation of results related to population size.

**Hypothesizes and Objectives**

It is hypothesized that spiny dogfish populations are much larger than estimated by the NEFSC and Register (2007). Consequently, I believe that the NEFSC's Calibrated Trawl Survey does not sample a large enough portion of the water column or area of the continental shelf to accurately represent the spiny dogfish population. In addition, it is highly unlikely that Register (2007) caught 100% of the spiny dogfish within 22.86 m on either side of the test gillnet. It is also hypothesized that tagged dogfish are not recaptured at different rates than untagged dogfish.

The objectives of this study are:

Chapter 2:

1) Determine the percentage of spiny dogfish captured within 22.86 m of the gillnet with varying densities of dogfish.

2) Determine if tagged spiny dogfish are recaptured at different rates than untagged spiny dogfish.

Chapter 3:

1) Determine the percentage of spiny dogfish located above seven-feet in the water column.

2) Determine the percentage of spiny dogfish located above seventeen-feet in the water column.

3) Determine the vertical diel variability of spiny dogfish location in the water column.

Chapter 4:

1) Re calculate population estimates from Register (2007) using the linear equation derived in Chapter 2.

2) Recalculate population estimates from Register (2007) using the maximum catch efficiency from Chapter 2.

3) Estimate the percent error of our recalculated population estimates.

This work provides estimates and methods of estimating the number of spiny dogfish being missed by the NEFSC's calibrated trawl survey. Estimates of the percentage of spiny dogfish caught during a 10-minute soak of a gillnet with a known area and density had high variability and uncertainty. However, this is the first time anyone has attempted to estimate the actual percentage of fish a gillnet catches in a given area. The percentage of fish located above the trawl headrope height is important to managers since this had not previously been estimated. While actual estimates of the biomass of spiny dogfish overwintering in North Carolina waters have high variability they do provide insight into the number of spiny dogfish overwintering in North Carolina which were previously done by Register (2007) through a sensitivity analysis.

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Chapter 2: Gillnet Efficiency for Capture of Spiny Dogfish

## Abstract

Gillnets are widely used for commercial fishing, surveying fish populations as well as being used by recreational fisherman. However, gillnets are a passive gear hence their effectiveness relies on the morphology and activity of fish to be entangled in the net. Their efficiency and selectivity can also be manipulated by altering the hanging ratio, mesh size, and twine size. Environmental factors such as turbidity, gear saturation, water flow, water temperature, and time of day have also been documented to affect gillnet efficiency. The goal of this portion of my study was to determine the percentage of spiny dogfish caught in a given area with my test net, using 10-minute soak times while varying the densities. This was completed using a depletion type study. I found the maximum catch efficiency to be 8.6% with a 95% confidence interval of 5.8% to 11.3% during a 10-minute soak. The minimum catch efficiency was 1.6% with a 95% confidence interval of 0.9% to 2.2%. These findings support the hypothesis that the catch percentage is effectively much lower than 100% within 22.86 m of the test gillnet, using a 10-minute soak time. I also investigated whether spiny dogfish tagged with Floy SS-94 single barb dart tags were recaptured at rates different than untagged spiny dogfish. Using a t-test ($p = 0.63$) and a Wilcoxon Signed-Rank test ($p = 0.37$) I found that tagged and untagged spiny dogfish were not recaptured at significantly different rates.

## Introduction

Gillnets are used to harvest fish both recreationally and commercially as well as by researchers to track abundances and trends. In North Carolina gillnets are used by commercial fishermen for a variety of species that range from the smallest of inshore species to sharks (Dewey Hemilwright, Commercial Fisherman, Personal Communication). Recreational fishermen also use gillnets to harvest fish with a commercial recreational gear license (CRGL) within their conventional recreational bag limits (NCDMF, 2005). The North Carolina Division of Marine Fisheries (NCDMF) uses gillnets of various sizes and configurations to assess fish populations. These gillnets are regularly used to estimate species abundances and track trends (NCDMF, 2005).

Gillnets are a passive gear type, which means a fish has to actively encounter a gillnet under its own power thus limiting efficiency (Prchalova et al., 2009). In addition, the body shape and characteristics, swimming speed, and swimming distance influence the probability of a fish to encounter and be retained in gillnets (Olin and Malinen, 2003). Several other factors could potentially influence gillnet efficiency: visibility, turbidity, water flow, twine size, mesh size, hanging ratio, gear saturation, water temperature, and time of day (Hamley and Regier, 1973; Hamley, 1975; Hansson, 1988; Hansson and Rudstam, 1995; Trent et al., 1997; Reis and Pawson, 1999; Olin et al., 2004). The turbidity of the water can have a significant impact on the visibility of gillnets to fishes; as turbidity increases and visibility decreases the ability of dogfish to detect and avoid the net should decrease (Olin et al., 2004). Water flow can have an impact on whether and how a fish encounters gillnets. Water currents can also influence how fish encounter or avoid gillnets, by pushing them into the net or pulling them away from it. Also, water currents can push the gillnet causing it to lay out flat, or become bunched, entangled, or slack (Dewey Hemilwright, Commercial Fisherman, Personal Communication). Twine size affects the catchability of fish in a gillnet in different ways. A smaller twine size is more effective in entangling fish, but does not retain them as well as larger twine sizes (Hamley, 1975). Hang ratio also has an effect on the efficiency of the net. Different hang ratios catch fish with different body forms at different rates (Hamley, 1975; Machiels et al., 1994; Reis and Pawson, 1999).

Gear saturation is a concern with any type of sampling gear; as the number of fish retained in the gear increases, the potential to capture additional fish decreases (Hamley and Regier, 1973; Hamley, 1975; Olin et al., 2004). Water temperature also has an effect on the activity of fishes; lower temperatures decrease the catchability of fish in gillnets (Hansson and Rudstam, 1995). Many fish species are known to have diurnal migration behaviors; fishes might be more active at certain times of the day and even exhibit vertical migration, which would affect their susceptibility to gillnet capture (Hansson and Rudstam, 1995).

While gillnets have been used to track trends and abundances as well as many estimates of efficiency, my searches found very little information on the actual percentage of the fish population a gillnet catches within a given area and time. Prchalova et al. (2009) noted that the best condition for studying gillnet selectivity is to sample known populations but it is expensive and hard to complete. Multi-pass depletion sampling has been used to determine catch rates of different types of gear. Jellyman et al. (1999) found that multi-pass sampling was necessary to determine efficiencies of electro-shocking for eels. Multiple Capture Procedure is common for estimating abundance at a single site by removal sampling, in which fish are repeatedly removed from a closed population without replacement using a constant effort on each pass of a net or electrode (Wyatt, 2002). These multi-pass and multi-capture sampling techniques both use the same basic principles to assess populations based on the percentage of fishes that are removed from an enclosed area. This gives an estimate of the catchability of a species.

This portion of my project was designed to answer questions on the catch efficiency of gillnets for spiny dogfish. In 2006, East Carolina University performed an area density population estimate based on using the same 10- minute soak times and the same net as my test net used in the current study (Register et al., 2006; Register, 2007). The 2006 study used a sensitivity analysis that assumed 100% catch efficiency at distances of 9.14 m, 22.86 m, 45.72 m, and 91.44 m on either side of the sampling net (Register et al., 2006; Register, 2007). While a sensitivity analysis is useful when making assumptions about the efficiency of gillnets, there is no information or confidence in the estimates.

Acoustic tags are a newer method in assessing fish populations when compared to conventional methods (Restrepo, 1996). The main advantage of acoustic tags is their ability to collect location information without the recapture or harvest of the fish (Heupel et al., 2006). Acoustic receivers continuously monitor for tagged fish and record the detection of a fish near the receiver (Restrepo, 1996). However, a main disadvantage of acoustic tagging is the high initial cost of purchasing receivers and the subsequent cost of additional acoustic tags. Acoustic tags also have a limited battery life, which is affected by water temperature, size, ping intervals, and power output (Vemco, personal communication). Migratory species also present a problem when using acoustic tags (Vemco, personal communication). A migratory fish may have a large range and not encounter a receiver during the life of the tag.

Conventional tags provide a low cost (~$1.00 each) method for conducting tagging studies but only provide information at the time of initial tagging and subsequent recapture. Other advantages of conventional tagging are no equipment upkeep, non-surgical implantation, and no manpower to monitor. Conventional tagging also allows for detection over a large area that cannot practically be covered by acoustic tagging methods. Reporting, tag retention, tag detection, angler behavior, catchability, and recapture all present problems in quantifying conventional tagging studies (Donnelly and Vaske, 1991). Reporting rates are commonly low and require the cooperation of fisherman; monetary rewards and public perception have effects on reporting rates (Meyer et al., 2012). The reporting of a tag requires the cooperation of both commercial and recreational fishers. A successful tag return requires harvest of the fish, tag detection, and subsequent reporting of the tag (Donnelly and Vaske, 1991). Consequently, presence of a tag can also affect angler behavior (Donnelly and Vaske, 1991); i.e. some anglers may choose to selectively harvest tagged fish or selectively release tagged fish. This behavior will subsequently affect mortality rate estimates (Donnelly and Vaske, 1991). Tag retention is an area of concern in a conventional tagging study because tag retention can affect reporting rate estimates (Ramstad and Woody, 2003). Tag shedding rates are unknown for some species but it is presumed to be low based on estimates from other studies (Barrowman and Myers, 1996). Furthermore, the recapture of fish may be difficult in areas of low fishing pressure, which may subsequently affect assumptions about migration. The recapture of a fish requires that individual fish are selected by a piece of gear (i.e., biting a fishing hook, trawl, or gillnet recapture). Little is known about what influence tags may have on a fish's ability to be recaptured due to tag entanglement in gillnets; it is assumed by Myers and Hoenig (1997) assumed that spaghetti tags do not affect gillnet selectivity. Therefore, my study also investigated the “catchability” of tagged verses untagged fish in gillnets to determine if tags influence catchability of spiny dogfish.

## Materials and Methods

A "corral" was constructed southwest of Roanoke Island, North Carolina, between Roanoke and Croatan sounds , at latitude 35° 48'14.62 N and longitude 75° 37" 51.50 W (Figure 1) to hold dogfish for the study. The area was approximately 3.6 m (12-ft) deep with a sandy mud bottom.

Salinity averaged ~ 16 ppt but was variable due to its close proximity to the Albemarle Sound, Croatan and Roanoke Sounds, Pamlico Sound and Oregon Inlet. In addition, the area was located on the southwest side of the island where it was very susceptible to winds and currents.

The corral was framed by driving 6.1 m (20-ft) long sections of 2.5x2.5 $cm^2$ ($1x1in^2$) square tubing in the shape of a square 45.7x45.7 m (50x50 yd); the tubing was spaced every 6.4 m (7 yd). A special 4.3 m (14-ft) high and 192 m (210-yd) long gillnet was used to surround the framing. The framing net was constructed of # 12 (57-mm) monofilament with 63.5 mm (2.5-in) stretch mesh. The framing net had a double lead line to keep it in constant contact with the bottom, and large floats on the top line at the surface of the water. The framing net was wrapped around the outside of the frame and fastened at every tube section. The two ends of the net were overlapped and fastened together so that no fish could escape from where the net was joined. The 45.7 x 45.7 m (50 x 50 yd) dimensions created a "corral" that enclosed an area of 2090.3 $m^2$ (2,500 $yards^2$).

The commercial vessel F/V Tarbaby was used to collect test spiny dogfish in the coastal Atlantic Ocean by long-line to eliminate the possibility of gillnet avoidance or gillnet affinity by the test animals. Dogfish were immediately placed in live wells onboard the vessel to keep them in good condition, and they were then transported in aerated live wells to the test location.

Three gillnet catch depletion trials were conducted by adding a known number of longline-caught dogfish of known sex and length to the corral. Dogfish dorsal fins were marked using a standard hand-held paper hole punch. Dogfish added for Trial 1 received no markings on the dorsal fin. Dogfish added for Trial 2 received one hole in the dorsal fin, and those added during Trial 3 received two holes in the dorsal fin. Fifty-five spiny dogfish were tagged in each trial with Floy SS-94 single barb dart tags applied with a canula adjacent, but just below and posterior to, the origin of the first dorsal fin.

For the three depletion experiments I chose a minimum value of 106 spiny dogfish, which was the maximum number of dogfish captured by the Register et al. (2006) study using a 50-yd net in 10-minute sets (Table 1). Depletion trials 1- 3 had 106, 128, and 124 spiny dogfish added to the corrals which were mostly females. Lengths across depletion trials ranged from 211 to 1,030 mm TL (Table 1 and Figure 2). In contrast the 211 mm TL dogfish was abnormally small with the next smallest dogfish measuring 598 mm TL Figure 2.

Ten spiny dogfish were fitted with Vemco (V-16) acoustic transmitters, and then tracked with a VEMCO 100 acoustic receiver to ensure that the fish were acclimated and active within the corral. In addition, fish were observed freely swimming around the corral, swimming near the surface and then descending towards the bottom. Fish quickly acclimated to the corral so sampling commenced shortly after adding the test specimens.

