Not to be cited with our reference to authors
ICES CM 2010/E:16

Dismissing Dogma? What do we really know about the spiny dogfish, *Squalus acanthias*, population in the U.S. western north Atlantic Ocean

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Abstract

The status of the spiny dogfish, *Squalus acanthias*, stock in the U.S. portion of the northwest Atlantic has become a contentious issue. Distributed from Maine to Florida, this species was once considered to be the most abundant shark throughout its' U.S. range. As a result of reported declines below biomass threshold levels, in early 2000 the Mid-Atlantic, New England Fishery Management Councils, and Atlantic States Marine Fisheries Commission implemented a management plan which imposed annual quotas and possession limits for vessels fishing in both federal and state waters. Due to such characteristics as slow growth, extended gestation period, small litter size, and a spawning stock biomass (SSB) below threshold levels as recent as 2005, the spiny dogfish population was not anticipated to rebound for more than a decade. However, recent Northeast Fishery Science Center (NEFSC) survey data suggest a four-fold increase in SSB has occurred and has been maintained between 2005-2009. Based on the aforementioned life history characteristics, this substantial increase in biomass is considered biologically unrealistic. We present preliminary data to support hypotheses' that are divergent to common paradigms: 1) we hypothesize that the biological unrealistic increases in SSB may be due, in part, to a substantially more active vertical movement pattern that prevents this species from being effectively captured by NEFSC otter trawl surveys; 2) we hypothesize that there are regional differences in the reproductive cycles across this species U.S range; and 3) there may be more than one genetic stock of dogfish along the U.S. Atlantic east coast.

Introduction

The status of the spiny dogfish, *Squalus acanthias*, population along the U.S Atlantic East coast has become a contentious issue. In this region, spiny dogfish are most abundant from Maine to Cape Hatteras (Collette and Klein-MacPhee, 2002). Seasonal migrations are thought to occur northward (from North Carolina) in the spring and summer, and southward in the fall and winter (from the Gulf of Maine; Stehlik, 2007; Cudney and Rulifson, 2008). In the past, spiny dogfish were considered to be the most abundant shark species along the U.S Atlantic East coast. However, with the decline of traditional groundfish resources in the last 25 years, an increase in directed fishing for spiny dogfish resulted in a nearly ten-fold increase in U.S. landings from 1987-1996. The culmination of this fishing pressure was presumed responsible for the population biomass falling below threshold levels in 2005. Based on this reported decline and low biomass levels, conservation groups are suggesting the species should be protected. In contrast, the commercial fishing industry believes spiny dogfish are actually abundant in these waters. The National Marine Fisheries Service and the Mid Atlantic Fishery Management Council, agencies charged with managing the spiny dogfish, are thus in the middle of a volatile issue. Currently these agencies rely on Northeast Fishery Science Center (NEFSC) bottom trawl survey data to estimate spawning stock biomass and make management decisions. A management plan consisting of a 4 million pound annual quota and reduced possession limits for vessels fishing in federal waters was established in 2000. Despite these measures, the "k" selected life history characteristics of this species were thought to preclude the spiny dogfish stock from rebounding before 2020. However, recent NEFSC survey data suggest a four-fold increase in spawning stock biomass occurred between 2005-2008 (Armstrong, 2008); an increase considered biologically unrealistic by many. We present preliminary data to support hypotheses' that are divergent to common paradigms: 1) we hypothesize that the biological unrealistic increases in SSB may be due, in part, to a substantially more active vertical movement pattern that prevents this species from being effectively captured by NEFSC otter trawl surveys; 2) we hypothesize that there are regional differences in the reproductive cycles across this species U.S Atlantic East coast range; and 3) there may be more than one genetic stock of dogfish along the U.S. Atlantic East coast.

Materials and methods

Satellite tag data

In 2007, three adult female spiny dogfish, were fitted with x-tags at 43°24.10' N 070°10.61' W on October 31st (n = 1) and November 7th (n = 2). An additional 20 adult dogfish were fitted with x-tags in October 2009 (five female and five male), and July 2010 (five female and five male) within approximately 10 km of the previous deployment location. All tags used in this ongoing study were set to release 12 months after deployment. Tag attachment was accomplished by drilling through the second dorsal spin and securing the x-tag using a 7.5 cm monofilament tether protected with flexible silicone tubing. Initial geolocation positions were produced by Microwave Telemetry, using a proprietary algorithm, were utilized in our analyses. End points of each track were assigned by choosing the first day at liberty where the depth of the shark was consistently near the surface water.

