EARLY LIFE ECOLOGY OF SAILFISH, *ISTIOPHORUS PLATYPTERUS*, IN THE NORTHERN GULF OF MEXICO

A Thesis

by

JEFFREY RICHARD SIMMS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Jay Rooker
Committee Members,	Ayal Anis
	Anna Armitage
Head of Department,	Thomas Lacher

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ABSTRACT

Early Life Ecology of Sailfish, *Istiophorus platypterus*,
in the Northern Gulf of Mexico. (May 2009)
Jeffrey Richard Simms, B.S., The University of North Carolina – Chapel Hill
Chair of Advisory Committee: Dr. Jay Rooker

Sailfish, *Istiophorus platypterus*, are commonly taken by the recreational and commercial fisheries in the Gulf of Mexico (Gulf) and larvae are frequently reported in the region, indicating the Gulf's potential role as spawning and/or nursery ground of sailfish. Five ichthyoplankton surveys were conducted in shelf and slope waters of the northern Gulf during the summers of 2005 (May, July, September) and 2006 (June, August). Surveys were conducted off the Texas and Louisiana coasts from 27 – 28°N and 88 – 94°W. During the two year study, 2,426 sailfish larvae were collected, ranging in size from 2.0 – 24.3 mm standard length (SL). Sailfish larvae were collected in 45.0% of collections with a peak density ranging of 51.5 larvae per 1000 m^{-2} of water sampled, and the highest larval abundances were observed within frontal features of the Loop Current. Sagittal otoliths were extracted from 1,236 larvae, and otolith microstructure analysis indicated sailfish ranged in age from 5 – 25 days post-hatch. Hatch-date distributions indicated fish were from early May to mid September spawning and/or hatching events. Instantaneous growth coefficients (g) ranged from 0.113 to 0.127 with intra- and inter-annual variations in growth observed. Growth coefficients correspond to a 10.7 – 11.9% increase in length per day. Instantaneous daily mortality rates (Z) were estimated from regressions of the decline in $\log_e$-transformed abundance on age and ranged from 20.4% to 29.2% per day suggesting large losses during the early life interval. Instantaneous weight-specific growth coefficients (G) ranged from 41.5% to 45.9% per day and were indexed to daily mortality to assess intra- and inter-annual variation in recruitment potential. Recruitment indices > 1.0 were observed during all surveys, suggesting cohort biomass was increasing and that conditions were favorable for growth, survival and recruitment. The results of this study indicate that the northern Gulf represents viable spawning and nursery habitat of sailfish and the sustainability of Atlantic sailfish populations may be linked to spawning in the Gulf.

DEDICATION

To my dear wife Mary for her constant support and encouragement and for never complaining when I took off to go fishing for ‘work’ and to my parents for their continual love and support throughout my academic career.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Billfishes (family Istiophoridae) are highly sought pelagic species throughout tropical and sub-tropical oceans (Prince et al., 1986; Ortiz et al., 2005). Sailfish, *Istiophorus platypterus*, white marlin, *Kajikia albida*, and blue marlin, *Makaira nigricans*, stocks in the Gulf of Mexico (Gulf) are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) and biomass levels of all three species are below the level needed to support maximum sustainable yield (MSY) (ICCAT, 2001; NMFS, 2002). Furthermore, current levels of fishing mortality are above that needed to maintain MSY, thus increasing the strain on already depleted stocks (ICCAT, 2001; NMFS, 2002). Pelagic longline fishery data indicates that much of this mortality results as bycatch in commercial fisheries targeting tunas and swordfish, *Xiphias gladius* (Ortiz and Brown, 2002; Goodyear, 2003), which contributes to ratios of current fishing mortality (F) to sustainable mortality (M) ranging from 1.4 for sailfish to 8.3 for white marlin (NMFS, 2002; Restrepo et al., 2003). Although sailfish stocks in the Atlantic have not declined to the extent of blue or white marlin, sailfish bycatch rates in the Gulf are high (Ortiz and Brown, 2002), and further reductions in population size could alter ecosystem structure and stability in the Gulf (Goodyear, 1999; Worm and Myers, 2003).

Declining populations emphasize the need for a better understanding of sailfish

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This thesis follows the style of *Fishery Bulletin*.

biology and habitat use, as well as the natural and anthropogenic causes of mortality and recruitment variability (Holland, 2003; Serafy et al., 2003). Sailfish are a fast growing and long-lived pelagic species (Chiang et al., 2004; Ortiz et al., 2005; Hoolihan, 2006), which do not display extensive, trans-oceanic migrations (Hoolihan, 2003; Ortiz et al., 2005). Recent age and growth studies on adult and sub-adult specimen indicate rapid growth during the first two years (Chiang et al., 2004; Ortiz et al., 2005; Hoolihan, 2006) and maturation at 3 – 5 years (Chiang et al., 2006), with a protracted spawning season throughout their range (de Sylva and Breder, 1997; Chiang et al., 2006). Despite this recent work, corresponding studies on sailfish biology during the early life period are limited.

Information on spawning habitat and early life stages of istiophorids has been derived from ichthyoplankton surveys conducted in the Atlantic Ocean and Caribbean Sea (Luthy et al., 2005; Sponaugle et al., 2005; Richardson, 2007). Studies conducted in the western Atlantic suggest that sailfish grow rapidly and experience high mortality during early life. However, information on the early life history of istiophorids in other potential spawning areas (i.e. the Gulf) is limited (Luthy et al., 2005; Sponaugle et al., 2005; Tidwell, 2008), despite data that suggests adult populations are broadly distributed (Ortiz et al., 2005; NMFS, 2008). Thus, a better understanding of the extent of spawning habitat and the factors that influence growth and survival during early life is necessary to properly manage these ecologically important apex predators.

CHAPTER II

EARLY LIFE ECOLOGY OF SAILFISH, *ISTIOPHORUS PLATYPTERUS*, IN THE NORTHERN GULF OF MEXICO

Introduction

Mortality during the early life interval of marine fishes is high, and subtle variations in growth and survival during this period often determine year class strength (Houde, 1987; Fuiman, 2002; Jones, 2002). Studies have shown that rapidly growing individuals have shorter larval durations and consequently spend less time exposed to predators (Houde, 1989; Leggett and Deblois, 1994; Sponaugle et al., 2006). This reduction in predation pressure can lead to differences in early life survival and recruitment potential (Bailey and Houde, 1989; Rooker and Holt, 1997; Bergenius et al., 2002), which can translate into large variations in adult population size (Davis and Levin, 2002; Houde, 2002; Jones, 2002). Thus, understanding biotic and abiotic factors affecting growth during the early life interval can be used to assess important determinants regulating survival and recruitment potential.

Early life stage growth and survival rates often vary temporally and spatially with environmentally-mediated differences frequently observed in marine species (Bergenius et al., 2002; Cowan and Shaw, 2002; Sponaugle et al., 2006). Variations in growth and survival during the early life stages of fishes have been linked to biotic and abiotic factors, including food availability (Houde, 1989; Fitzhugh et al., 1996), predation pressure (Houde, 2002) and physicochemical conditions (McCormick and

Molony, 1995; Folkvord, 2005; Sponaugle et al., 2006). More rapid growth and increased survival have been observed in areas of higher sea surface temperature (Sponaugle et al., 2006) and increased chlorophyll and zooplankton abundance (Grimes and Finucane, 1991; Wexler et al., 2007) for species in reef and estuarine habitats. While the factors influencing temporal and spatial variations in growth during the early life interval are well studied in estuarine- and reef-dependent species, comparable studies for pelagic fishes are limited.