The test experimental gillnet was identical to that used in the Register et al. (2006) study: 45.72 m (50 yards) long with one section 22.86 m (25 yards) long of 11.43-cm stretch mesh, and a second section 22.86 m long of 13.97-cm stretch mesh. The test net was designed to extend from one side of the corral to the other. The gillnet was deployed from a 24-ft skiff down the middle of the corral, thereby bisecting it into two halves 22.86 m in width between the test net and the side of the corral (Figure 3). The assumption was made that fish would behave in one of two ways: they would either encounter the net and become entangled, or encounter the net and avoid it. It was hypothesized that fish would avoid the test gillnet by going over or under the test net, or encountering the test net and turning away. This assumption is similar to what would happen in the wild, outside of the corral net.

This depletion type experiment involved setting the test net within the corral for 10 minutes, removing it, counting the catch by sex, measuring each fish (TL, mm), recording whether the fish was tagged, and then the animal was released outside of the corral. This procedure was repeated for a total of 15 net sets or until three consecutive catches of zero occurred; the maximum number of sets was 15 per trial. When depletion was reached, the test gillnet was then set overnight to determine the number of dogfish that were remaining in the net, assuming all others had escaped. This provided a baseline number of dogfish that remained in the corral overnight to determine my maximum catch efficiency and account for escapement.

## Analysis

The average percentage of fish caught was calculated by two different methods. The first method calculated a conservative estimate of the total number of fish captured by assuming that no fish escaped the corral; this number will be referred to hereafter as the "Minimum Catch Efficiency." The second method assumed fish escapement, and was modified by using the overnight catch as the remainder of the fish in the net (i.e., fish not captured by the overnight net set had escaped); this number will be referred to hereafter as the "Maximum Catch Efficiency". All test net sets for each trial were added together to calculate the average percentage of fish captured with each set of the net to determine maximum catch efficiency and minimum catch efficiency. The mean percentage of fish caught in each net set was calculated as:

Confidence intervals were used to account for variance in individual net sets and the average percentage caught.

A density dependent model was used to account for gear saturation and behavior difference based on decreasing density as the number of fish in the corral was depleted. The number of fish caught was plotted against the density in the net. This was used to formulate a linear equation to calculate the number of fish in an area based on the number caught.

The mean length of the longline-caught dogfish before adding to the corral was compared to the dogfish captured during the trials (dogfish recaptured) using a means t-test and a Wilcoxon Signed- Rank test to ensure that the selectivity of the test net was not affecting catchability based on fish size. These comparisons were completed to ensure that selectivity differences between longline and gillnet did not affect my results.

**Results**

As expected, the multi-pass sampling technique resulted in lower catch rates as the population inside the corral was depleted. Trial one was completed but not analyzed since no fish were recaptured during the trial. Trial two showed a downward trend in catch rate ($R^2$ = 0.49) with the trendline intersecting zero percent on the 15$^{th}$ haul (Figure 4). Trial three resulted in a very slight downward trend ($R^2$ = 0.03) but the trendline did not intersect the zero percent on the 15$^{th}$ haul; haul 12 – 14 all had catches of one dogfish (Figure 4). Resulting in the percentage caught in hauls 12 – 15 to increase due to the catch remaining one while having less fish in the corral.

The test net fished at much lower efficiency than the 100% assumed by Register et al. (2006). The test net fished at a maximum catch efficiency of 8.6% with a 95% confidence interval of 5.8% to 11.3% during a 10-minute set, when overnight sets were used to adjust for escapement. The minimum catch efficiency (assuming no escapement) was 1.6%, with a 95% confidence interval of 0.9% to 2.2%. Mean size of dogfish added to the corral and the mean size of dogfish recaptured in the test net were compared for statistical difference due to potential gear bias. The longline-captured dogfish added to the corral had a mean total length (TL) of 835.7 mm, and the fish gillnet recaptured had a mean total length of 830.05 mm (Figure 5). A means t test produced a t statistic of -1.29 (df = 85) resulting in p = 0.198. In addition a Wilcoxon Signed-Rank test resulted in a two-sided p = 0.06. Therefore, there was not a significance in bias of the gillnet catchability with the randomly collected individuals used in the experiment.

The density present in the corral and the total number caught during each replicate during the depletion study were used to develop the linear regression equation:

Density per 2090.3 $m^2$ (2,500 $yd^2$) = 0.0081524 + 0.0012853 * number captured (Figure 6).

Projections of estimated dogfish densities were created using the aforementioned linear regression equation (Figure 6) and are demonstrated in Figure 7 and *Table 2*.

Length distributions for tagged dogfish compared to untagged dogfish added to the corral were not significantly different (Figure 8); p values were 0.40, 0.67, and 1.00 respectively for Trial 1, Trial 2, and Trial 3. A Wilcoxon Signed-Rank test was also used to compare the length distributions resulting in p values of 0.49, 0.75, and 0.75 respectively for Trial 1, Trial 2, and Trial 3. All three trials combined resulted in a p value of 0.63 when tagged verses untagged individuals when compared using a t-test. In addition, a Wilcoxon Signed-Rank test was also used to compare tagged verses untagged individuals combined from all three trials resulting in a two-sided p value of 0.37. Untagged spiny dogfish (n=193) had a mean TL of 834.52 mm, ranging from 598 – 1,030 mm compared to tagged spiny dogfish (n=165) had a mean TL of 837.20, ranging from 211 – 961 mm (Table 3 and Figure 9).

No significant difference in the percentage of tagged verses untagged individuals caught was detected in the study. The catch percentages of untagged fish compared to tagged fish were not statistically different, resulting in a p value of 0.494. The catch percentage of tagged fish that were recaptured during the depletion experiment ranged from 0.0% to 7.3% with a mean of 1.7% and a 95% CI of 0.8% - 2.5%. Untagged fish catch percentage ranged from 0.0% - 8.7% with a mean of 1.4% and a 95% CI of 0.6% - 2.1%.

**Discussion**

This study combines the findings of Prchalova et al. (2009), which stated that a known population is the best condition for studying gillnet selectivity, and Wyatt's (2002) multi-capture procedure. This type of depletion experiment is not uncommon to assess fish populations. It was defined by Wyatt (2002) as a multi-capture procedure, which is common for estimating abundance at a single site; fish are repeatedly removed from a closed population without replacement using a constant effort on each pass of a net or electrode. Jellyman et al. (1999) also used this type of experiment using electro-fishing.

My findings were consistent with our hypothesis that the catch efficiency would be much lower at 22.86 m on each side of the test compared to the 100% that was assumed in the sensitivity analysis from Register (2007). My estimate using all dogfish added to the corral (minimum catch efficiency) was significantly lower than the estimate that did not use all of the fish (maximum catch efficiency), which supports the hypothesis that fish did in fact escape during the experiment, or were not susceptible to gillnet capture. The minimum catch efficiency estimate using all of the fish added to the corral, was 1.6% with a 95% confidence interval of 0.9% to 2.2%. The maximum catch efficiency estimate (8.6% with a 95% confidence interval of 5.8% to 11.3%) using only fish recaptured from the corral during the depletion hauls or the overnight sets was higher. Although the overnight sets were used to enumerate fish that were assumed to still be in the corral, it is possible that not all fish were captured during these overnight sets. Overnight sets were done to ensure a baseline number susceptible to gillnet capture and to account for escapement.

It is highly unlikely that the overnight set removed all of the fish from the corral or that no fish escaped. Using the minimum catch efficiency and maximum catch efficiency estimates I am confident that on average no less than 0.9% of the fish or that no more that 11.3% of the fish were caught with a single set of the test net. Therefore, I estimate that the true catch efficiency lies somewhere between 0.9% (lower 95% CI of my minimum catch efficiency) and 11.3% (upper 95% CI of my maximum catch efficiency number. However, it is hard to estimate exactly the tru value since we do not have an exact estimate of escapement.

During trial one of the three trials, high winds and rough seas prevailed overnight; no fish were caught from the first batch of fish added on the first day of sampling and only one fish from this batch was caught in subsequent trials. Most likely currents lifted the net off the bottom allowing for dogfish to escape under the sides of the “corral”, but fish from prior trials of fish added were captured in the subsequent trials. From this I assume the overnight sets did not remove all of the remaining dogfish from the corral; but what percentage is unknown.

Gear saturation is a concern and it is hard to estimate the point at which the gear declines in ability to capture fish. A longline type gear might be easier to estimate saturation. If you were to set 100 hooks and in 10 minutes you caught 50 fish, you would know the gear was 50% saturated after 10 minutes. For my experiments I chose to place no less than 106 dogfish in the corral to start each trial. This number was chosen because it was the maximum number of dogfish caught in Register et al. (2006) study. I made the assumption that 106 fish was saturation due to that being the maximum number captured during the 10 minute soak times of the test net.

Register (2007) made the assumption that 100% of the fish within 22.86 m (25 yards) on either side of the test net were captured. To refine this estimate I hypothesized that the maximum number of fish in my corral enclosure should correspond with maximum catch in the net from Register et al., (2006). This situation never occurred, and the highest percent of catch reached only 27.8%. I feel that the number of dogfish added to the corral was not sufficient enough to produce the densities needed to catch 106 spiny dogfish in a 10-minute soak.

I created a density dependent model to factor in for gear saturation. This density model was produced using JMP, to project the density and number of fish per 2090.3 $m^2$ based on the catch number. However, the accuracy of this equation is questionable due to the limited sample size and relatively low catches. This is expressed by Figure 7 and Table 2. The bivariate fit equation was used to account for differences in density and gear saturation instead of just using the average percentage of fish caught in each set of the net. The density equation adjusted for changes in density, where the overall percentage would not adjust for changes. However, due to the low catch numbers per set, the confidence interval of the density (number of fish in 2090.32 $m^2$) increases as the number caught increases. The increased variability associated with the increased number of fish caught using the density dependant model would make the model unfit for estimating large catch numbers. Approximately 1,235 fish would have been needed in the corral net to produce a catch of 106, using the average catch percentage of 8.6%. However, using the density equation only 302 would be needed to produce the catch of 106 fish which was the maximum catch in the Register's (2007) study. This leads me to believe that the density in my corral net was not high enough to accurately represent the higher catch numbers encountered in Register (2007). With five fish being caught using the density equation, a total of 30 fish would be present in the 2090.32 $m^2$ corral. This would be a catch rate of 16.7%. If

10 fish were caught there would be 44 fish present in the 2090.32 $m^2$ corral, which results in a catch rate of 22.7%. Ten fish was the highest number of fish caught in the test net during my study, which is too low to accurately project catches out to 106 fish using the density equation. The rate of fish capture greatly decreases as the catch number goes up using the density equation, which is likely a misrepresentation of the data since I did not have enough catches over 10 to accurately project number of fish in 2090.32 $m^2$ based on the number caught in the test net. However, it is also possible that this is not a misinterpretation since catchability is known to decrease with gear saturation. I do not believe this to be the case since my catch numbers were so low.

These results provide useful tools for estimating abundance of spiny dogfish in areas currently not sampled by the National Marine Fisheries Service, by using gillnets to predict the number of dogfish in a given area based on the catch within an area. It is unknown what the effects of corralling the fish actually had on the catchability, however, due to the large size of the corral it is assumed that they behaved normally other than being restricted from leaving the corral. It is known that fish activity and behavior can have an impact on a passive gears catches (Rudstam et al., 1984) nevertheless I do not believe fish behavior its self was affected by the study design.

A low number of both untagged (n = 27) and tagged (n = 25) dogfish were recaptured from the corral during the study compared to 193 untagged and 165 tagged dogfish added to the corral. Dogfish recaptured with no visible tag present showed no signs of tag loss, which supports no immediate tag loss (Rulifson, 2007). However, the short duration of this study may not have provided adequate time for the tag to be shed. Recapture rates of tagged and untagged dogfish and total lengths of recaptured tagged and untagged dogfish were not significantly different. Meaning it is highly unlikely that the Floy SS-94 single barbed dart tags, which are commonly used to tag dogfish, have an effect on catchability. These tags are constructed of a plastic single-tipped dart with a plastic-covered braided stainless steel wire (Rulifson et al. 2006; Rulifson 2007). The dart tag is flexible, easily bent, and would provide little resistance if entangled in a net. For this reason dart style spaghetti tags are not likely to increase the catchablity of a dogfish in a gillnet. In comparison a button tag, which is currently being used in dogfish tagging studies by NMFS, may cause higher entanglement. Button tags are hard round or rectangular flat disks affixed close to the body in which multiple strands of gillnet could become entangled or wrapped around the tag. Button tags used on flounder aid in the entanglement by adding a hard structure in which webbing can be entangled in addition some flounder were entangled by only their button tag (Chris Braddy, NCDMF, personal communication). The findings of this study suggest no conversion factors should be used to adjust for recapture rate differences of dogfish tagged with Floy SS-94 single barb dart tags, which is consistent with Myers and Hoenig (1997)'s findings that spaghetti tags do not affect the catchability of fish.