Reproduction

Twenty five female dogfish were collected from each of three regions along the U.S. Atlantic East coast; the Gulf of Maine (GOM), New Jersey (NJ), and North Carolina (NC). The collections occurred during two discreet time periods November, 2009 and January 2010. Each geographic area was sampled within three days of each other. To determine the gestational stage of pups, the uteri were removed and dissected to determine if pups or candles were present. If pups were present their stretch total length (STL)) was measured and sex was recorded. The STL was measured from the anterior most point of the snout to the posterior most point of the upper lobe of the caudal fin while fully extended. The STL was used as the standard length measure for embryos because caudal fin morphology changes during development (Sulikowski et al., 2007).

Genetics

Fin clips from a mix of 50 males and females were taken at each of the three aforementioned locations along the eastern coast of the United States, in the Spring of 2007 and 50 fin clips from a mixture of males and females were collected from the Gulf of Maine in the Fall of 2007, Summer 2008, and Fall of 2008. Fin clips were stored in 95% alcohol until DNA extraction using DNeasy extraction kits by Qiagen. These products were stored frozen until further analysis commenced. DNA from each sample was then amplified using polymerase chain reaction at 10 microsatellite loci developed for *S. acanthias* (McCauley et al 2004; Verissimo et al 2010) using fluorescently labeled primers. Products were genotyped using an ABI 3130 genetic analyzer and scored by hand. These genotypes were analyzed to detect possible scoring errors, Hardy-Weinberg Equilibrium, and linkage between loci. The frequency and size of alleles for each sampling location were analyzed to determine relationships using F statistics (Fstat 2.9.3.2) and pairwise comparisons of allele frequency differences using Fisher's exact test (Arlequin 3.1). Allelic differentiation was examined to test homogenous distribution across all sampling locations. Significance of p-values was adjusted using Dunn-Sidak (or Bonferroni) methods to account for multiple comparisons while maintaining a level of significance of 0.05.

Results/Discussion.

Satellite tags.

To date, 23 satellite tags have been deployed on spiny dogfish within the GOM. Tag retention rates have ranged from six weeks to nine months. Geolocation data from three sharks tagged in 2007 suggest an eastern movement into offshore waters after tagging, with two moving into southern waters off the coast of NJ and New York (NY), USA where the tags popped off (Sulikowski et al, in review; Figure 1). In addition, five x-tags deployed in 2008 have transmitted data. Although filtering of that geolocation data is underway, all five tags released from the fish within the GOM. Interestingly, the dates the tags released from the sharks indicate that this occurred during the winter and spring of 2010. The occurrence of dogfish in the GOM (and off the coast of NJ and NY) during this temporal period is in contrast to studies by Rulifson et al. (2002) and Stehlik (2007), who suggest this species overwinters off the coast of North Carolina. Diel depth patterns were interesting in that each shark appeared to be active vertically during both the day and night (i.e not simply resting on the benthos; Figure 2a-c), a pattern suggested by Rago et al., (1999) and Stehlik (2007) but until now never documented. This vertical activity has the potential to reduce the catch ability of this species in a bottom trawl survey. We are currently evaluating this phenomenon in more detail with the use of additional satellite tags and side by side bottom and midwater trawl surveys.

Reproduction:

The preliminary data illustrated in Figure 3a-c suggest that there are asynchronies in the reproductive biology of this species along the U.S. eastern seaboard based on region of capture. For example, the samples from GOM in Figure 3a are clearly pupping (giving birth) in November as near term pups and newly formed candles were found within females dissected during that month. Females captured from both NJ (Figure 3b) and NC (3c) in November also appear to follow that same gestational trend. However, unlike the GOM, females from both NJ and NC have another size class of pups moving through gestation (those ranging from ~40 to ~140 cm TL). In January, more anomalies become apparent as the 40mm to 120mm size class that was observed in November from specimens captured from both NJ and NC has grown, and now encompasses a size range of ~100mm to 190mm in total length. However, this size group is absent from the GOM. Additionally, full term pups were only observed in the females collected from NC in January, while newly formed candles are present in the uteri of dogfish captured from all geographic areas. We are currently collected additional specimens from each location in hopes of better understanding the apparent spatial anomalies in reproduction.

Genetics

There was no spatial population structuring detected along the U.S. East coast as indicated by low Fst values (Table 1), which is in agreement with other studies (i.e Stehlik, 2007). However, there was significant differentiation temporally in the GOM. Samples collected in the summer of 2008 were significantly different from all other GOM samples and those collected in the autumn of 2008 were significantly different than those from autumn 2007. This indicates the possible presence of multiple populations of spiny dogfish in the U.S portion of the western Atlantic. Because the summer 2008 samples were completely differentiated from any other sample, there could be temporal movement of spiny dogfish into the GOM or finer scale spatial structuring as these samples were obtained more inshore than all other samples. We are currently collecting additional tissues in order to investigate the observed anomalies in population structure along the U.S. Atlantic East coast.