Distribution and abundance of reef and pelagic fish larvae has been linked to physicochemical conditions such as temperature and salinity (Hare et al., 2001; Okazaki and Nakata, 2007) and ocean hydrography (Olson and Backus, 1985; Richards et al., 1993; Hanisko and Lyczkowski-Shultz, 2003). Environmental and hydrographic conditions vary spatially and temporally, often leading to variations in larval fish distribution (Loeb et al., 1983; Cowen et al., 1993; Hardman-Mountford et al., 2003). Frontal features resulting from hydrodynamic convergence have been shown to influence phytoplankton and zooplankton production (Grimes and Finucane, 1991; MacGregor and Houde, 1996) as well as aggregate larval fishes (Sabates, 1990; Govoni and Grimes, 1992). However, densities are often variable throughout frontal features, suggesting that conditions influencing larval fish abundance at fronts vary (Govoni et al., 1989; Govoni and Grimes, 1992). Thus, an understanding of hydrodynamic conditions and frontal features within the Gulf is critical to identifying factors that impact the distribution and abundance of pelagic fish larvae in the region.

In the Gulf, the Loop Current produces dynamic oceanographic conditions that vary spatially and temporally and affect all aspects of biology in the region (Richards et al., 1989; Lamkin, 1997; Sturges and Leben, 2000). The Loop Current is comprised of warm surface waters from the Caribbean Sea entering the Gulf through the Yucatan Strait and turning eastward before exiting through the Straits of Florida (Sturges and Leben, 2000). In the process of turning eastward the clockwise rotating current forms a 'loop' which pushes northwestward with varying intensity each year, and the northern extent of the current reaches as far as the Mississippi River delta (Vukovich and Maul, 1985; Wiseman and Dinnel, 1988). Anti-cyclonic eddies composed of warm surface water (warm core eddies) spin off from the main current and often drift westward toward Texas and Mexico, while adjacent cyclonic eddies of cold water (cold core eddies) develop (Vukovich, 1988; Lamkin, 1997). These features vary in frequency and intensity each year, suggesting that the Loop Current and its associated features play a role in the accumulation, transport, and retention of fish larvae in this region (Vukovich, 1988; Richards et al., 1993; Lamkin, 1997).

Several species of pelagic fishes including billfishes, tunas and swordfish reside in the northern Gulf, with the larval and early juvenile stages of each taxa only recently investigated (Govoni et al., 2003; Serafy et al., 2003; Luthy et al., 2005). Data on distribution, abundance, age, and growth of pelagic taxa are derived from ichthyoplankton surveys which suggest that the spatial distributions of larvae are influenced by physical processes (Richards et al., 1993; Hanisko and Lyczkowski-Shultz, 2003; Hoffmeyer et al., 2007). Frontal boundaries of the Loop Current and its associated features have been shown to produce higher abundances of pelagic taxa throughout the northern Gulf (Richards et al., 1989; Lamkin, 1997; Hoffmeyer et al., 2007). Additionally, otolith-based demographic data suggests that growth of pelagic fishes is rapid and mortality is high during early life (de Vries et al., 1990; Govoni et al., 2003; Luthy et al., 2005; Sponaugle et al., 2005). Growth and survival during the early life interval has been observed to vary spatially and temporally and is influenced by both biotic and abiotic factors, including chlorophyll levels (Wexler et al., 2007), physicochemical conditions (de Vries et al., 1990; Sponaugle et al., 2005), and diet (Lang et al., 1994; Govoni et al., 2003). While our knowledge of the early life history of some pelagic species has improved in recent years, information on istiophorids is particularly limited (Serafy et al., 2003; Luthy et al., 2005; Sponaugle et al., 2005).

The goal of this study was to assess the early life ecology of sailfish in the northern Gulf. Specific objectives were to characterize sailfish distribution and abundance in the northern Gulf and to assess the influence of oceanographic features on sailfish density and growth. Further, temporal variations in growth, mortality and recruitment potential were assessed using otolith-based age estimates and data on abundance and size of sailfish larvae.

Materials and Methods

Field collections

Five ichthyoplankton surveys were conducted in shelf and slope waters of the northern Gulf during the summers of 2005 (May, July, September) and 2006 (June, August). May and June surveys were considered early season, July and August mid season and September a late season survey. Surveys were conducted in the region from 27 to 28°N and 88 to 94°W, where bycatch of adult billfishes by U.S. longliners peaked from 2000 – 2007, during the summer spawning periods (Goodyear, 1999; NMFS, 2008) (Fig. 1). Istiophorid larvae were collected with paired neuston nets (2 m width x 1 m height frame). Two mesh sizes (500 µm and 1200 µm) were utilized to account for potential differences in capture success between mesh sizes. Nets were towed through the upper meter of the water column at approximately 2.5 knots for 10 minutes. Paired tows were taken at approximately 60 – 70 sampling stations approximately 15 kilometers (km) apart during each survey. Sampling was conducted at approximately 15 km intervals to allow coverage of a large area encompassing multiple oceanographic features. The September 2005 survey was shortened (39 stations sampled) due to weather.

At each station, sea surface temperature (°C), salinity (ppt), and dissolved oxygen (mg/L) were recorded using a Sonde 6920 Environmental Monitoring System (YSI Inc.). Sea surface height (cm) at each station was determined from archived satellite altimetry data provided by the Colorado Center for Astrodynamics Research (CCAR) Real-Time Altimetry Project (R. Leben, pers. comm.), while ocean depth (m) at each station was acquired from bathymetric data from the Marine Geoscience Data System (Carbotte et al., 2004). General Oceanics flowmeters (Model 2030R, Miami, FL) were used to record the amount of water filtered during each tow, which was converted to surface area sampled during each tow (m^{-2}) using a formula provided by the manufacturer. The mean volume of water filtered each day was calculated and used in

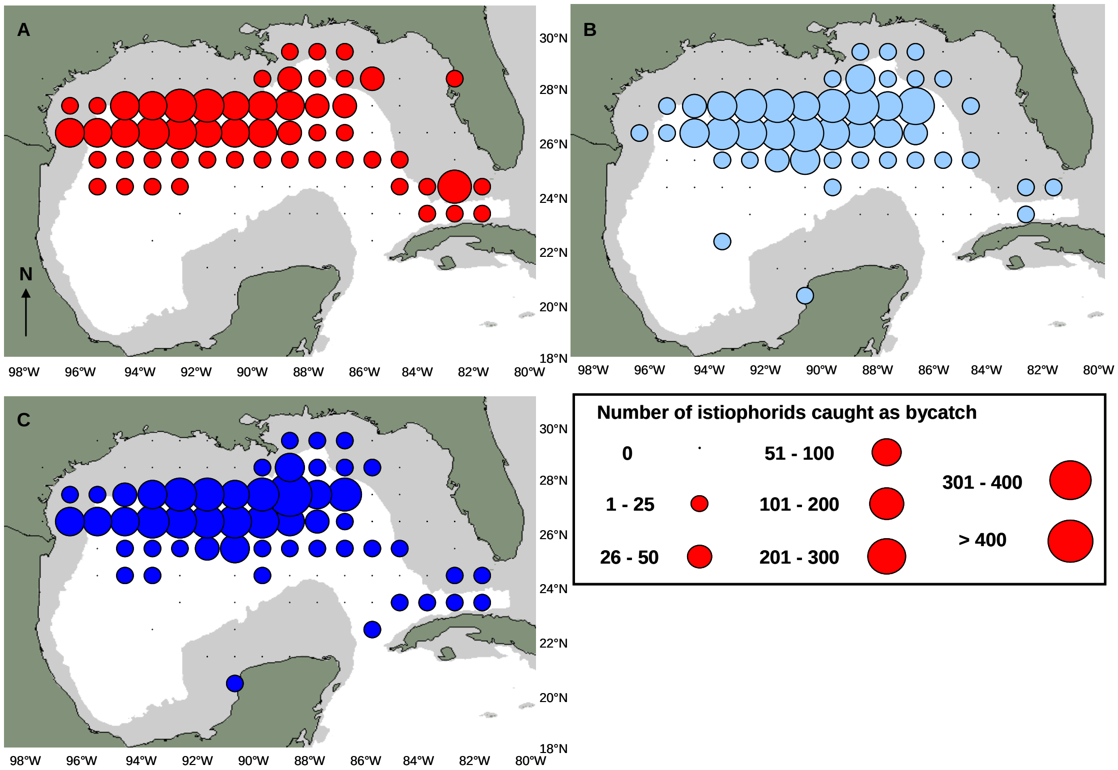

Figure 1

Adult istiophorid bycatch distribution during summer months (May – September) in the Gulf of Mexico from 2000 – 2007. Bubble size represents total number caught in 1° grid. Bycatch information comes from U.S. Pelagic Longline Logbook data. Grey area represents depths ≤ 1000 m. (**A**) sailfish (**B**) white marlin (**C**) blue marlin Note: some locations appear on land as catch locations were binned by whole degrees.