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## Chapter 3: Vertical Distribution of Spiny Dogfish


### Abstract

Spiny dogfish (*Squalus acanthias*) have long been thought to be a demersal fish species which is surveyed annually by the North East Fishery Science Center's (NEFSC) Calibrated Trawl Survey. The NEFSC's calibrated trawl survey currently uses a new four-seam trawl that samples 0 – 5.2 m of the water column compared to the yankee-36 trawl which was previously used and sampled from 0 – 2.1 m of the water column. It has been noted that gillnets are an important tool in assessing diurnal, seasonal and vertical distribution of fish, dating back to 1955. Commercial fishermen suggested that spiny dogfish might tend to be demersal but may also be vertically suspended throughout the water column. This goal of this portion of my thesis was to determine the percentage of spiny dogfish suspended in the water column from 0 – 2.1 m, 2.1 – 5.2 m, and 5.2 – 10.0 m for both inshore and offshore areas of the continental shelf. I found that 48.8%, 29.4%, and 21.8% of the spiny dogfish caught in inshore areas were in the bottom panel (0 -2.1 m), middle panel (2.1 – 5.2 m), and top panel (5.2 – 10.0 m) respectively. Similarly, I found that the offshore areas had 45.2%, 33.0%, and 21.8% of spiny dogfish caught in the bottom panel (0 -2.1 m), middle panel (2.1 – 5.2 m), and top panel (5.2 – 10.0 m) respectively. My findings were not consistent with what you would expect from a demersal fish species, however, spiny dogfish do tend to congregate near to the bottom. Furthermore, my results show that the NEFSC's calibrated trawl survey using the new four-seam trawl could be missing 21.8% of the spiny dogfish population.

## Introduction

Gill nets are routinely used in population assessments by fisheries managers (Hansson and Rudstam, 1995; Hansson, 1988; Dergerman et al., 1988). Gillnets are a passive type of fishing gear used by scientists and both commercial and recreational fisherman due to their effectiveness in catching fish. As a passive gear, catches depend on a fish's behavior more specifically its activity (Rudstam et al., 1984). A fish must actively swim into the gill net and become entangled.

Vertical gillnets have been used in several different studies dating back to Wisby, 1955 in which he found that vertical gillnets were useful to assess differences in the vertical distribution of fish species. Vertical gillnets are an important tool in assessing diurnal, seasonal, and vertical distribution of fish (Leik, 1960; Hartman, 1962; Vašek et al., 2009). However, most vertical gillnet studies are in freshwater environments or areas with little current and a constant depth (Hansson, 1988).

Spatial, temporal, and diurnal patterns are important for assessing fish populations. It is hypothesized that spiny dogfish will exhibit vertical migrations in the water column and are not as demersal as previously thought. The Northeast Fishery Science Center (NEFSC) Calibrated Trawl survey conducted each fall and spring does not take into account changes in vertical distribution (ASMFC, 2002). Reliability of such survey indices depend on the stability of the bias caused by vertical distribution between surveys (Algen et al., 1996). Spiny dogfish have been observed at or near the surface during both night and daytime hours (Diadorrio, East Carolina University, personal communication; Dewey Hemilwright, Commercial Fisherman, personal communication).

Bottom-trawl surveys do not sample the complete water column. Fish distributed close to the bottom are susceptible to capture by a bottom trawl, while fish distributed higher up vertically in the water column become less susceptible (Algen et al., 1996). Algen et al. (1996) also points out that the two types of density estimates may be affected by variation in the vertical density of fish over an area. Vertical distribution of fish is mainly affected by the density of fish and depth; diel effects on surveys may not be significant (Godo, 1994). Some fish species also tend to aggregate more during daylight hours than nighttime hours (Boudreau, 1992). These factors may lead to higher catch rates during the day due to a herding effect of the net as opposed to nighttime hours when the fish may be more evenly dispersed (Wardle, 1993).

The goal of this portion of my thesis was to test the hypothesis that spiny dogfish do inhabit the water column and are not as demersal as previously reported. As a result they may not be as susceptible to capture in traditional (bottom) gillnets used in the dogfish commercial fishery or by bottom trawls like the ones used by the federal government in their survey work. I was interested in fish size differences as a function of position in the water column, and diel changes in abundance of fish caught in the net which has been reported for other fish species. Sims et al., (2006) reported that diel vertical migration is a widespread phenomenon marine organisms and more specifically *Scyliorhinus canicula*, a relative to spiny dogfish.

**Materials and Methods**

The Study Area covered a large area ranging from 35° 24’ 7.78” N to 36° 3’ 3.60”N and 74° 49’ 20.39” W to 75° 38’ 6.58” W (Figure 10). This area incorporated near-shore coastal waters and waters out to the continental shelf break with depths ranging from 11.8 m to 101 m. The mean sample depth was 37.4 m with an inter quartile range of 21.0 m to 45.3 m. Bottom substrates in the sample area included live bottom areas, muddy bottoms, sandy bottoms and areas around structure. The F/V Tarbaby was used to set a vertically elongated gill net of several mesh sizes in inshore and offshore locations during both day and night.

The relative abundance of spiny dogfish was assessed throughout the water column using a vertically-elongated gillnet constructed of #177 monofilament webbing hung at a 2:1 hanging ratio. Three 47.2-meter sections of net were used: The first section of 7.62 cm stretched mesh (CSM); the second of 11.43 CSM; and the third of 13.97 CSM. Each 47.2-meter panel was constructed of two 5.0-meter high sections of net fastened together using a polypropylene rope for support (Figure 11). The polypropylene rope was hung in the middle of the two sections using traditional net making methods to create a net 10.0 meters tall and 137.2 meters long.

The bottom gillnet panel spanned 0 -2.1 m from the bottom to collect fish susceptible to the old NEFSC trawl survey, which used a calibrated trawl net with a 2.1-m tall head rope pulled by the R/V Albatross. A second gillnet panel 2.1 – 5.2 m from the bottom represented a newer calibrated trawl design used by the R/V Henry Bigelow in the NEFSC trawl survey (Figure 11). The top panel (5.2 – 10.0 m) represented all fish present in the water column above the Bigelow trawl headrope up to 10.0 m from the bottom.

Vertical net panels were separated by two different methods. The bottom panel (0 – 2.1 m) was colored using net dye. The 2.1 – 5.2 m panel was not dyed and was divided from the 5.2 – 10.0 m panel by the rope joining the two 5.0 m vertical panels together. The vertical height of 10.0 m was chosen because of limitations imposed by commercial webbing dimensions and concern for deployment and retrieval issues

An Oceanic Geo dive computer affixed to the end of the gillnet was used to measure the gillnet sink rates. The Oceanic Geo is a water activated dive computer and starts logging dive (net-sink) time once it is deployed and enters the water. The dive computer was zip tied and taped to the top line of the vertically elongated gillnet such that the water and pressure sensor was left exposed. The average time to sink to 30 feet was calculated and the average sink time per foot was calculated. The gillnet had an average sink rate of 0.93 feet per second. Table 3. Number, minimum total length (TL), max TL, mean TL, and SD in (mm) of tagged and untagged longline caught spiny dogfish which were used for the three depletion experiments. N = 106 was chosen due to being the maximum catch in the test net in previous studies.

| | N | min TL (mm) | max TL (mm) | mean TL (mm) | SD (mm) |
|---|---|---|---|---|---|
| Trial | | | Tagged | | |
| 1 | 55 | 211 | 940 | 837.62 | 55.30 |
| 2 | 55 | 682 | 961 | 818.40 | 59.88 |
| 3 | 55 | 671 | 929 | 855.56 | 47.93 |
| Total | 165 | 211 | 961 | 837.20 | 56.35 |
| Trial | | | Untagged | | |
| 1 | 51 | 645 | 1,030 | 824.32 | 107.96 |

| | | | | | |
|---|---|---|---|---|---|
| 2 | 73 | 598 | 995 | 822.03 | 72.75 |
| 3 | 69 | 691 | 1,004 | 855.12 | 57.46 |
| Total | 193 | 598 | 1,030 | 834.52 | 80.00 |

Table **4** was created from the average sink rate to determine the net set time for various depths. The target bottom time was 10 minutes from the estimated time it settled on the bottom.

Research was completed aboard the F/V Tarbaby, a 42 foot longline and sink net vessel. The F/V Tarbaby was equipped with a hydraulic net reel and a goal post type net guide system equipped with bearing rollers. The vertical gillnet was deployed from the rear of the vessel using a runoff method in which the boat pulls forward setting the net in a quick manner, taking only a few moments to deploy a 137.2 meter net. Once deployed, the net was set for a 10-minute bottom soak time; depth was estimated by a Furuno color sounder and Table 3. Number, minimum total length (TL), max TL, mean TL, and SD in (mm) of tagged and untagged longline caught spiny dogfish which were used for the three depletion experiments. N = 106 was chosen due to being the maximum catch in the test net in previous studies.

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| 3 | 69 | 691 | 1,004 | 855.12 | 57.46 |
| Total | 193 | 598 | 1,030 | 834.52 | 80.00 |

Table **4** was used for the corresponding net set time.

During retrieval, each dogfish was removed from the net during the retrieval process and placed in labeled totes corresponding to the panel in which they were removed. Each fish was then removed from the totes, sexed, and measured (TL, mm).

Each data sheet included the date, haul number, depth (m), time, salinity (ppt), temperature (°C), and GPS coordinates. The depth and time were recorded from a Furuno chart plotter and depth sounder. Salinities (ppt) and water temperatures (°C) were measured at 1.8-m using an YSI Model 85 multimeter.

A total of 80 gillnet sets being were set in federal and state waters (

Table 5). These sets were made over seven working days during both nighttime and daytime hours. Depths less than 25 m were considered inshore, and depths equal to or greater than 25 m were considered offshore. Time was separated into four periods of six hours each: 0001 – 0600 hrs, 0601 – 1200 hrs, 1201 – 1800 hrs, and 1801 – 2400 hours, respectively. Of the 80 sets, 29 were made in inshore waters (< 25 m) and 51 were made in offshore waters (>25 m). Number of sets was evenly distributed among the periods, with the exception of the 0100-0600 period (

Table 5).

**Analysis**

Proportions of the dogfish catch located in each panel of the net by time period and location (inshore vs offshore) were calculated using SAS. An ANOVA was used to test for significant difference of the percent of dogfish in each vertical section of the vertically elongated gillnet. The variability was tested by both vertical panels and inshore or offshore locations as defined above.

I calculated the p based on the assumption that for every additional 4.9 m above the 10.0 m height of the vertically-elongated gillnet, the density of fish catch would reduce at the same rate as the density of the net section below it. This allowed for an estimate based on a constant reduction in the number of fish caught with decreased depth in the water column, which would be consistent with fish thought to be primarily demersal species. The assumption was made that spiny dogfish would be concentrated towards the bottom and gradually decrease at a constant rate

The percentage of fish missed above 17 feet from the bottom was estimated using the formula:

,

,

and percentage missed above 7 feet was estimated using the formula:

+ Pm,

where
Wd = water depth,
Dn = net depth,
P5.2 = proportion captured in the 5.2 – 10.0 m panel, and
Pm = Percentage missed in the middle panel 2.1 – 5.2 m.

## Results

Depth ranged from 11.8 to 101.0 m in the 80 gillnet sets with a mean of 37.4 m. The salinity ranged from a low of 22.0 ppt to a high of 31.1 ppt with a mean of 28.7 ppt. The mean water temperature was 7.1 C°, ranging from 5.0 to 13.2 C°.

I found no significant difference for proportions of spiny dogfish caught in different sections of the vertically-elongated net based on time or between inshore or offshore locations (Table 6 and Table 7) using an ANOVA.

For the purpose of presenting my results, proportions were converted to percentages by multiplying the proportion by 100. My results showed that 48.8% of the spiny dogfish were in the bottom panel (0 – 2.1 m), 29.4% in the middle panel (2.1 – 5.2 m), and 21.8% in the top panel (5.2 – 10.0 m) for the inshore sampling locations. The offshore sampling locations had 45.2% in the bottom panel (0 – 2.1 m), 33.0% in the middle panel (2.1 – 5.2 m), and 21.8% in the top panel (5.2 – 10.0 m). Combining the catches from the bottom two panels of the net represented the height of the four-seam trawl, which is used by the current (Bigelow, NOAA research vessel which uses the new Four-Seam Trawl) NMFS trawl survey. The combined catch of the bottom two panels (0-17 ft) was 78.2% of the total catch for both inshore and offshore areas (Table 6).

Estimates of the percentage of fish that would be missed above certain trawl heights were calculated based on water depth. It was estimated that a trawl with a headrope height of 2.1 m was being used at a water depth of 9.1 m, then it would miss 52.6% of dogfish present in the water column (Table 8and Figure 12). If a trawl with a headrope height of 5.2 m (17 ft) was used at a water depth of 9.1 m (30 ft), then 20.8% of dogfish present would be missed (Table 8 and Figure 13). As the depth increased the percentage increased but at a much smaller rate than in shallower water.