Summary

Although preliminary in nature, the anomalies described herein challenge three antiquated paradigms of spiny dogfish found along the U.S. east coast. These are 1) Seasonal migrations occur northward in the spring and summer, and southward in the fall and winter; 2) that this species has a synchronous reproductive cycle; and 3) that spiny dogfish are a unit stock. Further research is being conducted in order to better understand the significance of the observed anomalies.

Acknowledgments

We thank Tim Arienti for help in capture of the fish for x-tag deployment, and Viking Village, Sea Trade Inc, and Garden State Seafood Association for assistance in collection and transportation of fish along the U.S. Atlantic east coast for genetic and reproductive studies. Thanks are further extended to Marie Quinlan, Cassidy Peterson, and Ryan Knotek for assistance in organization of the data. This manuscript represents MSC contribution number XX.

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Figure 1. Geolocation deployment (circle) and pop off (sharks) locations for spiny dogfish using x-tags. All pop off locations were within 600 km of the deployment location regardless of time at liberty.

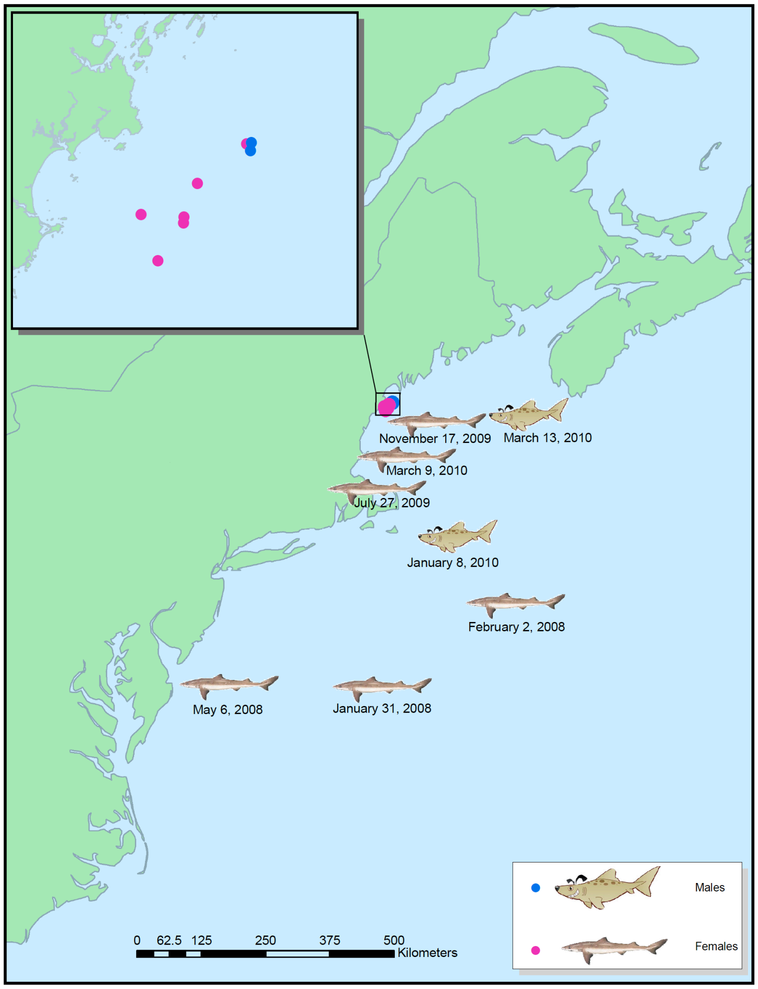


Figure 2a-c: Fine scale representative vertical movement patterns for three spiny dogfish (male # 96476 panel a; male 96477 panel b; and female # 96479, panel c), tagged with x-tag pop off satellite tags. Movement patterns are depicted over a 48 hour period.