place of inaccurate or unavailable flowmeter readings (6.6% of all tows); readings were deemed inaccurate if they varied by more than 100% from the daily mean. Flowmeter readings were unavailable for the first survey (May 2005), so GPS coordinates were used to determine the surface area sampled in each tow using the equation:

$$\text{Surface area sampled } (\text{m}^{-2}) = \text{distance sampled (m)} * 2 \text{ m (net width)}$$

Paired flowmeter and GPS-based calculations were tested for differences in surface area sampled and found to be non-significant (paired t-test, $p = 0.46$), supporting the use of GPS coordinates when flowmeter readings were unavailable.

Fish larvae and associated biota collected were preserved in 95% ethanol onboard. Preserved samples were sorted in the lab with the use of a Leica MZ stereomicroscope and all istiophorid larvae were counted, removed, and stored in 70% ethanol. Istiophorid larvae were photographed and measured for standard length (SL) to the nearest 0.1 mm before genetic identification.

Genetic identification

Identification of istiophorid larvae to the species level was performed in the lab following the protocol of J. Magnussen and M. Shivji, Nova Southeastern University (pers. comm.). A single eyeball was removed from each istiophorid larva and DNA was extracted using the QIAGEN DNeasy blood and tissue kit (QIAGEN # 69506). Multiplex polymerase chain reaction (PCR) was performed according to the protocol using an Eppendorf mastercycler gradient, QIAGEN Hot Star Taq DNA Polymerase

(QIAGEN # 203203), and PCR grade dNTP mix (QIAGEN # 201901). Four primer pairs were used in each PCR reaction: a universal billfish primer set and species-specific primers for sailfish, white marlin, and blue marlin. PCR reactions were examined via gel electrophoresis using 1% agarose gels containing ethidium bromide. Species identifications were based on gel banding patterns, as each species-specific primer pair yields a unique banding pattern (J. Magnussen and M. Shivji, Nova Southeastern University, pers. comm.) (Fig. 2). Stations with 10 or more istiophorid larvae had a minimum of 25% of larvae randomly selected for identification using a random number generator. If all sub-sampled larvae were the same species, remaining larvae from that station were considered the same species. If more than one species was detected, all remaining larvae from the station were identified genetically.

Larval density and oceanographic features

The total number of sailfish caught at each sampling station during all surveys was divided by that station's surface area sampled to determine larval density in number of larvae per 1000 m^{-2} (no. per 1000 m^{-2}). Average density did not vary between the two mesh sizes (500 μm and 1200 μm) in any survey (paired t-test, all $p \geq 0.05$), indicating no difference in capture success between net sizes. However, mean standard length was smaller in the 500 μm net gear (5.2 mm vs. 5.6 mm; $F_{(1,3116)} = 21.3$, $p < 0.01$), suggesting a larger fraction of smaller larvae were retained by the finer mesh.

Oceanographic condition(s) at each station was determined using remotely sensed sea surface height (SSH) data (Hamilton et al., 2000; Sturges and Leben, 2000; Leben et al., 2002). The high velocity core of the Loop Current and associated anti-

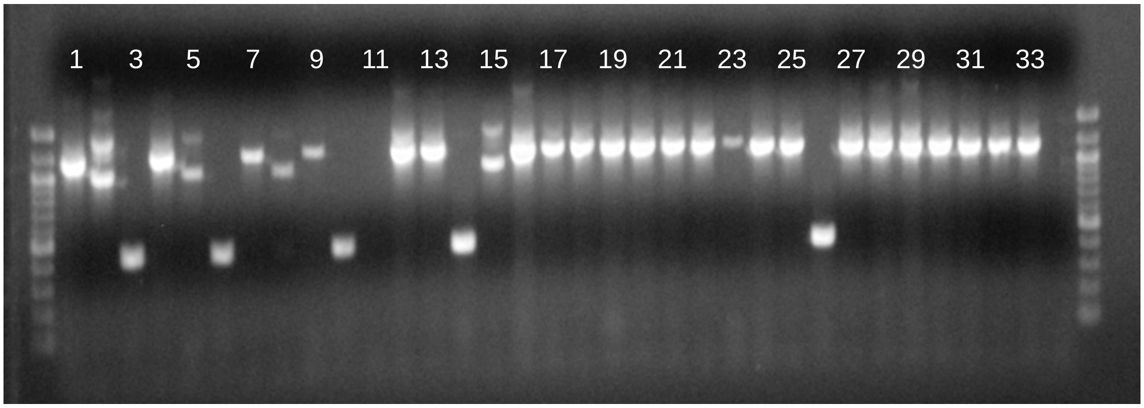

Figure 2

Agarose gel illuminated with ultraviolet light showing PCR products for istiophorid larvae. Lane labels shown at top. Lane 1 contains DNA from an adult sailfish. Lane 2 contains DNA from an adult blue marlin. Lane 3 contains DNA from an adult white marlin. All remaining lanes contain DNA from unknown istiophorid larvae. Larvae were identified to species by comparing DNA banding patterns to those of known controls (1st three lanes). Lanes 5, 8, and 15 indicate larvae are blue marlin. Lanes 6, 10, 14, and 26 indicate larvae are white marlin. All other lanes indicate sailfish larvae with 2 reactions failing to produce PCR product (11 and 34).

cyclonic eddies was defined by the 17 cm sea surface height (SSH) contour (Hamilton et al., 2000; Leben et al., 2002). Thus, stations with a SSH greater than 17 cm were classified as being conducted in an anti-cyclonic eddy (‘Anti-cyclone’). Further, the core of adjacent cyclonic eddies (‘Cyclone’) were identified by a SSH of less than -10 cm. Frontal features associated with the Loop Current and anti-cyclonic eddies have been reported to extend up to 60 km from the 17 cm contour (R. Leben, pers. comm.). Therefore, any collection station within 60 km of the 17 cm SSH contour, but in a SSH > -10 cm, was classified as being in a frontal feature or ‘Front.’ Remaining stations were classified as ‘Open Ocean.’