**Discussion**

Though spiny dogfish are generally considered to be a demersal species they are also found vertically in the water column. During this study dogfish were visible on the water surface on several occasions. The captain identified aggregations of fish on the depth sounder present in up to 50% of the water column in areas where spiny dogfish were caught in large numbers. It was hypothesized by the captain that these were also dogfish due to the color and sensitivity of the scope of the depth sounder. It is my opinion that these were dogfish as hypothesized by the captain but I was unable to confirm this due to water depths far exceeding the height of my gill net. If these were dogfish as hypothesized by the captain then my projections of dogfish missed in Figure 12 and Figure 13 may be underestimated. However, the projections depicted in Figure 12 and Figure 13 are outside of the limitations of the data due to the inability to sample above 10.0 m in vertical depth with my gillnet.

A large percentage (78.2%) of dogfish captured in the vertical gillnet were caught near the bottom (0 – 5.2 m, 0-17 ft) and the remaining 21.8% were captured higher in the water column at 5.2 – 10.0 m (17-33 ft) from the bottom. However, it is highly unlikely that all dogfish were vertically distributed between 0 – 10.0 m (0-33 ft) since our net was only able to test from 0 – 10.0 m; this was confirmed by the observance of dogfish swimming at the surface. Our net sampled only 10% of the water column in some areas. It has been suggested by commercial fishermen that these aggregations of spiny dogfish are congregating at or near the surface for foraging or reproduction. I was unable to confirm this. In a concurrent pilot study I used a net with 7.62-cm stretched mesh webbing to ascertain the presence of pups and juvenile spiny dogfish offshore of Oregon Inlet, NC. No pups or juveniles had previously been documented in the area but it was the opinion of the Captain Dewey Hemilwright that they may be present in the area; however, none were caught during the study. It was suggested by the captain that the 7.62- cm webbing may have been too large to detect pups and neonates in the area. Therefore, I was unable to document the possibility of the near surface aggregations congregating for reproduction purposes (i.e., giving birth). Also, there was no evidence of diel migrations in the water column, as the average catch percentages stayed relatively consistent between day and night periods. The average percentage of dogfish remained fairly constant regardless of time period or depth in the bottom, middle, and top panels of the vertical gillnet. This suggests that spiny dogfish do not make vertical migrations, with the largest percentage remaining near the bottom regardless of the time of day.

The large percentage (at least 53.6%) of spiny dogfish captured above 0 – 2.1 m (0-7 ft) suggests that the trawl head rope height of the Yankee – 36 trawl previously used by the NMFS calibrated trawl surveys was not sampling the dogfish population adequately. A large percentage of spiny dogfish in the area could have been excluded due to their pelagic location above the net. Therefore, the calibrated trawl survey by the R/V Albatross survey likely underestimated the dogfish population. The new Four - Seam trawl used by the NMFS Calibrated Trawl Survey used by the R/V Henry Bigelow survey has a headrope height of approximately 5.2 m (17 ft). This new trawl design should improve abundance estimates; however, a substantial portion (21.8%) of dogfish caught in my gillnet between 5.2 – 10.0 m would be excluded.

My results document that a substantial percentage of the spiny dogfish population has been, and currently is being excluded from the NMFS abundance estimates. In addition, my gillnet only sampled 50% of the water column in much of the study area, and in some areas as low as only 10% of the pelagic waters. Therefore, the actual percentages of dogfish missed may be much higher than reported here. I estimated that up to 42.5% of dogfish may be missed in the Four - Seam trawl in 360 ft of water. Due to limited coverage of the water column, estimates presented in Table 8 should not be used for management use. However, I feel that the proportion missed presented in Table 6 should be accounted for in population estimates. I suggest that this vertically elongated experimental gillnet might help answer questions by fisherman regarding the pelagic distribution of dogfish. Also, it can be used in hardbottom areas or locations near wrecks and other structure currently not available for sampling with trawls.

I recommend that this procedure be repeated in concert with trawls by the R/V Henry Bigelow to assist calibration of the higher profile trawl in order to provide estimates of spiny dogfish abundance more closely linked to observations and recommendations of the commercial fishing industry.

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Chapter 4: Population Estimates and Percent Error


**Abstract**

The spiny dogfish (*Squalus acanthias*) population is surveyed annually using the NEFSC's calibrated trawl survey. Recently the methodology and the accuracy of this survey have been questioned by both fishermen and scientists. Two major concerns are if the calibrated trawl survey is sufficiently sampling areas where spiny dogfish are present along the continental shelf, and what percentage of the population is suspended above the headrope height. The goals of this portion of my thesis were to refine population estimates from a previous study by incorporating the catch efficiency of my test gillnet and to calculate the percent error of the NEFSC's population estimate. Revised population estimates using maximum catch efficiency and the linear density equation resulted in mature female population estimates of 9.09 x $10^6$ mt with a variance of 5.37 x $10^6$ mt and 3.87 x $10^6$ mt respectively. Percent error was calculated for each of the estimates using a previous study estimate (1.95 x $10^6$ mt) that assumed 100% catch efficiency within 9.14 m of the test gillnet. The percent error for the revised maximum catch efficiency was 365.5 % error and 98.0 % error for the linear equation recalculated estimate. My findings are consistent with the hypothesis that the NEFSC's calibrated trawl survey may be underestimating the spiny dogfish population. However, due to funding and sampling limitations my sample sizes were too small which resulted in large variances. The large variances make it difficult to draw concrete conclusions estimating the extent that the NEFSC is underestimating the spiny dogfish population.

## Introduction

The methodology of the Northeast Fisheries Science Centers (NEFSC) fall and spring trawl surveys have recently come into question (Campana et al., 2008). Fishermen and scientists alike believe that the NEFSC trawl survey may greatly underestimate the overall abundance of spiny dogfish in the Northwest Atlantic. Spiny dogfish are known to school by sex and size (Templeman, 1944; Jones and Geen, 1977; Silvia and Ross, 1993; Rago et al., 1994; NOAA, 1999; Alonso et al., 2002) with males tending to occupy deeper higher salinity waters while larger mature females tend to occupy shallower salinity waters. One problem with the NEFSC trawl survey is the inability to enter and effectively sample these shallower, lower salinity waters. Dogfish aggregation areas may also include hardbottom, livebottom, roughbottom, and around wrecks; these are difficult to sample with trawls (Backiel and Welcomme, 1980; Hjellvik et al., 2001; Register et al., 2006).

For management purposes of spiny dogfish, the Spawning Stock Biomass (SSB) is used for target levels and thresholds. It is a concern that the NEFSC's trawl survey may be missing a large portion of the SSB due to its inability to sample in shallower waters where a higher concentration of larger mature females may exist (Register et al., 2006).

Trawls are also known to be selective for smaller individuals, as larger individuals may be able to avoid a trawl (Richardson, 1956). Furthermore, a species body shape, maneuverability, swimming ability and speed may enable it to escape from a trawl or avoid it all together (Olin et al., 2009). Underestimation of larger individuals of a species such as spiny dogfish may be a result of trawl escapement or avoidance.

In 2006, Rulifson and Register conducted a study to determine the abundance of overwintering dogfish along the coastal waters of North Carolina from the Virginia/North Carolina line South to Ocracoke Inlet, NC. This study incorporated two different types of estimates and two different gear types. Gillnets deployed from the commercial fishing vessel F/V Tarbaby based out of Wanchese, NC operated by Captain Dewey Hemilwright and twin otter trawls deployed from the NOAA vessel Oregon II. The trawl samples were taken during the annual Cooperative Winter Tagging Cruise taking place in late January of each year.

The 2006 study showed a significant number of spiny dogfish overwintering in North Carolinas coastal waters. The trawl portion of the study used a Schnabel estimate resulting in an estimate of 65,635.47 mt of mature female biomass. The gillnet portion of the study used an area-density method and a sensitivity analysis, which assumed linear distance influences of 9.14, 22.86, 45.72, and 91.44 meters in catching spiny dogfish. The sensitivity analysis resulted in estimates ranging from 871,045,200 individuals (1,953,057.54 mt SSB) at 9.14 m of influence to 34,801,164 individuals (78,031.17 mt SSB) at 91.44 m of linear influence.

The wide range of estimates for the area-density methods is a result of very little being known about gillnet catch efficiency. In contrast, research has been done to estimate size selectivity in gillnets based on twine size, mesh size, and hanging ratios, but my searches found none on the percentages of fish caught by gillnets. Chapter 2 addresses the catch efficiency of gillnets within a given area, which is applied to area-density estimates in this chapter.

**Materials and Methods**

In the Register (2007) study several assumptions were made:

1. All nets fished at 100% efficiency.

2. All nets were set for approximately the same time.

3. Dogfish were uniformly distributed within the aggregation.

4. Fish were not highly mobile during the study and remained in the same general area.

5. Only those dogfish within 10-100 yards of the net were captured.

6. None of the fish captured and released were recaptured in subsequent samples.

7. Estimated surface area of the dogfish aggregation accurately described the aggregation size.

8. Fish leaving from natural mortality and entering the commercial fishery was equal and stable during this period.

The formula was

$$\hat{N} = \frac{A}{a} \sum_{i=1}^{a} N_i$$

Where

$\hat{N} =$ estimated population;

A = number of equal units of area occupied by the total population;

a = number of units sampled; and

$N_i$ = number of animals counted in any given sample area, this was used to calculate the total number of dogfish within the aggregation (Register, 2007; Cushing, 1957; Ricker, 1968). Biomass of the stock was calculated using an assumed average weight of 2.72 kg per dogfish from Newman et al. 2000 (Register, 2007). Mature female biomass was calculated using 3.03 kg per dogfish from Register (2007).

Population estimates were refined by applying the linear regression equation (Density per 2090.32 $m^2$ = 0.0081524 + 0.0012853 * number captured) from chapter two (Figure 6). This equation was created from a bivariate linear regression fit of the spiny dogfish density present in the corral net and the total number of captured in a 10-minute soak. The linear density equation was applied to the number caught in each 10 minute soak (each haul) during Register's (2007) study, so that the total number of fish caught in the 2007 study was adjusted by my results. The estimated catch numbers subsequently were applied to the Ricker population equation. The Ricker equation estimates the total population number in individuals.

Population estimates were also recalculated using the average maximum catch efficiency. A multiplying factor was calculated by dividing 100 by the average catch percentage. The average maximum catch efficiency resulted in a multiplying factor of 10.0.

The total numbers of individuals from the Ricker population equation were then applied to other population characteristics from the Register (2007) study. In the 2007 study 74% of all spiny dogfish were mature females. The total number of mature females was calculated by multiplying the total number of individuals by 0.74. The total biomass was calculated by multiplying the total number of individuals by 2.72 kg, and the mature female biomass was calculated by multiplying the total number of mature females by 3.03 kg.

The variance of the average maximum catch efficiency recalculation estimate was calculated by:

—

The percent error was calculated for revised population estimates; for all calculations the estimated mature female biomass (SSB) was used. Revised estimates from Register (2007) and the 2006 NMFS calibrated trawl survey were compared to the revised linear equation method from Register (2007). The 100% catch efficiency estimate within 9.14 m of the test gillnet from Register (2007) was used as the accepted value.

The equation used for percent error calculation was:

% error = (|Experimental Result – Accepted Value| / Accepted Value) x 100

**Results**

The recalculated catch estimates from the 2006 study (Register, 2007) using the linear equation yielded 8,385 total dogfish, with 6,205 mature females captured along the Outer Banks from the Virginia line to Cape Hatteras for the 200 10-minute gillnet sets. Extrapolating these new estimates over the surface area covered in the 2006 study resulted in an estimated 1.73 x $10^9$ sub-adult and adult individuals, or 1.28 x $10^9$ mature females. The total biomass was re-estimated at 4.69 x $10^6$mt of harvestable spiny dogfish, equaling 3.87 x $10^6$ mt of mature female biomass (

Table 9) (it should be noted that this estimate is outside the limitations of my data as explained in Chapter 2).

Estimates using the average maximum catch efficiency of fish caught in each net set and its 95% confidence intervals, resulted in higher estimates of abundance than the linear equation method. The estimated mature female biomass (SSB) using the average catch percentage (8.6%) was 9.09 x $10^6$mt (

Table 10) with a variance of 5.37 x $10^6$ mt.

A comparison of the two different methods resulted in a large difference; the linear regression method was lower in all instances. The 100% catch efficiency estimate within 9.14 m of the test gillnet from Register (2007) was used as the accepted value (Table 11).

The percent error of my study, was recalculated from Register (2007) and Register et al. (2006) (FRG#: 05-FEG-07) a previous FRG study verses two other previous studies: the National Marine Fisheries calibrated trawl survey (106,000 mt) for 2006 and a previous gillnet study (1.95 x $10^6$ mt) using 100% catch rate at a linear distance of 9.14 meters on each side of the net. The comparison of the NMFS estimate verses the estimate (1.95 x $10^6$) from Register's (2007) study resulted in a percent error of 97.3% (Table 11). A second comparison was used to compare the linear equation revised gillnet estimate from Register (2007) to a previous study using 100% catch efficiency at a linear distance of 9.14 meters on both sides of the gillnet; this comparison resulted in 98.0% error (Table 11). The maximum catch efficiency revised gillnet estimate from Register (2007) was also compared to the previous study using 100% catch efficiency at a linear distance of 9.14 meters on both sides of the gillnet; this comparison resulted in 365.5% error (Table 11).