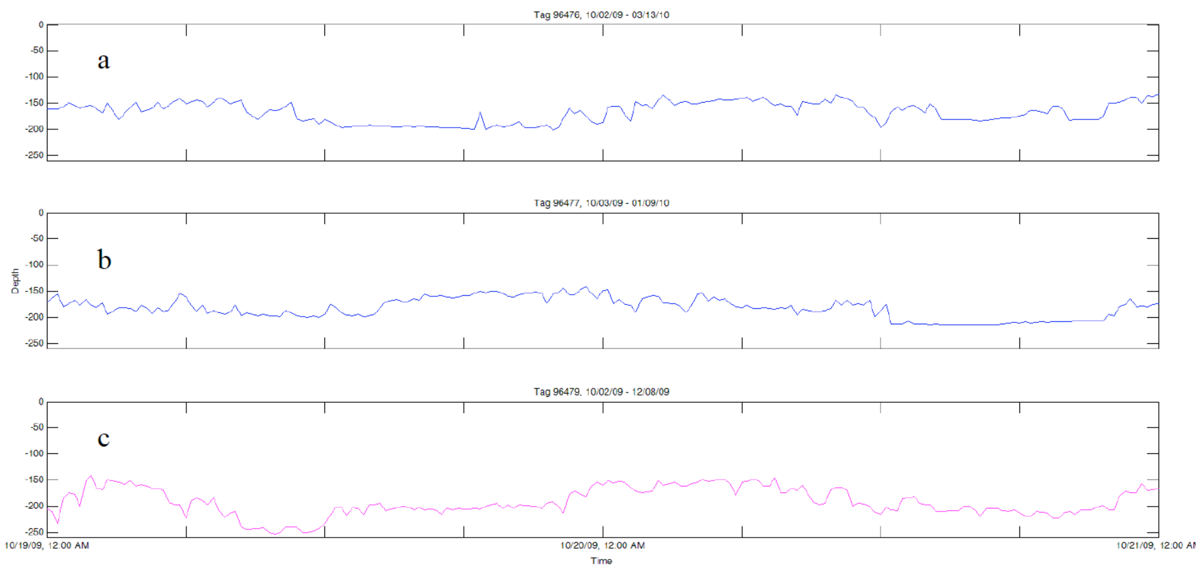
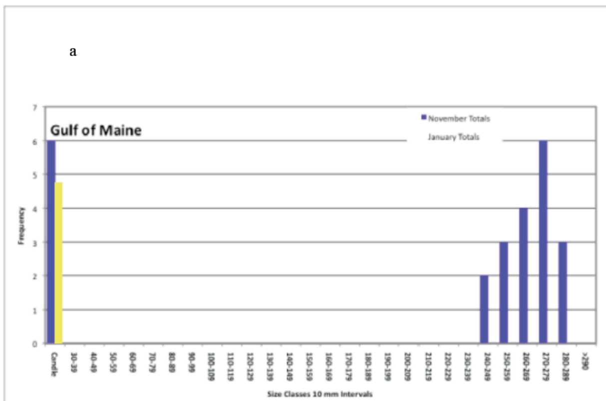
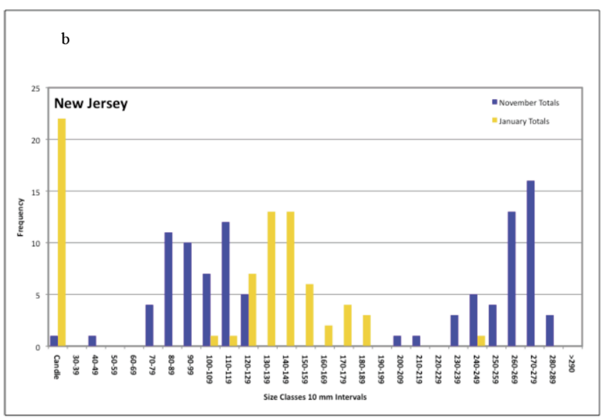


Figure 3a-c: The monthly size frequency of spiny dogfish pups in 10mm size class increments captured from (a) Gulf of Maine (GOM;), (b) New Jersey (NJ), and (c) North Carolina (NC). The collections occurred during two discreet time periods November, 2009 and January 2010.





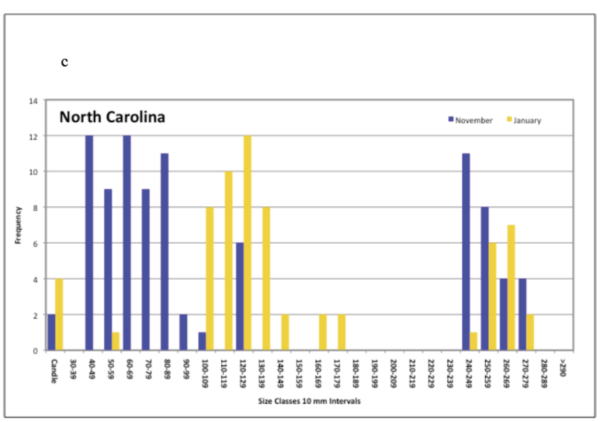


Table 1. Spatial and temporal comparisons of F_{ST} values between locations in the western north Atlantic and Gulf of Maine, respectively. Significant differences between locations with pairwise comparisons using Fisher's exact test are highlighted.

		Spring '07			Fall '07	Summer '08
		NC/VA	***DE/NJ***	***G of M***	***G of M***	***G of M***
Spring '07	***DE/NJ***	0.00106	-	-	-	-
	G of M	0.00017	0.00171	-	-	-
Fall '07	***G of M***	0.01023	0.01158	0.00709	-	-
Summer '08	***G of M***	0.01871	0.01967	0.01946	0.03853	-
Fall '08	**G of M**	0.01183	0.00885	0.00789	0.02010	0.01328