Otolith microstructure analysis

Sagittal otoliths were extracted, cleared of remaining tissue in immersion oil, and preserved in mounting media (Flotexx, Fisher Scientific #14-390-4) for a subset of sailfish covering the range of standard lengths observed during each survey (Fig. 3A). Mounted otoliths were photographed under high magnification (400x) with an Olympus BX41 light microscope and daily growth increments were enumerated using Image-Pro Plus software (version 4.5, Media Cybernetics Inc.) (Fig. 3B). Inner increments of large otoliths were sometimes difficult to enumerate, thus a regression of growth increment radius on age was used to predict the number of increments at various distances from the core (Rooker et al., 1999). Final age was determined by adding the predicted age for the unreadable section to the increment count for the enumerated section. Corrections to age estimates were made for 52% of all larvae, with 50% of these larvae corrected by only 1 day. If corrections accounted for more than 40% of the final age estimate, the larva was

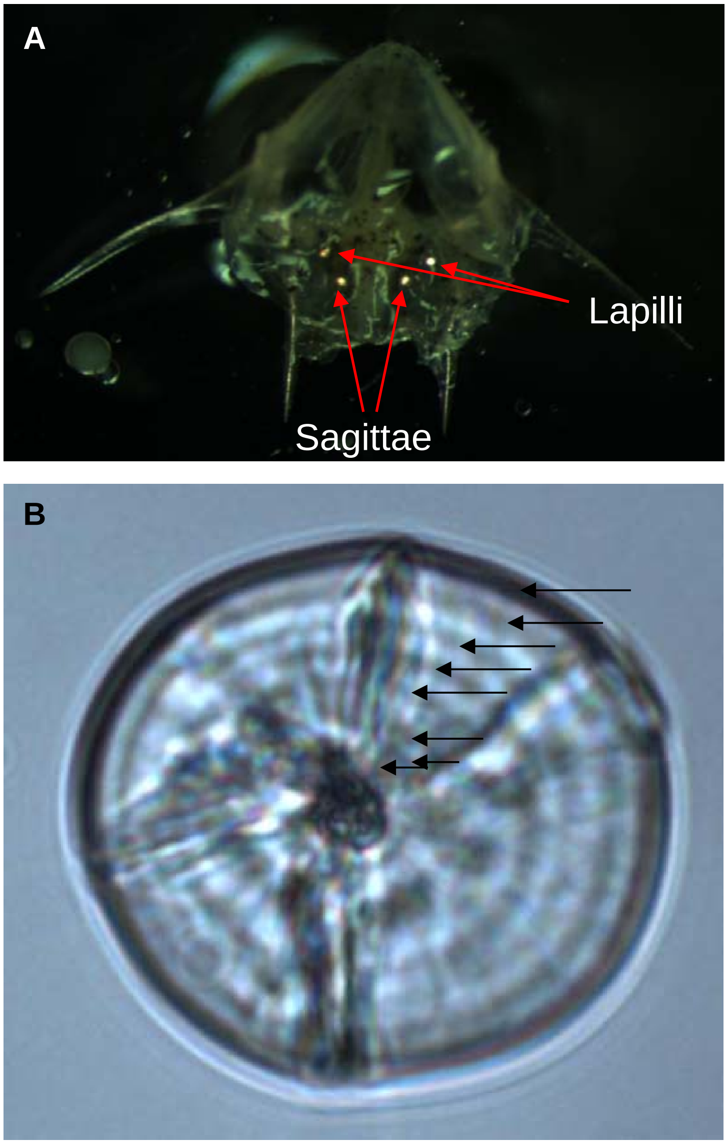

Figure 3

Location of otoliths in a 3.6 mm sailfish larva and growth increments of a sagitta. (**A**) Location of otoliths within a 3.6 mm sailfish larva with body, gills and lower jaw removed. View is ventral with snout facing upward. Otoliths are visible under polarized light; asteriscii are not visible. (**B**) Sagitta from an 8-day post-hatch sailfish (400x magnification). Presumed daily increments indicated by arrows.

not used for age and growth assessments. Two independent readings of daily increments were conducted for a single sagittal otolith from each larva by a single reader; when two readings were within 10% one of the readings was randomly selected for further analysis. When readings differed by >10%, a third independent reading was performed. If the third reading differed from the others by >10%, the otolith was not used for age and growth assessments. If the third reading was within 10% of one of the former readings, one of the two similar readings was randomly selected for analysis.

To date, daily increment formation has not been validated for istiophorids due to the difficulty associated with keeping larvae alive in captivity (Post et al., 1997; Idrisi et al., 2003). Nevertheless, daily increment formation has been assumed for prior studies on larval istiophorids (Luthy et al., 2005; Sponaugle et al., 2005) and is supported by otolith microstructure of juvenile and young adult blue marlin (Prince et al., 1991).

Growth, mortality and hatch dates

Growth rates were determined by using otolith-derived age estimates (n = 1,236) and length data. Due to the fact that ages varied among surveys, with older sailfish present later in the season, growth-rate analyses were conducted on a limited age range (≤ 18 days or the maximum age in May 2005 collections) to minimize any affect that variable age ranges might have on growth analysis (Rilling and Houde, 1999). Daily instantaneous growth coefficients (g) were calculated from an exponential model: $L_t = L_0e^{gt}$, where L_t = length (mm SL) at time t; L_0 = the estimated length at hatching, g = the instantaneous growth coefficient (/d), and t = the otolith-derived age (days after hatching). Ages of sailfish without an otolith-derived age were predicted using age-length relationships (n = 1118). A total of 72 sailfish larvae were damaged, preventing SL measurements and, therefore, age estimates.

Mortality estimates for each survey were estimated from regressions of the decline in $\log_e$ abundance on age. Mortality estimates were assessed over a short interval in order to minimize the effects of gear avoidance behavior by larger larvae (Houde, 1987). A five-day interval was deemed unreasonable due to broad peaks in age distributions for some surveys resulting in positive mortality estimates. Further, differences in mortality estimates were negligible between eight- and ten-day intervals (10% different), thus mortality estimates were based on a ten-day interval. The age of peak abundance varied across survey, thus mortality was calculated beginning at age of peak larval abundance and also beginning at ten days post-hatch for each survey for comparison. Differences in mortality were negligible for all surveys (less than 15% different); therefore all mortality estimates begin at ten days post-hatch. Daily instantaneous mortality rates (Z) were calculated from the exponential model of decline: $N_t = N_0e^{-Zt}$, where N_t = abundance at time t, N_0 = the estimated abundance at hatching, Z = the instantaneous mortality coefficient (/d), and t = the otolith-derived age.

Dry weight (mg) was calculated for larvae from all surveys using the length-weight relationship of Luthy et al. (2005): weight (mg) = $0.002(\mathrm{SL(mm)})^{3.0118}$. Weight-at-age data were fitted with exponential growth models to determine weight-specific instantaneous growth coefficients (G) for each survey using the equation: $W_t = W_0e^{Gt}$, where W_t = dry weight (mg) at time t; W_0 = the estimated weight at hatching, G = the weight-specific instantaneous growth coefficient (/d), and t = the otolith-derived age.

The recruitment potential of each survey was assessed by examining the ratio of weight-specific growth to daily mortality (*G:Z*). This ratio incorporates both growth and mortality and is used as an index of stage-specific survival of larval cohorts (Rilling and Houde, 1999; Rooker et al., 1999). A survey with a $G:Z > 1.0$ was considered to be gaining biomass with individuals having an increased probability of survival (Houde and Zastrow, 1993).

Data analysis

Prior to parametric testing, the assumption of normality was evaluated with a Kolmogorov-Smirnov test with departures from normality observed in some situations; however, departures from normality are unlikely to influence results (Underwood, 1997). Homogeneity of variances was tested with Levene's test, and transformations were performed to minimize heteroscedasticity when required: standard length and age data were Ln transformed, and, due to the presence of zero values, density data were Ln+1 transformed. However, heterogeneity was still observed in some instances. In situations of unequal variances a non-parametric analysis (Brown-Forsythe F-Test; Brown and Forsythe, 1974) was compared to parametric results, but no differences in significance ($\alpha = 0.05$) were observed between parametric and non-parametric tests. In response, only parametric tests are presented.

Temporal variation in environmental parameters and larval density was analyzed across year and survey using a one-way analysis of variance (ANOVA) due to unequal replicates in 2005 and 2006. One-way ANOVA was also performed to assess temporal variation in length and age of sailfish larvae with year and survey as factors. Spatial variation in environmental parameters and larval density was analyzed across features with a one-way ANOVA (factor: oceanographic feature). *Post-hoc* differences among levels of the main effect were examined with Tukey's honestly significant difference (HSD) test when variances were equal and with a Dunnett's T-3 test when variances were unequal (Zar, 1996, Mikulas and Rooker, 2008). Analysis of covariance (ANCOVA) was used to test for spatial and temporal variations in growth and mortality (covariate: age). ANCOVA models were used to determine if the slopes of the regression lines differed (slopes test). Statistical power (β) was used to assess the likelihood of type II error in ANOVA and ANCOVA analysis.