**Discussion**

The population estimates for spiny dogfish along the Outer Banks in 2006 increased significantly based on the findings of Chapter 2 of this study. The low catch rates on known densities of dogfish during 10-minute gillnet sets demonstrated that the recalculated rate from Register (2007) would be significantly lower than the 100% catch rate assumed in that study for 22.86 m of linear influence. These numbers are consistent with observations and the opinion of fishers and some scientists that the population may be much larger than estimated by NMFS calibrated trawl survey. In addition, the original estimate of 100% capture for 9.14 m of linear influence from Register (2007) were 98.0 and 365.5 percent different than recalculated estimates from Chapter 1 of this study, providing further support for NMFS underestimating abundances. Gill nets may fish at close to 100% efficiency at 9.14 m of linear influence, or they may capture a high percentage close to the net and a smaller percentage as distances from the net increase. This would combine for the close to 100% catch efficiency at 9.14 m of linear influence. The catchability of fish in reference to their linear distance from the net would be a result of fish activity level; an active fish would be more likely to encounter a net than an inactive fish.

The NMFS calibrated trawl survey for 2006 had a much lower estimate than the estimates from Register 2007 (94.6% error). Trawls are a less selective gear due to it being an active gear and provides for a more reliable estimate of species abundance and length distribution (Olin et al., 2009). Trawls are not as applicable in shallower or rough bottom areas (Backiel and Welcomme, 1980). This is a major concern with the NMFS calibrated trawl survey due to the fact that many of the overwintering areas along the North Carolina coast are shallow water or rough bottom areas, where NMFS surveys cannot sample. Larger and faster swimming individuals of a certain species may be able to avoid trawls (Bethke et al., 1999), but more are vulnerable to gillnets due to increased movement of larger individuals (Richardson, 1956).

Species such as spiny dogfish might be more susceptible to a gillnet than a trawl, because the probability that a fish will be retained in a gillnet depends on its morphology, activity, and speed (Backiel and Welcomme, 1980). A fish such as the spiny dogfish would be more likely to be retained in a net once it encounters the net due to it being a slower species with spines. Trawls and gillnets alone may not be sufficient in estimating a fish population, and a combination of both would likely enhance the data gathered (Olin and Malinen, 2003). My finding of a large biomass of mature females in inshore strata does not coincide with the NMFS estimates that a very small fraction of the biomass exists there (personal communication; Rago, 2006). This is supported by NEFSC data that show females make up 75% of the population near shore. The findings of this study are of particular concern and suggest that a gillnet supplement to the NEFSC trawl survey may be needed to accurately account for larger individuals, and for fish located in areas unable to be sampled by the current NMFS calibrated trawl survey due to gear limitations.

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## Conclusions and Recommendations

### Conclusions

The results of the gillnet catch efficiency support the hypothesis that gillnet catch efficiency is variable and dependant on density. Gillnet catch efficiency (8.6%) was lower in a 2090.32 $m^2$ area than the 100% catch efficiency assumed by Register (2007) in her study for the same 2090.32 $m^2$ area. Findings in Chapter 4 of this study when compared to 100% catch efficiency of fish located within 9.14 m of the net support that the chances of catching a fish decrease with increased distance from the net. A 98.0% difference was found when using 100% catch efficiency at 9.14 linear m of influence compared the linear equation method. The tagging of spiny dogfish using Floy SS-94 single barbed dart tags does not affect their catchability in a gillnet.

I did not detect diurnal migrations vertically in the water column as the catch rates remained variable with no clear pattern. Spiny dogfish do tend to be demersal but can and do aggregate in the water column throughout night and daytime hours in high abundance. Large numbers of spiny dogfish were observed near the surface at several times throughout this study but the cause of the activity was not determined; perhaps shifting position for reproduction or food and foraging. Due to aggregations of spiny dogfish in the water column, the NMFS calibrated trawl survey may be excluding a large portion of the population from estimates.

Recalculated population estimates from both the linear equation and the average percentage caught resulted in population estimates significantly exceeding the NMFS population estimates. Due to populations varying in density, I feel that the linear equation recalculated estimates from Register (2007) would account for differences in catchability in aggregations of different densities. However, due to low sample sizes and the inability to capture numbers of dogfish equivocal to the number Register 2007 did, estimates using the linear equation recalculation are outside the limitations of my data. The recalculated population estimates show that a significant number of spiny dogfish can be located in near shore waters from the North Carolina Virginia state line to Ocracoke Inlet, NC, during a portion of the overwintering period.

## Recommendations

The NMFS may be excluding a large portion of the spiny dogfish population in stock assessments and should consider modifying its sampling and models used for population estimates.

The NMFS needs to incorporate areas south of Cape Hatteras, NC into their spring trawl surveys; spiny dogfish commercial fisheries exist as far south as Beaufort, NC. Shallow water areas should also be sampled due to large aggregations of sexually mature females being located in the lower salinity, shallower waters in near shore areas. It is hypothesized that dogfish may be residing in southern waters for longer periods of the year based on reports from commercial and recreational fisherman that frequent these waters.

A significant number of spiny dogfish were found to be located above the head rope height of the trawl; the NMFS should use alternative gears to sample mid-water and surface waters. Estimates of spiny dogfish that are present above the headrope of the NMFS calibrated trawl should also be incorporated into population models. Incorporation of an estimate of the portion of the population above the headrope would improve the models precision.

Table 1. Sex, number, minimum total length (TL), max TL, mean TL, and SD in (mm) of longline caught spiny dogfish which were used for the three depletion experiments. N = 106 was chosen due to being the maximum catch in the test net in previous studies.

| | Females | Males | Total | | | | |
|---|---|---|---|---|---|---|---|
| Trial Number | N | N | N | min TL (mm) | max TL (mm) | mean TL (mm) | SD (mm) |
| 1 | 95 | 11 | 106 | 211 | 1,030 | 831.35 | 84.18 |
| 2 | 123 | 5 | 128 | 598 | 995 | 820.47 | 67.29 |
| 3 | 122 | 2 | 124 | 671 | 1,004 | 855.32 | 53.24 |

Table 2. Table of projected densities and number of spiny dogfish present within the prescribed area based on number of fish caught in 10 minutes.

| Number caught | Density/$m^2$ | Number/2090.32$m^2$ |
|---|---|---|
| 5 | 0.01 | 30 |
| 10 | 0.02 | 44 |
| 15 | 0.03 | 57 |
| 20 | 0.03 | 71 |
| 25 | 0.04 | 84 |
| 30 | 0.05 | 98 |
| 35 | 0.05 | 111 |
| 40 | 0.06 | 125 |
| 45 | 0.07 | 138 |
| 50 | 0.07 | 151 |
| 55 | 0.08 | 165 |
| 60 | 0.09 | 178 |
| 65 | 0.09 | 192 |
| 70 | 0.10 | 205 |
| 75 | 0.10 | 219 |

Table 3. Number, minimum total length (TL), max TL, mean TL, and SD in (mm) of tagged and untagged longline caught spiny dogfish which were used for the three depletion experiments. N = 106 was chosen due to being the maximum catch in the test net in previous studies.

| | N | min TL (mm) | max TL (mm) | mean TL (mm) | SD (mm) |
|---|---|---|---|---|---|
| Trial | | | Tagged | | |
| 1 | 55 | 211 | 940 | 837.62 | 55.30 |
| 2 | 55 | 682 | 961 | 818.40 | 59.88 |
| 3 | 55 | 671 | 929 | 855.56 | 47.93 |
| Total | 165 | 211 | 961 | 837.20 | 56.35 |
| Trial | | | Untagged | | |
| 1 | 51 | 645 | 1,030 | 824.32 | 107.96 |
| 2 | 73 | 598 | 995 | 822.03 | 72.75 |
| 3 | 69 | 691 | 1,004 | 855.12 | 57.46 |
| Total | 193 | 598 | 1,030 | 834.52 | 80.00 |

Table 4. Estimated test net sink time and net set time by depth based on a sink rate of 0.93 feet per second.

| Depth (ft) | Depth (m) | Sink Time (sec) | Sink Time (min) | Set Time (min) |
|---|---|---|---|---|
| 30 | 9.14 | 28.08 | 0.50 | 10.50 |
| 35 | 10.67 | 32.76 | 0.58 | 10.58 |
| 40 | 12.19 | 37.44 | 0.67 | 10.67 |
| 45 | 13.72 | 42.12 | 0.75 | 10.75 |
| 55 | 16.76 | 51.49 | 0.92 | 10.92 |
| 60 | 18.29 | 56.17 | 1.00 | 11.00 |
| 65 | 19.81 | 60.85 | 1.08 | 11.08 |
| 70 | 21.34 | 65.53 | 1.17 | 11.17 |
| 75 | 22.86 | 70.21 | 1.25 | 11.25 |
| 80 | 24.38 | 74.89 | 1.33 | 11.33 |
| 85 | 25.91 | 79.57 | 1.42 | 11.42 |
| 90 | 27.43 | 84.25 | 1.50 | 11.50 |
| 95 | 28.96 | 88.93 | 1.58 | 11.58 |
| 100 | 30.48 | 93.61 | 1.67 | 11.67 |
| 105 | 32.00 | 98.29 | 1.75 | 11.75 |
| 110 | 33.53 | 102.97 | 1.83 | 11.83 |
| 115 | 35.05 | 107.65 | 1.92 | 11.92 |
| 120 | 36.58 | 112.33 | 2.00 | 12.00 |
| 125 | 38.10 | 117.01 | 2.08 | 12.08 |
| 130 | 39.62 | 121.69 | 2.17 | 12.17 |
| 135 | 41.15 | 126.37 | 2.25 | 12.25 |
| 140 | 42.67 | 131.06 | 2.33 | 12.33 |
| 145 | 44.20 | 135.74 | 2.42 | 12.42 |
| 150 | 45.72 | 140.42 | 2.50 | 12.50 |
| 155 | 47.24 | 145.10 | 2.58 | 12.58 |
| 160 | 48.77 | 149.78 | 2.67 | 12.67 |
| 165 | 50.29 | 154.46 | 2.75 | 12.75 |
| 170 | 51.82 | 159.14 | 2.83 | 12.83 |
| 175 | 53.34 | 163.82 | 2.92 | 12.92 |
| 180 | 54.86 | 168.50 | 3.00 | 13.00 |
| 185 | 56.39 | 173.18 | 3.08 | 13.08 |
| 190 | 57.91 | 177.86 | 3.17 | 13.17 |
| 195 | 59.44 | 182.54 | 3.25 | 13.25 |
| 200 | 60.96 | 187.22 | 3.33 | 13.33 |
| 205 | 62.48 | 191.90 | 3.42 | 13.42 |
| 210 | 64.01 | 196.58 | 3.50 | 13.50 |
| 215 | 65.53 | 201.26 | 3.58 | 13.58 |

Table 5. The number of vertically-elongated gillnet sets according to time period and location. Inshore= <25 m; offshore = ≥25 m.

| Period | Inshore | Offshore | Total |
|---|---|---|---|
| 0001-0600 | 1 | 8 | 9 |
| 0601-1200 | 12 | 17 | 29 |
| 1201-1800 | 6 | 12 | 18 |
| 1801-2400 | 10 | 14 | 24 |
| Total | 29 | 51 | 80 |

Table 6. Proportions of catch for each period, location, and panel of the vertically-elongated Gillnet.

| Location and section of vertically-elongated net | Period of the day 0001-0600 | 0601-1200 | 1201-1800 | 1801-0000 | Grand total |
|---|---|---|---|---|---|
| Inshore | | | | | |
| Proportion in 7 - 33 ft | 0.00 | 0.59 | 0.47 | 0.50 | 0.51 |
| Proportion in 17 - 33 ft | 0.00 | 0.28 | 0.25 | 0.14 | 0.22 |
| Proportion in 7 - 17 ft | 0.00 | 0.31 | 0.22 | 0.36 | 0.29 |
| Proportion in 0 - 7 ft | 1.00 | 0.41 | 0.53 | 0.51 | 0.49 |
| Proportion in 0 - 17 ft | 1.00 | 0.72 | 0.75 | 0.86 | 0.78 |
| Offshore | | | | | |
| Proportion in 7 - 33ft | 0.37 | 0.64 | 0.60 | 0.51 | 0.55 |
| Proportion in 17- 33 ft | 0.14 | 0.24 | 0.22 | 0.24 | 0.22 |
| Proportion in 7 - 17 ft | 0.23 | 0.40 | 0.37 | 0.27 | 0.33 |
| Proportion in 0 -7 ft | 0.63 | 0.37 | 0.41 | 0.50 | 0.45 |
| Proportion in 0 - 17 ft | 0.86 | 0.76 | 0.78 | 0.76 | 0.78 |
| Inshore and Offshore Combined | | | | | |
| Proportion in 7 - 33 ft | 0.33 | 0.62 | 0.55 | 0.50 | 0.54 |
| Proportion in 17 - 33 ft | 0.12 | 0.25 | 0.23 | 0.20 | 0.22 |
| Proportion in 7 - 17 ft | 0.21 | 0.36 | 0.32 | 0.30 | 0.32 |
| Proportion in 0 - 7 ft | 0.67 | 0.38 | 0.45 | 0.50 | 0.46 |
| Proportion in 0 - 17 ft | 0.88 | 0.75 | 0.77 | 0.80 | 0.78 |