A multiple regression model was developed to assess the influence of biotic and abiotic factors on sailfish density. The full regression model included sea surface temperature (°C), salinity (ppt), dissolved oxygen (mg/L), sea surface height (cm), and ocean depth (m) as factors. A forward selection multiple regression approach was used such that only variables which significantly add to the model are reported (MacNally, 2000; Braca et al., 2006). Pearson correlation coefficients were also calculated to evaluate the strength and direction of relationships between larval density and individual model factors. All data analysis was performed with SPSS 15.0 (SPSS Inc., Chicago, IL) and significance was accepted at the $\alpha = 0.05$ level.

Results

Environmental conditions

Temporal variation across surveys was pronounced for sea surface temperature (ANOVA, $F_{(4, 283)} = 386.0$, $p < 0.01$), salinity (ANOVA, $F_{(4, 283)} = 26.6$, $p < 0.01$) and dissolved oxygen (ANOVA, $F_{(4, 283)} = 36.2$, $p < 0.01$). Mean temperature, by survey, ranged from 26.4 – 30.4 °C in 2005 and 28.7 – 30.1 °C in 2006 with peak temperatures observed in mid season surveys of both years (July and August, respectively) (Table 1). Mean salinity, by survey, ranged from 35.2 – 36.5 ppt in 2005 and 35.8 – 36.2 ppt in 2006 with increased salinities in the final survey of 2005 and 2006 (September and August, respectively). Mean dissolved oxygen (DO) for 2005 surveys ranged from 6.3 – 7.1 mg/L and varied significantly among surveys (May-September: ANOVA, $F_{(1, 97)} = 39.0$, $p < 0.01$; July-September: ANOVA, $F_{(1, 97)} = 7.3$, $p < 0.01$). A probe malfunction during August 2006 sampling resulted in inaccurate DO measurements.

Spatial variations in sea surface temperature, salinity, and dissolved oxygen were detected across the four oceanographic features investigated: anti-cyclone, cyclone, front and open ocean. Sea surface temperature was lower in cyclones (25.5°C) compared to all other features during May 2005 collections (ANOVA, $F_{(3, 56)} = 5.9$, $p < 0.01$) (Table 1); however, during August 2006 collections sea surface temperature was lower in frontal features (29.9°C) compared to anti-cyclones (30.3°C) (ANOVA, $F_{(2, 63)} = 9.5$, $p < 0.01$). Salinity varied across oceanographic features during all but the August 2006 survey: May 2005 (ANOVA, $F_{(3, 56)} = 10.1$, $p < 0.01$), July 2005 (ANOVA, $F_{(3, 57)} = 13.3$, $p < 0.01$), September 2005 (ANOVA, $F_{(2, 36)} = 96.6$, $p < 0.01$), and June 2006 (ANOVA, $F_{(3, 58)} = 3.0$, $p = 0.04$). Salinity was significantly higher within frontal features compared to cyclones during May 2005 (35.9 vs. 35.2, respectively) and September 2005 (36.7 vs. 34.7, respectively). However, consistent patterns were not observed across all surveys as salinity was lower in the open ocean (34.5) compared to other features during July 2005,

Table 1

Environmental conditions for stations classified within four oceanographic features: anticyclone, cyclone, front or open ocean during ichthyoplankton surveys in the northern Gulf of Mexico in 2005 and 2006. Number of collections conducted within each feature during each survey is given (*n*). Mean temperature (°C), salinity (ppt) and dissolved oxygen (mg/L) are arranged by survey and oceanographic feature. Environmental parameters were recorded at the surface for each sampling station during all surveys. Dissolved oxygen is not reported for August 2006 survey due to probe malfunction.

Survey	Oceanographic feature	*n*	Temperature (SD)	Salinity (SD)	Dissolved oxygen (SD)
May 2005	Anticyclone	12	26.7 (0.71)	35.7 (0.65)	7.1 (0.64)
	Cyclone	9	25.5 (0.49)	35.2 (0.39)	6.9 (0.17)
	Front	19	26.9 (1.01)	35.9 (0.32)	6.9 (0.64)
	Open ocean	20	26.3 (0.84)	35.0 (0.69)	7.3 (0.98)
	Total	60	26.4 (0.94)	35.5 (0.66)	7.1 (0.74)
July 2005	Anticyclone	15	30.3 (0.53)	36.1 (0.08)	6.7 (1.15)
	Cyclone	6	30.3 (1.00)	36.0 (0.11)	8.9 (2.08)
	Front	8	30.3 (0.69)	36.1 (0.07)	6.4 (0.08)
	Open ocean	33	30.5 (0.69)	34.5 (1.35)	6.6 (0.83)
	Total	62	30.4 (0.68)	35.2 (1.26)	6.8 (1.23)
September 2005	Anticyclone	0	NA	NA	NA
	Cyclone	3	29.5 (0.17)	34.7 (0.11)	6.5 (0.13)
	Front	13	29.9 (0.29)	36.7 (0.08)	6.1 (0.32)
	Open ocean	23	29.8 (0.74)	36.7 (0.30)	6.3 (0.49)
	Total	39	29.8 (0.60)	36.5 (0.59)	6.3 (0.43)
June 2006	Anticyclone	11	28.4 (0.20)	36.0 (0.20)	6.6 (0.10)
	Cyclone	11	28.8 (0.41)	36.0 (0.17)	6.6 (0.22)
	Front	19	28.6 (0.45)	35.7 (0.30)	6.6 (0.07)
	Open ocean	21	28.8 (0.64)	35.6 (0.59)	6.5 (0.14)
	Total	62	28.7 (0.50)	35.8 (0.42)	6.6 (0.14)
August 2006	Anticyclone	18	30.3 (0.42)	36.3 (0.15)	NA
	Cyclone	0	NA	NA	NA
	Front	24	29.9 (0.17)	36.2 (0.19)	NA
	Open ocean	24	30.1 (0.21)	36.2 (0.64)	NA
	Total	66	30.1 (0.31)	36.2 (0.41)	NA

and lower in the open ocean (35.6) compared to cyclones (36.0) in June 2006. Dissolved oxygen displayed spatial variation during July 2005 collections with highest dissolved oxygen observed within cyclones (8.9 mg/L) compared to other features: anti-cyclone (6.7 mg/L), front (6.4 mg/L) and open ocean (6.6 mg/L) (ANOVA, $F_{(3, 57)} = 9.1$, $p = 0.02$) (Table 1).

Catch composition of istiophorids

A total of 3,064 larval istiophorids (sailfish, white marlin and blue marlin) was collected during the course of sampling in 2005 and 2006 (Table 2). Sailfish was the dominant istiophorid, accounting for 79.2% ($n = 2426$) of collections. Blue marlin and white marlin accounted for 19.6% ($n = 601$) and 1.2% ($n = 37$) of the remaining istiophorids, respectively. Sailfish were collected during all five surveys, with blue marlin collected in all but the May 2005 survey; all white marlin, except 1 larva, were collected in early season surveys of both years (Table 2). Sailfish had the highest percent occurrence appearing in 45.0% of collections with blue marlin (20.4%) and white marlin (5.9%) less frequently observed. White marlin were most frequently observed in early season surveys (May and June), with sailfish and blue marlin occurring more frequently in mid and late season surveys (July and September, respectively).

Sailfish distribution and abundance

Densities of sailfish larvae varied significantly across surveys (ANOVA, $F_{(4, 573)} = 3.8$, $p < 0.01$). Lowest densities were observed in early and late season surveys: May 2005 (0.6 ± 1.8) and September 2005 (0.6 ± 1.3), with numbers increasing during mid season surveys: July 2005 (2.1 ± 7.6), June 2006 (2.0 ± 4.7), and August 2006 (1.8 ±

Table 2

Catch composition of istiophorid larvae collected from the northern Gulf of Mexico in 2005 and 2006 arranged by survey. Number of stations during each survey (*n*) shown. Percent occurrence indicates the frequency of collection stations during each survey that yielded 1 or more larva

Survey	*n*	Sailfish	% occurrence	Blue marlin	% occurrence	White marlin	% occurrence
May 2005	60	212	26.7	0	0.0	14	10.0
July 2005	62	755	56.5	24	17.7	0	0.0
September 2005	39	134	46.2	213	41.0	0	0.0
June 2006	62	691	48.4	18	16.1	22	16.1
August 2006	66	634	47.0	346	33.3	1	1.5
Total	289	2426	45.0	601	20.4	37	5.9

3.1). Sailfish larvae were distributed throughout a large portion of the sampling corridor during all surveys; albeit larvae were observed at a lower percentage of sampling stations during the earliest survey (May 2005: 26.7%) (Fig. 4). Percent frequency of occurrence was between 40 and 60% for all other surveys: July 2005 (56.4%), September 2005 (46.2%), June 2006 (48.4%), and August 2006 (47.0%) (Table 2).

Distribution and abundance of sailfish were influenced by environmental factors and oceanographic conditions in the northern Gulf. Coefficients of determination (r^2) for regression models that included temperature, salinity, dissolved oxygen, sea surface height and depth ranged from 0.13 to 0.46 across the five survey periods, with best fits observed during early season surveys and weakest fits observed during mid and late season surveys (Table 3). Temperature and depth explained the most variability in density during early and mid season surveys. Temperature alone explained 32% of the variability during May 2005 collections with temperature and depth together explaining 43% of the variability during June 2006 collections. Depth explained a small portion of the variability in density during July 2005 collections (7%). Additional significant correlations were observed between environmental parameters and sailfish density: salinity in May 2005 and June 2006 and SSH in May 2005, but did not significantly contribute to regression models. Correlations between sailfish density and biotic and abiotic factors were limited for the August and September surveys (Table 3).

Oceanographic features, as defined by sea surface height, influenced distribution and abundance of sailfish larvae with higher densities of sailfish larvae observed within frontal features during early season surveys: May 2005 (ANOVA, $F_{(3,56)} = 5.6$, $p < 0.01$)

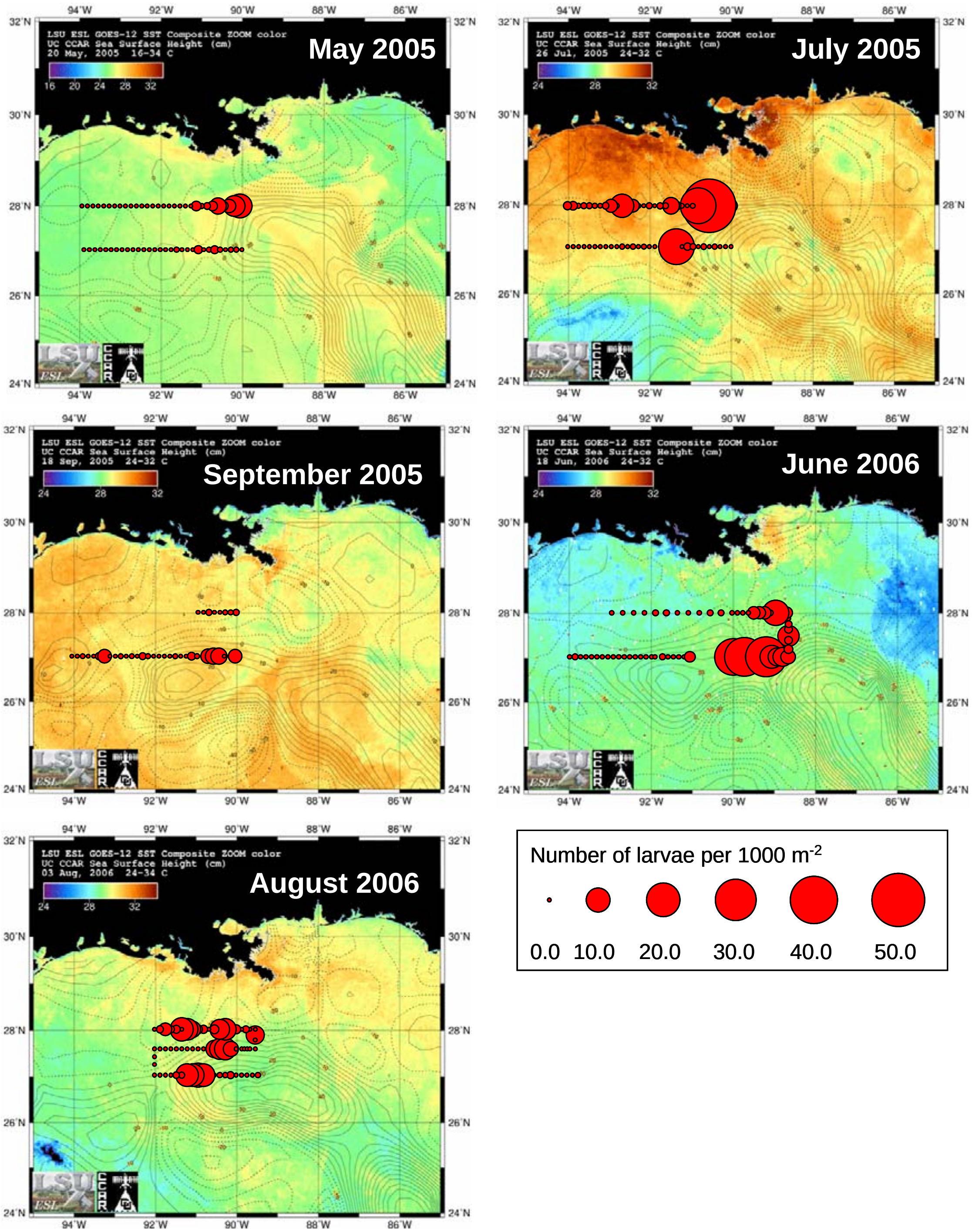

Figure 4

Distribution and abundance of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Bubble size corresponds to larval density (no. per 1000m^{-2}). Satellite altimetry images obtained from the Louisiana State University Earth Scan Laboratory web archives and are for a mid-date of each survey. Color represents sea surface temperature (°C), contour lines represent sea surface height (cm).

Table 3

Forward selection multiple regression models used to assess the influence of physicochemical parameters on sailfish density in the northern Gulf of Mexico in 2005 and 2006. Parameters included in full model: sea surface temperature (temp), salinity (sal), dissolved oxygen (DO), sea surface height (SSH) and depth; August 2006 survey excluded DO. Pearson correlation coefficients for individual factors are given (r_{sub}) with full model coefficients of determination (r^2). * indicates significance at $\alpha = 0.05$ level.

Survey	r_{temp}	r_{sal}	r_{DO}	r_{SSH}	r_{depth}	r^2
May 2005	0.565*	0.323*	-0.020	0.321*	-0.140	0.35
July 2005	0.112	-0.017	-0.174	-0.070	-0.257*	0.13
September 2005	0.105	0.135	0.265	0.107	0.255	0.21
June 2006	0.251*	-0.272*	-0.064	0.190	0.570*	0.46
August 2006	-0.201	-0.093	NA	-0.022	-0.202	0.14

and June 2006 (ANOVA, $F_{(3,58)} = 4.0$, $p = 0.01$) (Fig. 5). Additionally, significant variation in density for all surveys combined was observed across oceanographic features (ANOVA, $F_{(3, 285)} = 3.3$, $p = 0.02$) with cyclonic eddies having lower density compared to other features ($p < 0.05$).