Table 7. ANOVA results by panel depth and location for all time periods combined.

| Depth | Inshore | | Offshore | | Combined | |
|---|---|---|---|---|---|---|
| (ft) | F value | p value | F value | p value | F value | p value |
| 0-7 | 0.89 | 0.46 | 1.56 | 0.21 | 1.97 | 0.13 |
| 7-17 | 0.99 | 0.41 | 1.89 | 0.14 | 1.31 | 0.28 |
| 17-33 | 0.76 | 0.52 | 0.31 | 0.82 | 0.64 | 0.59 |
| 0-17 | 0.76 | 0.52 | 0.31 | 0.82 | 1.97 | 0.13 |
| 7-33 | 0.89 | 0.46 | 1.56 | 0.21 | 0.64 | 0.59 |

Table 8. Percentages missed at depth above the headrope height of the Yankee – 36 and new Four-Seam trawl used by the National Marine Fisheries Service.

| Depth ft | Percentage missed above 17 ft | Percentage missed above 7 ft |
|---|---|---|
| 30 | 20.8 | 52.6 |
| 60 | 27.0 | 58.8 |
| 90 | 30.4 | 62.2 |
| 120 | 32.7 | 64.5 |
| 150 | 34.6 | 66.4 |
| 180 | 36.2 | 68.0 |
| 210 | 37.5 | 69.3 |
| 240 | 38.7 | 70.5 |
| 270 | 39.8 | 71.6 |
| 300 | 40.8 | 72.6 |
| 330 | 41.7 | 73.5 |
| 360 | 42.5 | 74.3 |

Table 9. Recalculated population estimates from Register (2007) using the linear equation: Density per 2090.32 $m^2$ (2,500 $yd^2$) = 0.0081524 + 0.0012853 * number captured.

| Linear distance of influence | 25 yards (22.86 m) |
|---|---|
| | Total dogfish |
| Total number of dogfish | 8,385.0 |
| Total survey area ($km^2$) | 1,410,558.0 |
| Number of units in survey area | 205,620.7 |
| Total population size (individuals) | $1.73 \times 10^9$ |
| Total population size (2.72kg) | $4.69 \times 10^9$ |
| Total population size (mt) | $4.69 \times 10^6$ |
| Linear distance of influence | 25 yards (22.86 m) |
| | Mature female dogfish |
| Number of mature female dogfish | 6,205 |
| Total survey area ($km^2$) | 1,410,558.0 |
| Number of units in survey area | 205,620.7 |
| Mature female population size (individuals) | $1.28 \times 10^9$ |
| Mature female population size (3.03 kg) | $3.87 \times 10^9$ |
| Mature female population size (mt) | $3.87 \times 10^6$ |

Table 10 . Recalculated population estimates from Register (2007) using the average percentage of dogfish caught.

| 8.6% of dogfish caught | |
|---|---|
| Linear distance of influence | 25 yards (22.86 m) |
| | Total dogfish |
| Total number of dogfish | 19,720 |
| Total survey area ($km^2$) | 1,410,558 |
| Number of units in survey area | 205,620.7 |
| Total population size (individuals) | $4.05 \times 10^9$ |
| Variance (total population size) | $3.24 \times 10^9$ |
| Total population size (2.72kg) | $1.10 \times 10^{10}$ |
| Total population size (mt) | $1.10 \times 10^7$ |
| Variance (mt) | $9.8 \times 10^6$ |
| Linear distance of influence | 25 yards (22.86 m) |
| | Mature female dogfish |
| Number of mature female dogfish | 14,593 |
| Total survey area ($km^2$) | 1,410,558.0 |
| Number of units in survey area | 205,620.7 |
| Mature female population size (individuals) | $3.00 \times 10^9$ |
| Variance (mature female population size | $1.77 \times 10^9$ |
| Mature female population size (3.03 kg) | $9.09 \times 10^9$ |
| Mature female population size (mt) | $9.09 \times 10^6$ |
| Variance (mt) | $5.37 \times 10^6$ |

Table 11 . Percent error calculated by study assuming the recalculated population estimates from Table 7 is the accepted value, mature female population size (mt).

| Comparison | % error |
|---|---|
| Average catch percentage estimate ($9.09 \times 10^6$ mt) | 365.5 |
| NMFS (106,000 mt) | 94.6 |
| Linear equation estimate ($3.87 \times 10^6$ mt) | 98.0 |

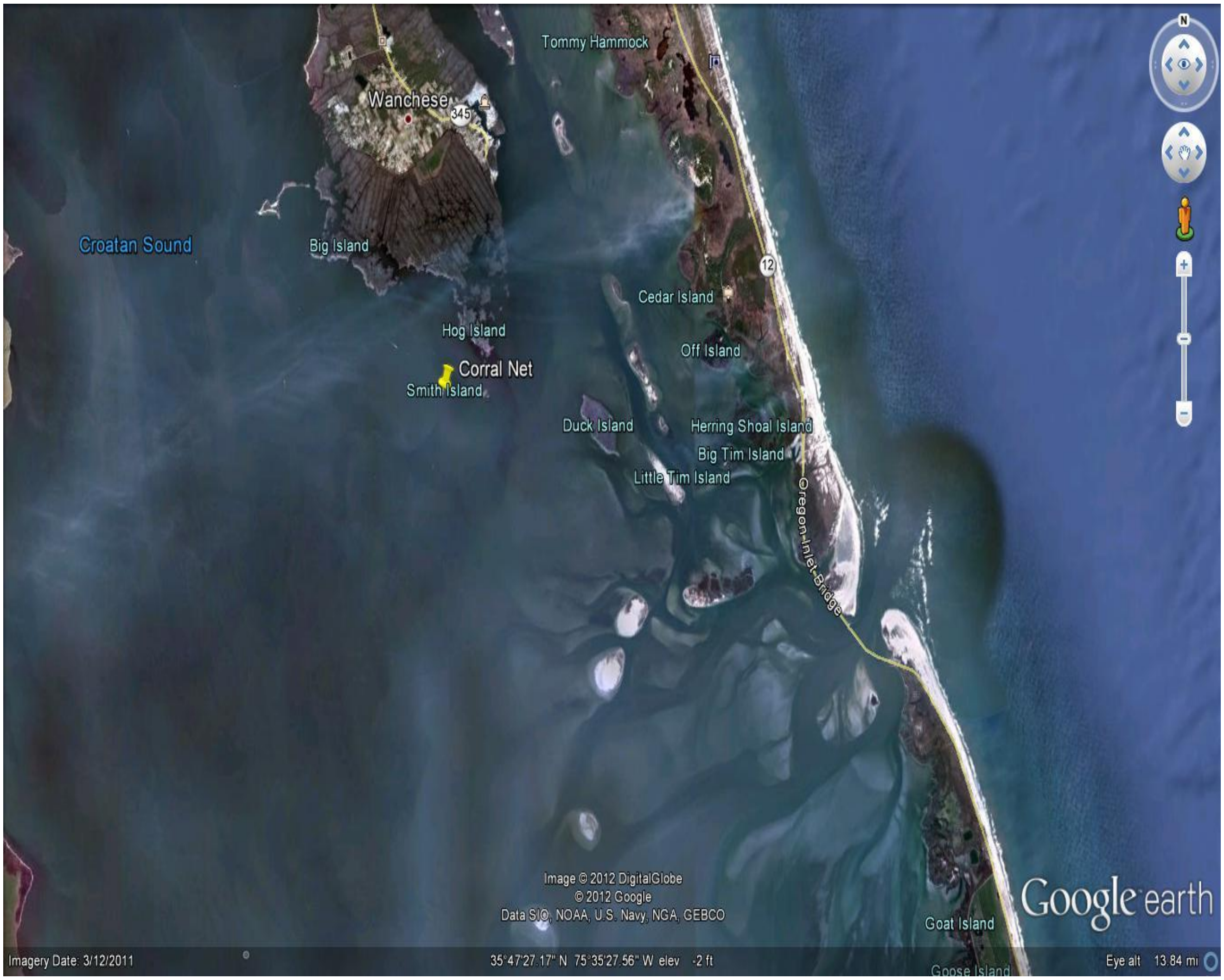


Figure 1. Aerial image of the corral net site on the south west side of Roanoke Island which was used for the gillnet efficiency portion of the study. The site was chosen due to its close proximity to Oregon Inlet, NC.

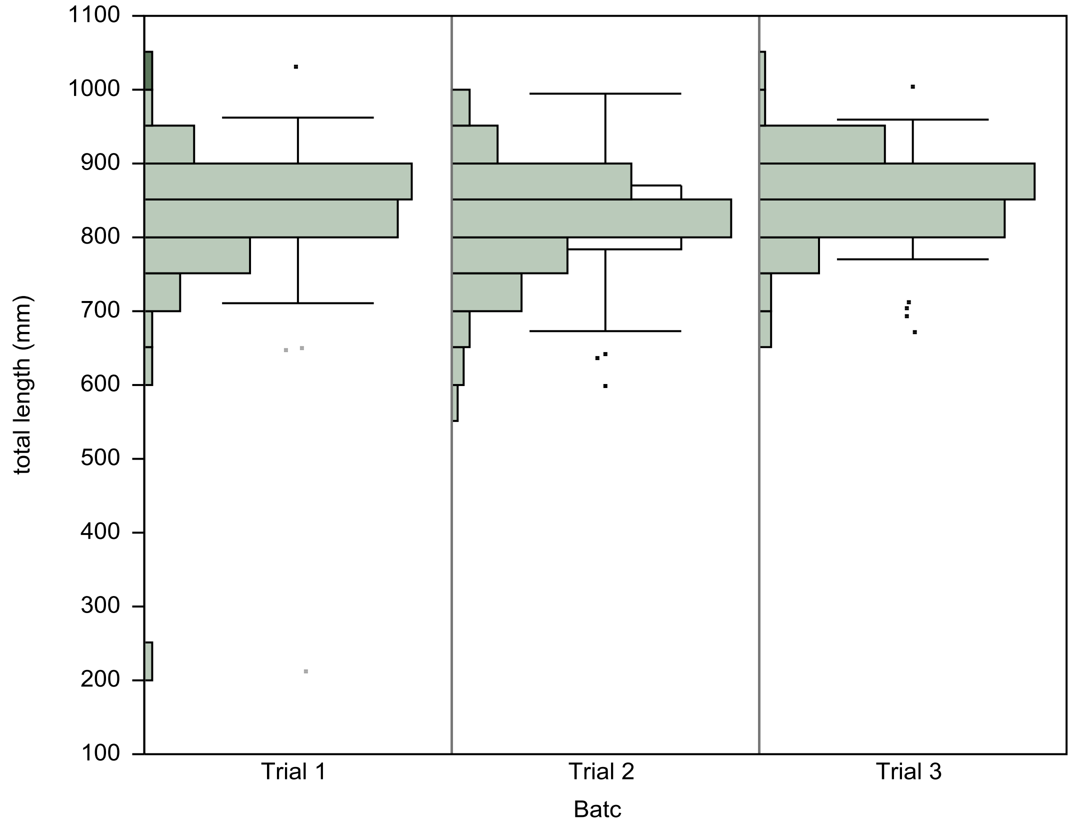


Figure 2. Length distributions of dogfish added to the corral during each depletion trial used to estimate gillnet catch efficiency.

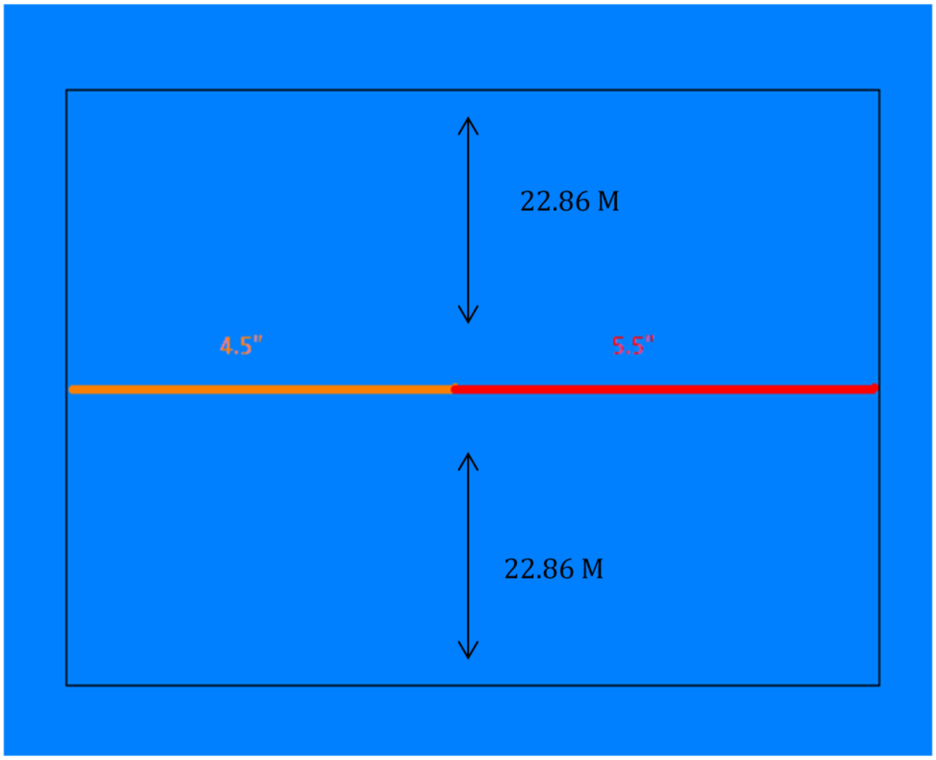


Figure 3. Test gillnet deployment showing gillnet mesh size (inch stretched mesh) and distance from each side of the corral net used in the gillnet efficiency portion of the study.