Sailfish length and age distributions

Length distributions of sailfish were similar between 2005 (5.1 ± 2.1 mm) and 2006 (4.9 ± 2.0 mm) (ANOVA, $F_{(1, 2352)} = 3.3$, $p = 0.07$, power = 0.44) (Fig. 6). Sailfish larvae were most abundant in the 3 – 6 mm size range with 70.4% and 65.9% in this range in both 2005 and 2006, respectively. Intra-annual variation in sailfish mean length was observed in 2005 (ANOVA, $F_{(2, 1034)} = 62.6$, $p < 0.01$) and 2006 (ANOVA, $F_{(1, 1315)} = 75.8$, $p < 0.01$) with smallest mean length observed in early season surveys (May 2005: 4.1 ± 1.6 mm and June 2006: 4.5 ± 1.6 mm), largest length observed in mid season surveys (July 2005: 5.4 ± 2.2 mm and August 2006: 5.4 ± 2.3 mm) and larvae of intermediate length collected in September 2005 (4.8 ± 1.8 mm) (Fig. 7).

Age distributions were also similar between 2005 (11.1 ± 3.1 days) and 2006 (11.5 ± 3.2 days) (ANOVA, $F_{(1, 1234)} = 2.7$, $p = 0.10$, power = 0.37) (Fig. 8). Sailfish larvae were most abundant in the 8 – 12 day range with 60.7% and 53.9% in this range in both 2005 and 2006, respectively. Intra-annual variation in sailfish mean age was observed in 2005 (ANOVA, $F_{(2, 521)} = 51.6$, $p < 0.01$) and 2006 (ANOVA, $F_{(1, 710)} = 47.9$, $p < 0.01$) with youngest mean age observed in early season surveys (May 2005: 9.0 ± 2.3 days and June 2006: 10.4 ± 3.1 days), oldest mean age observed in mid season surveys

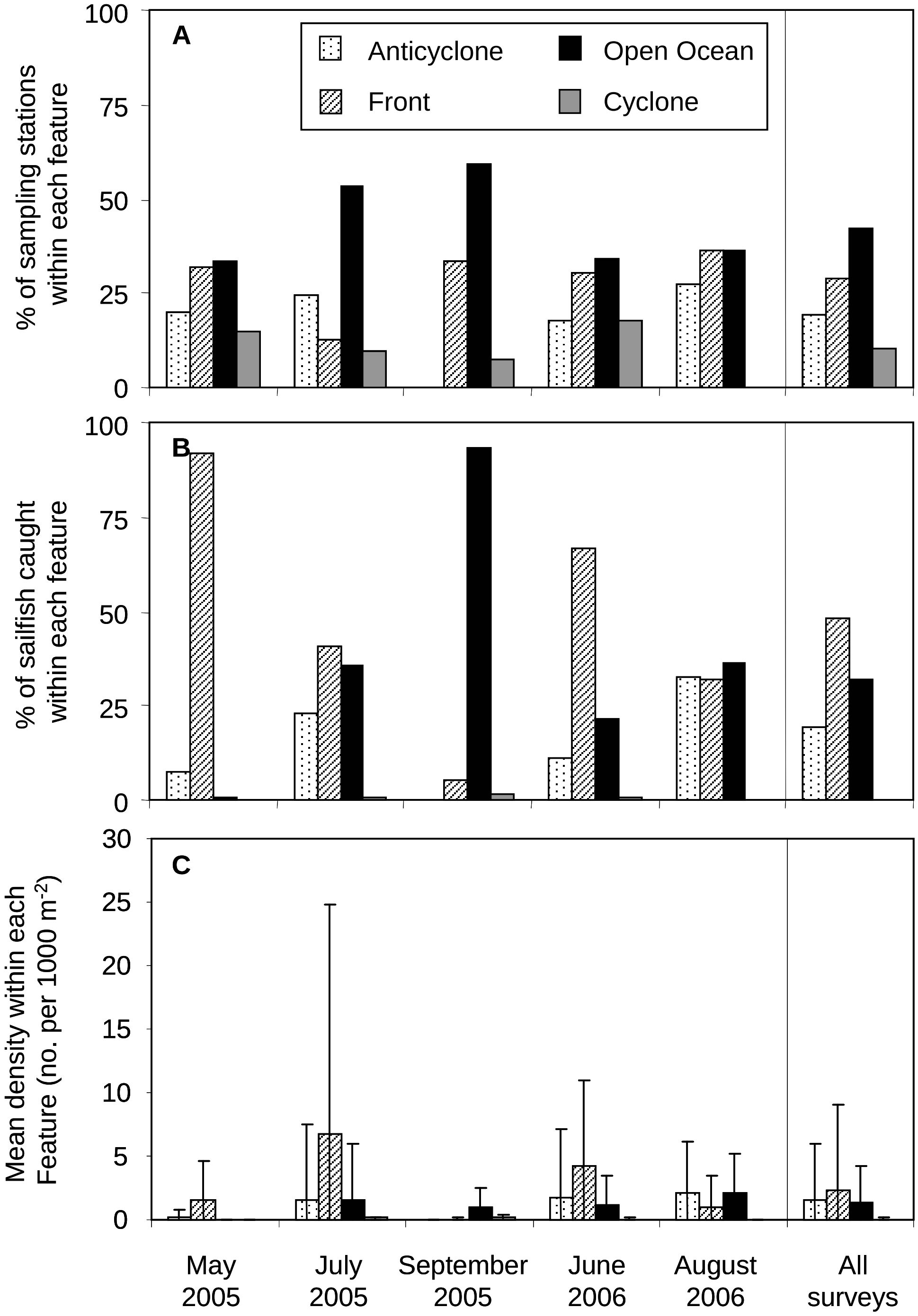

Figure 5

Sampling stations, sailfish larvae and density arranged by oceanographic feature for ichthyoplankton surveys conducted in the northern Gulf of Mexico in 2005 and 2006. (**A**) Percentage of collections conducted within each oceanographic feature (**B**) Percentage of larval sailfish caught within each feature (**C**) Mean sailfish density within each feature. Error bars indicate ±1 standard deviation.

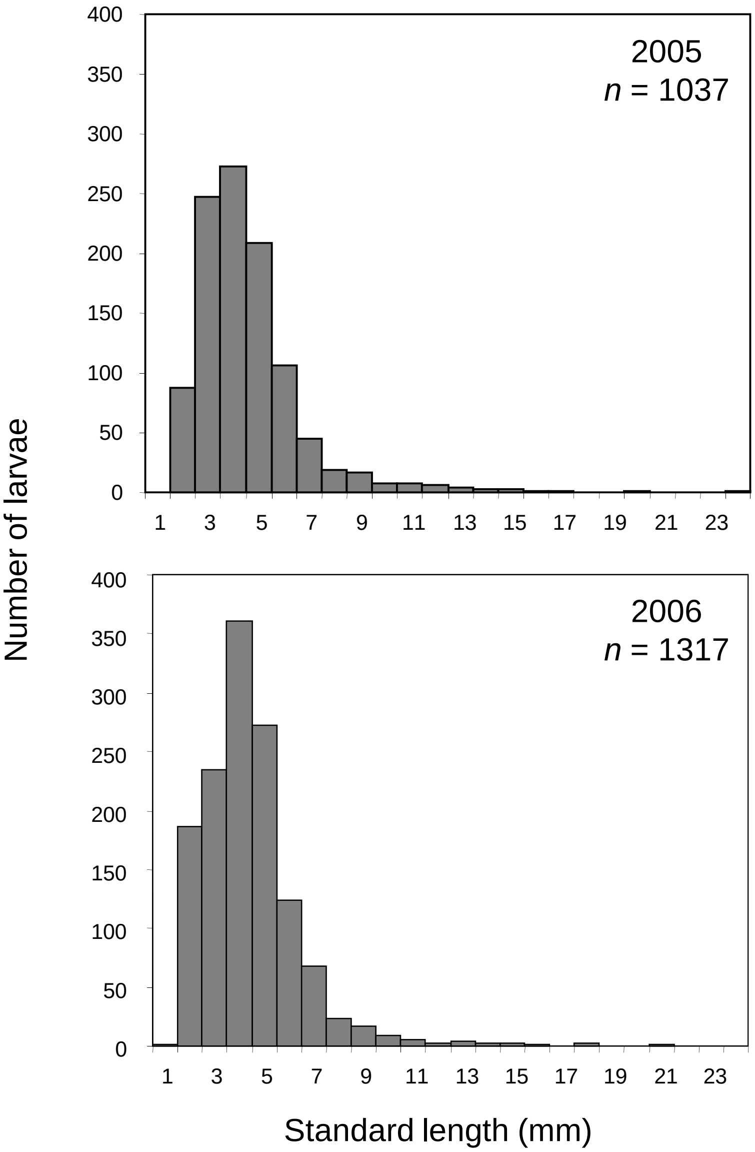

Figure 6

Length-frequency distributions of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Note: 72 sailfish larvae indicated in Table 2 were damaged and no length measurement was taken.