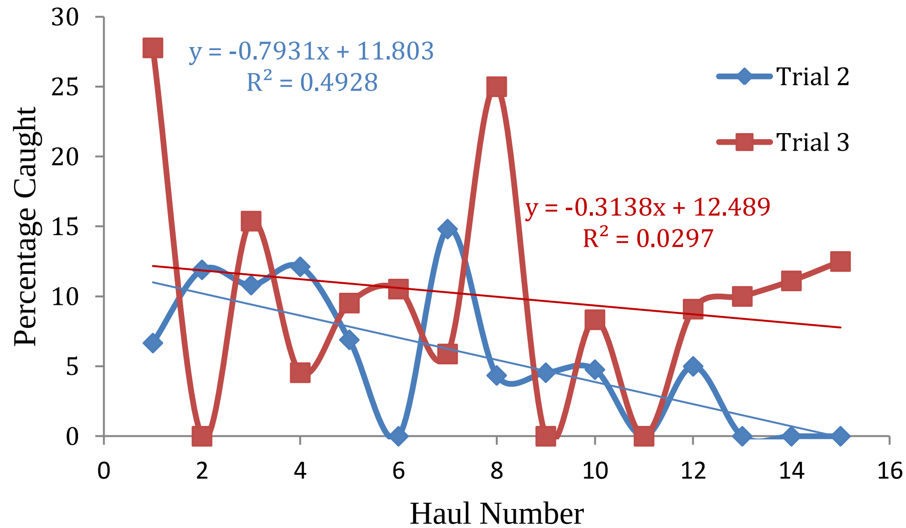


Figure 4. Graph of percent caught on for each haul for Trial 1 and Trial 2 from the gillnet efficiency portion of this study; data was normalized using percentages.

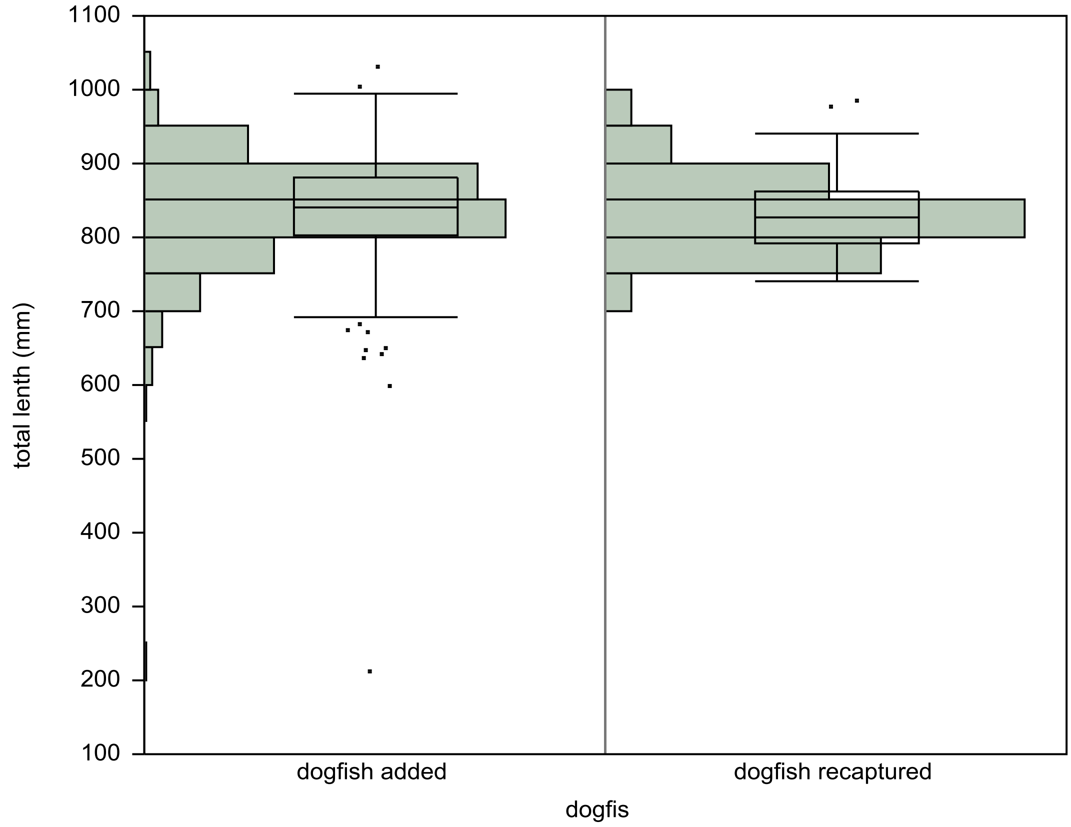


Figure 5. Length distribution in total length (TL) mm of spiny dogfish added to the corral and recaptured from the corral.

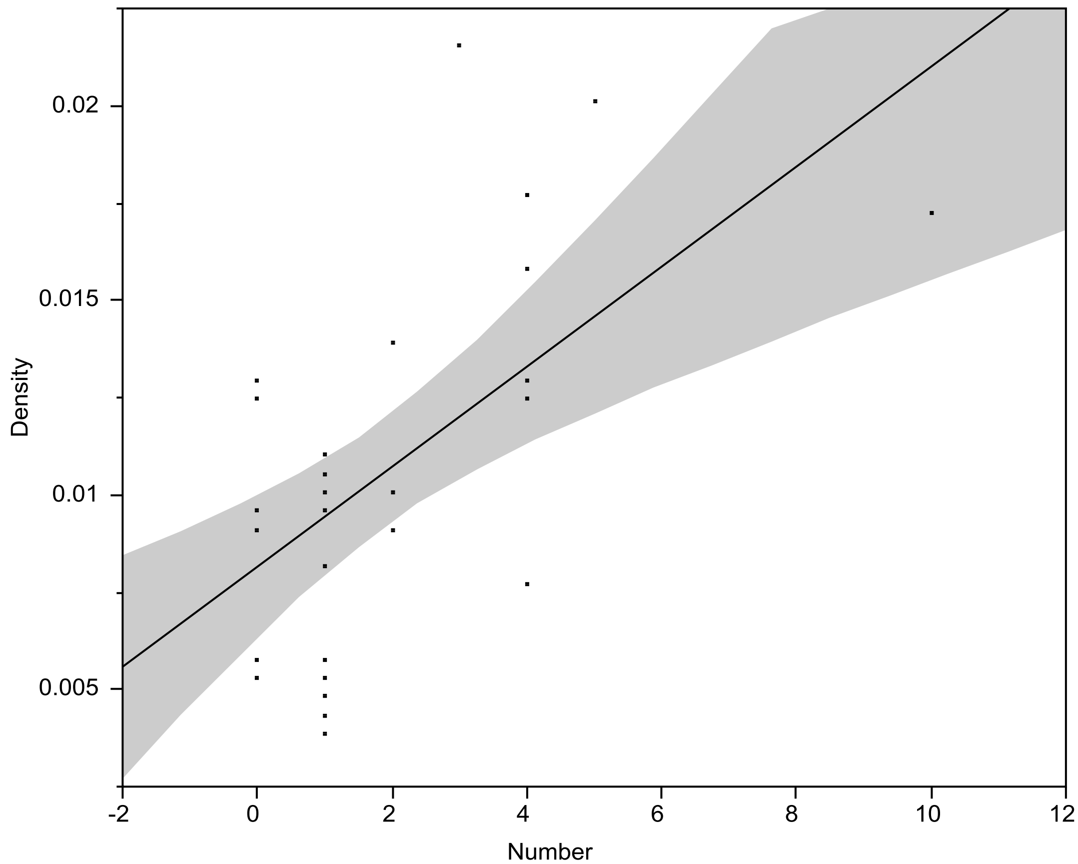


Figure 6. Bivariate linear regression fit of the spiny dogfish density present verses total number of dogfish caught to give a projection of the total density based on the number caught with a 95% confidence interval. Resulting in the density equation: Density per 2090.32 $m^2$ (2,500 $yd^2$) = 0.0081524 + 0.0012853 * number captured.

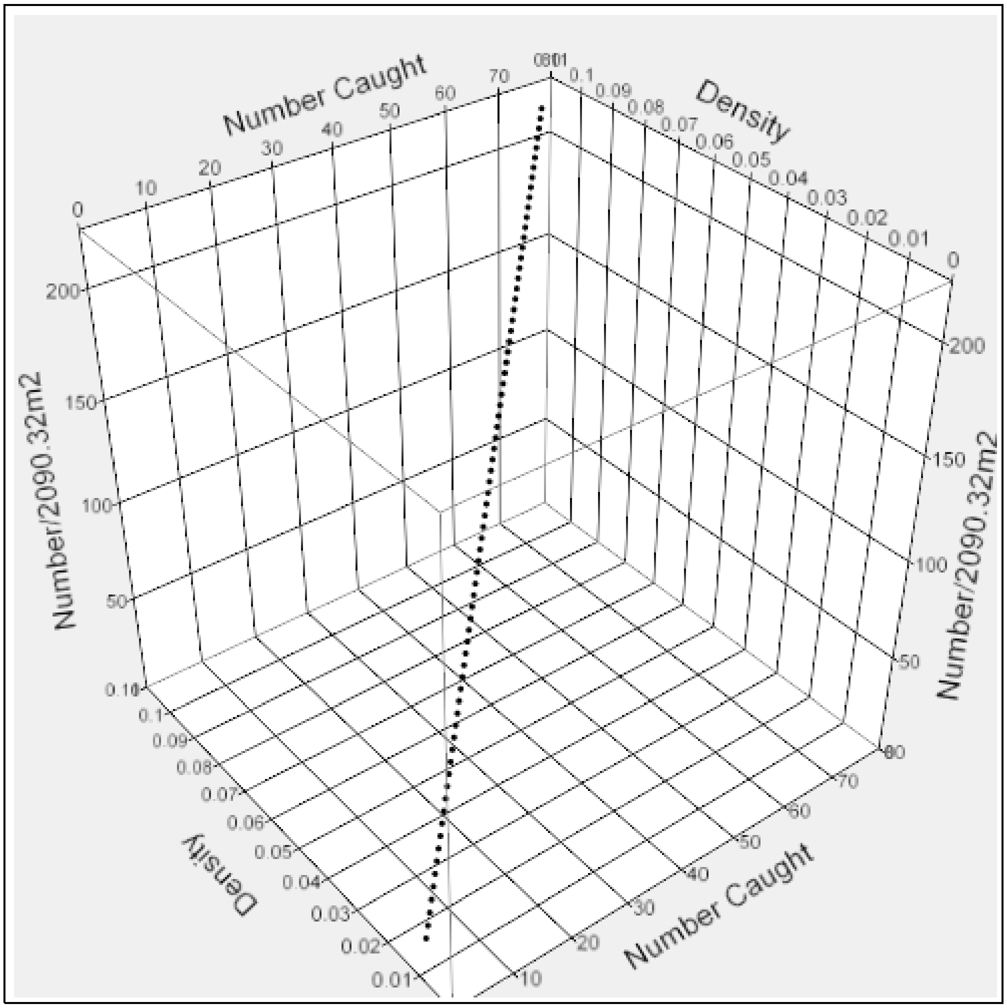


Figure 7. 3D graph of the projected spiny dogfish density and number of dogfish per 2090.32 $m^2$. Using the density equation: Density per 2090.32 $m^2$ (2,500 $yd^2$) = 0.0081524 + 0.0012853 * number captured.

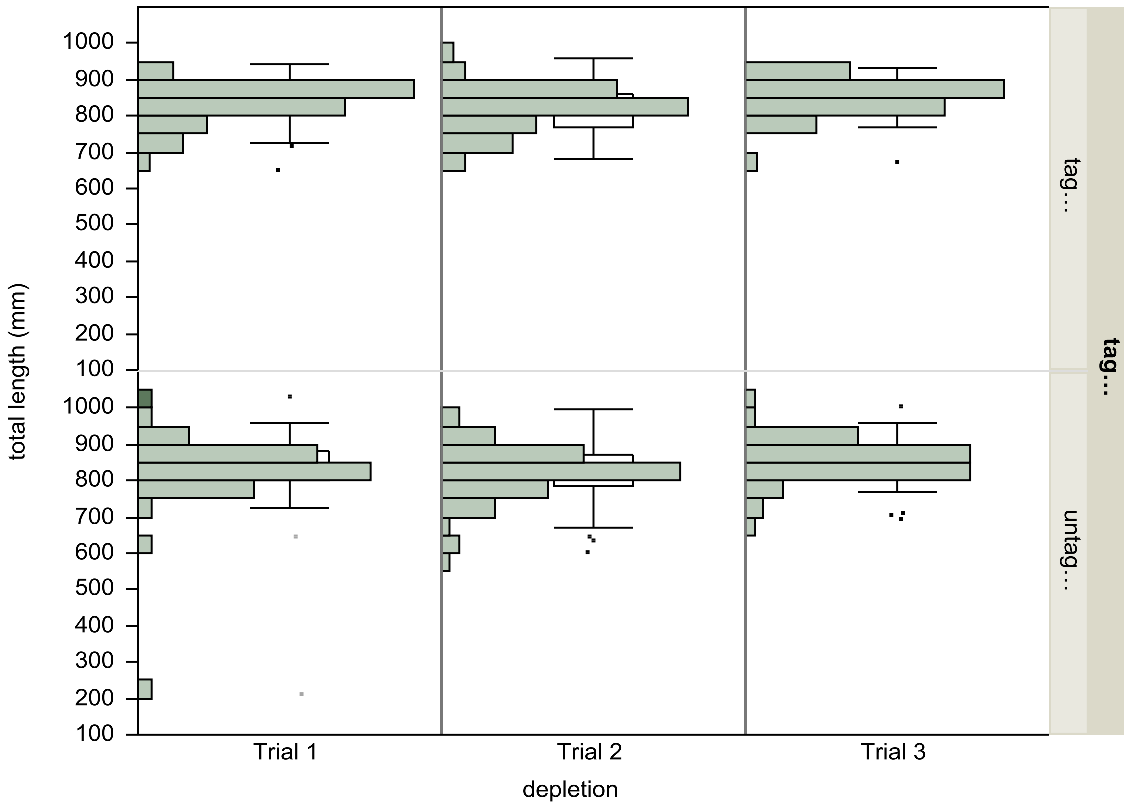


Figure 8. Length distribution for tagged and untagged spiny dogfish added to the corral for Trial 1, Trial 2, and Trial 3 used to determine if tagged spiny dogfish are captured at a higher rate than untagged spiny dogfish.

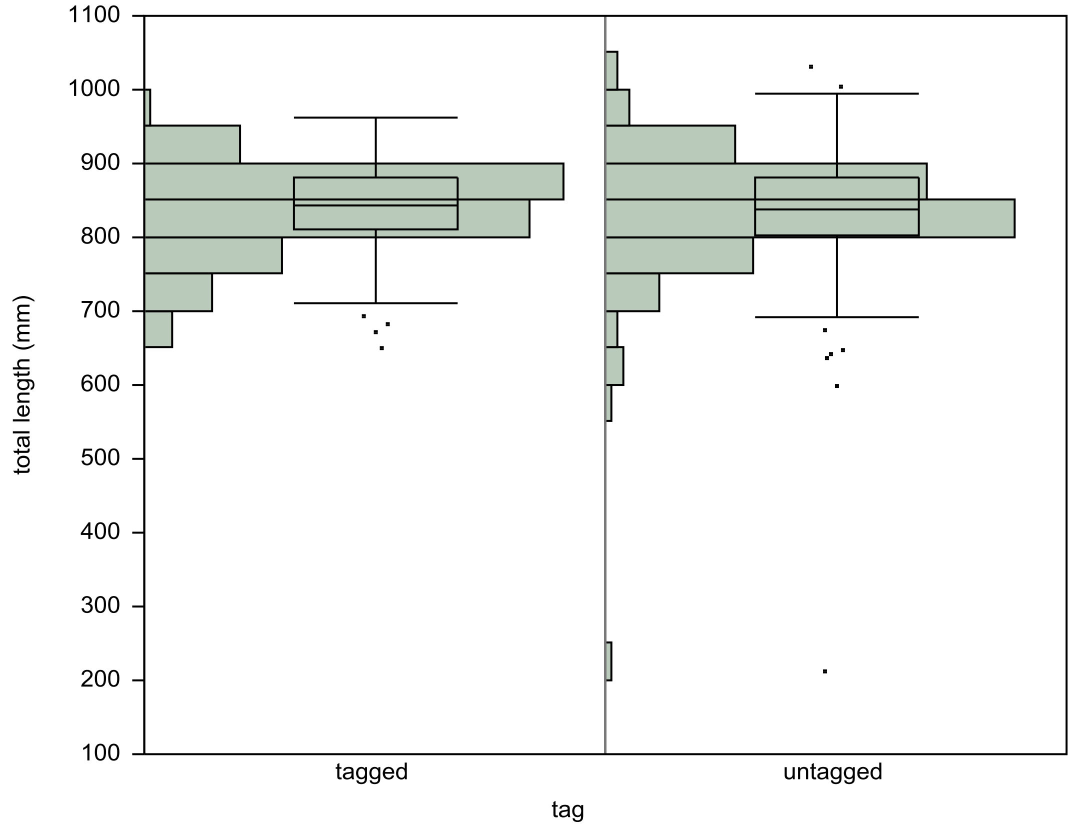


Figure 9. Length distribution in total length (TL) mm of spiny dogfish of tagged and untagged spiny dogfish added to the corral used to estimate the percentage of untagged and tagged dogfish recaptured.


Figure 10. Aerial image of all vertical gillnet sample sites from near shore waters to the continental shelf break off of Oregon Inlet, NC.

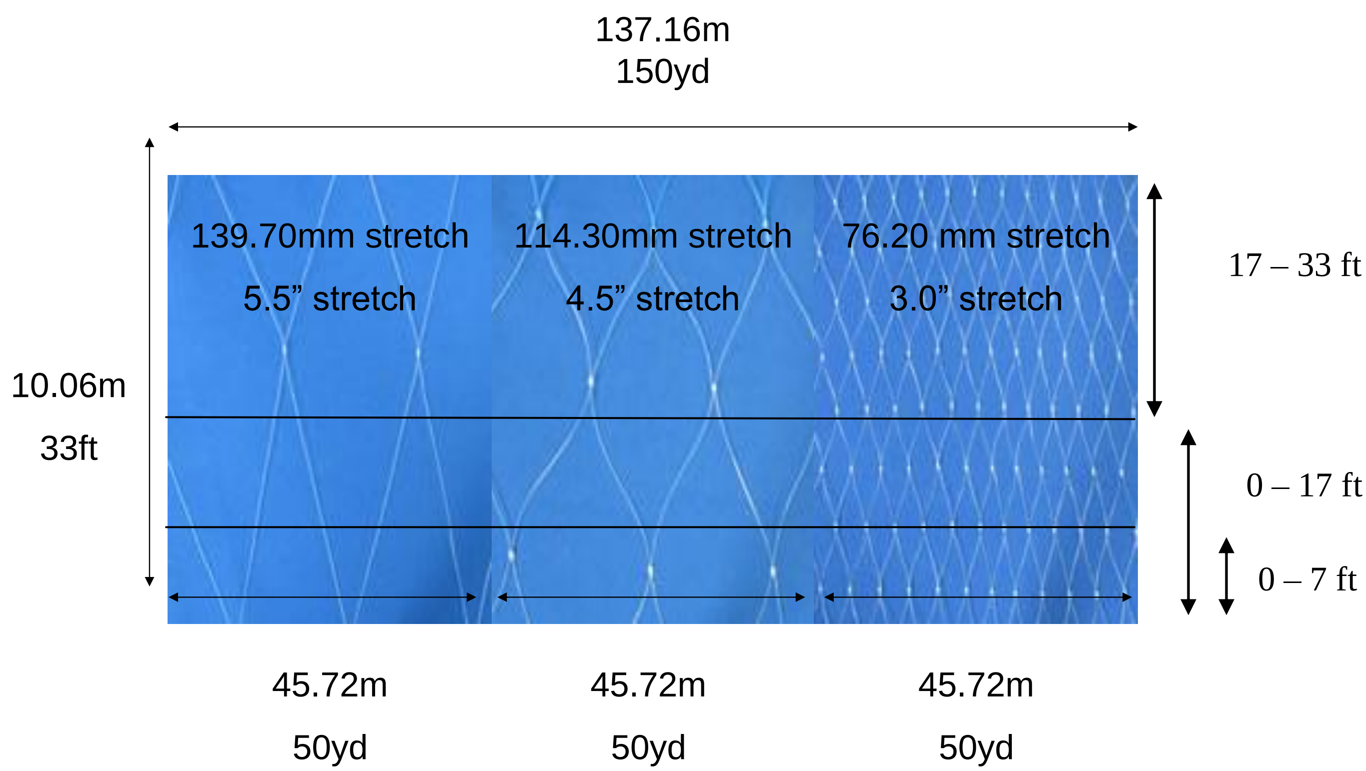


Figure 11. Dimensions of the vertically elongated gillnet illustrating mesh size and panel size used to estimate the location of spiny dogfish suspended in the water column.

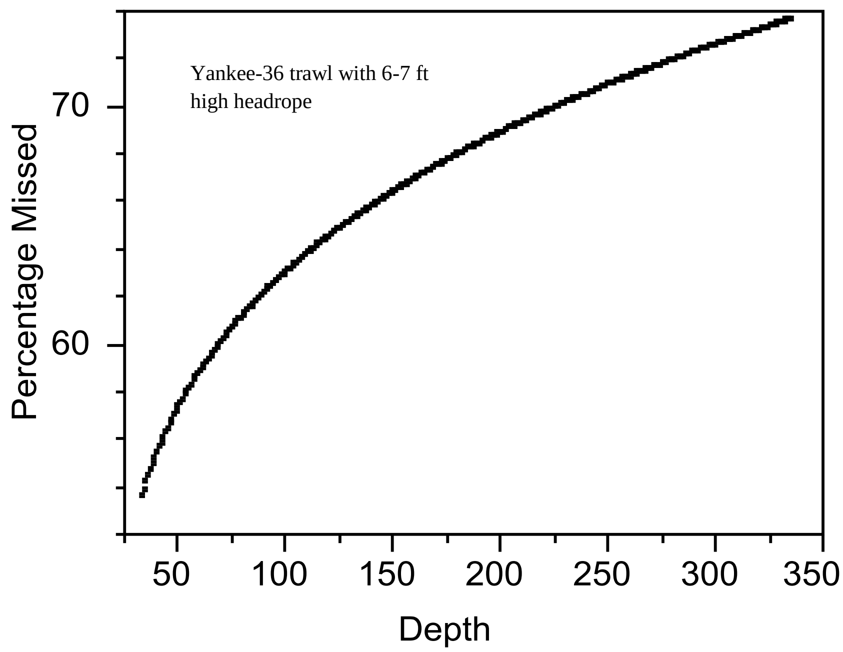


Figure 12. Estimated percentage missed above seven feet; the height of Yankee – 36 trawl based on the depth of the water column using projections from vertically elongated gillnets.

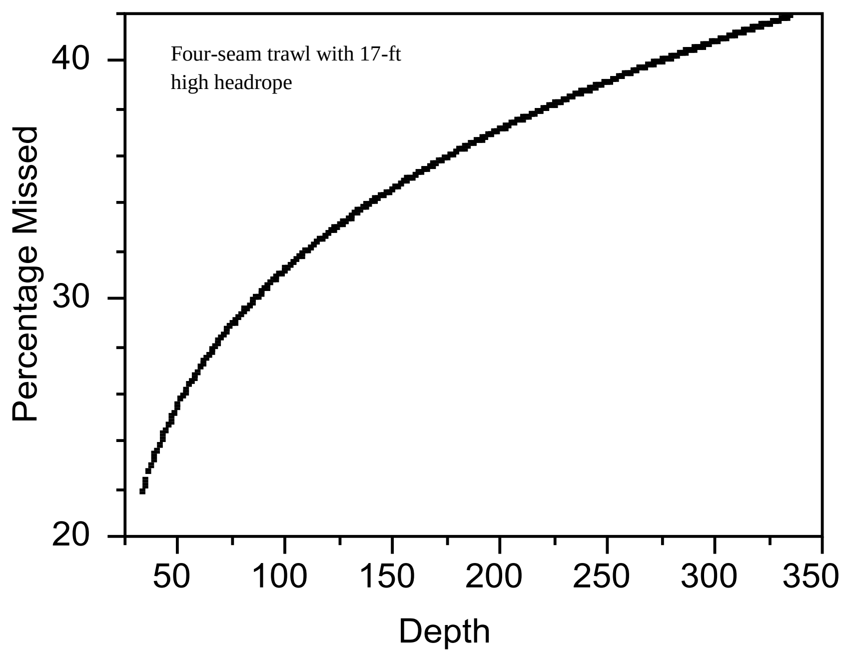


Figure 13. Estimated percentage missed above 17 feet; the height of the new Four – Seam trawl based on the depth of the water column using projections from vertically elongated gillnets.