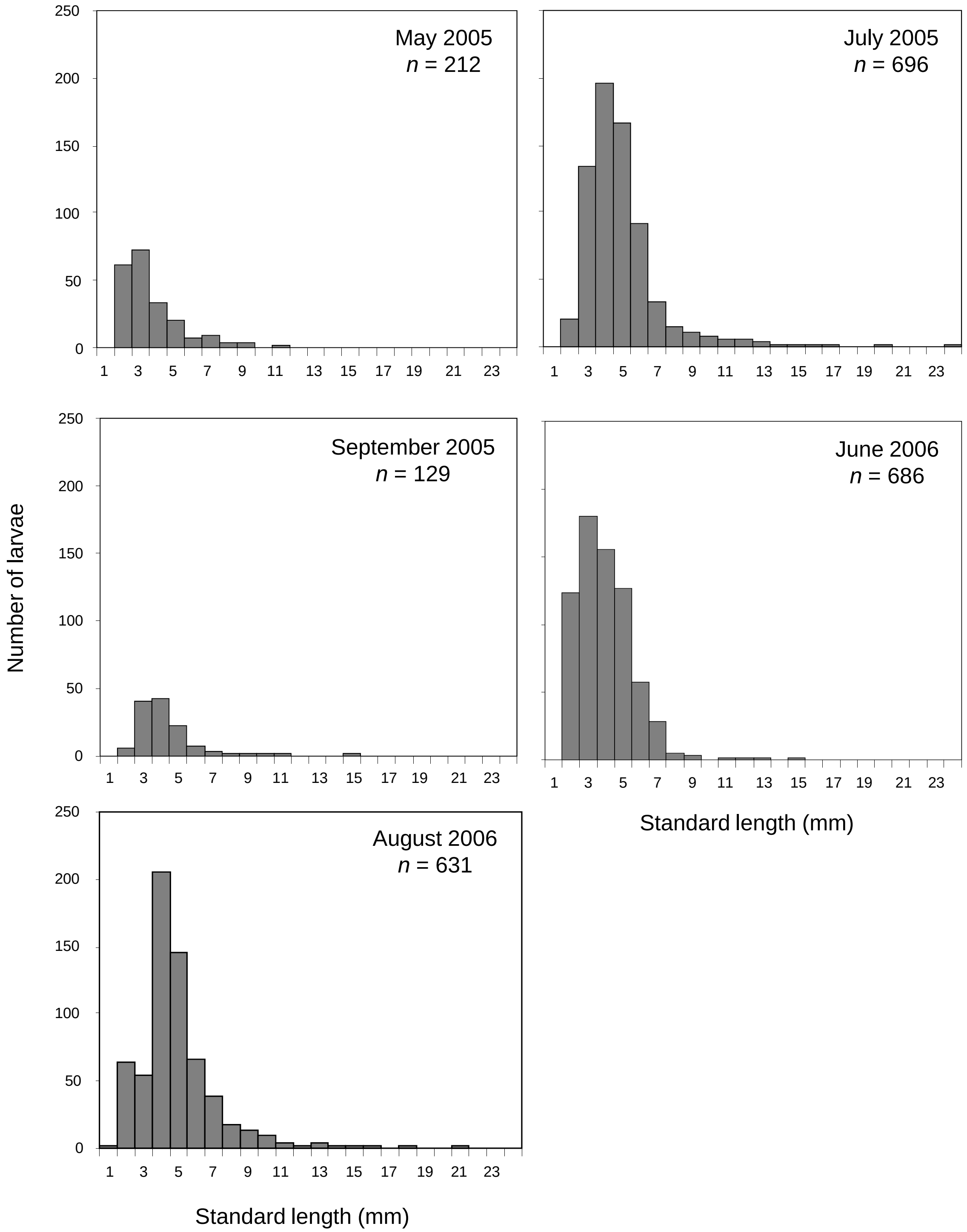

Figure 7

Length-frequency distributions of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006 arranged by survey.

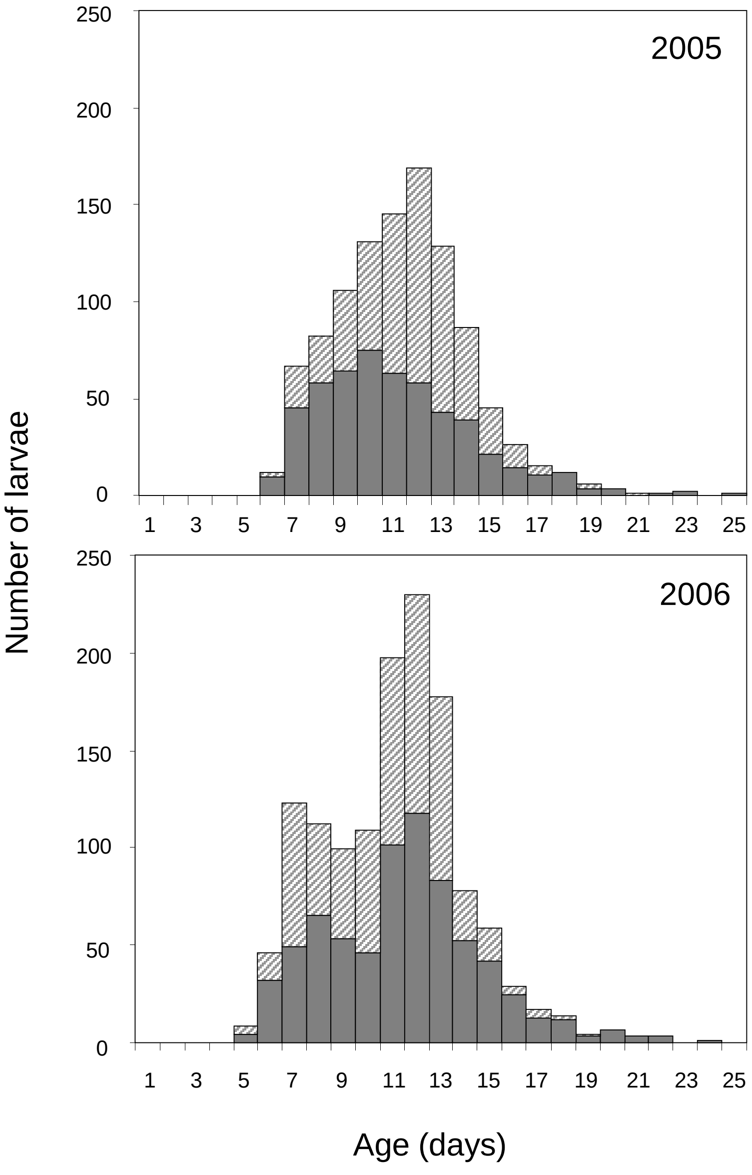

Figure 8

Age-frequency distributions of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Ages determined via otolith microstructure analysis (solid bars) or predicted using age-length key (dashed bars). Note: *n*-values same as Figure 6.

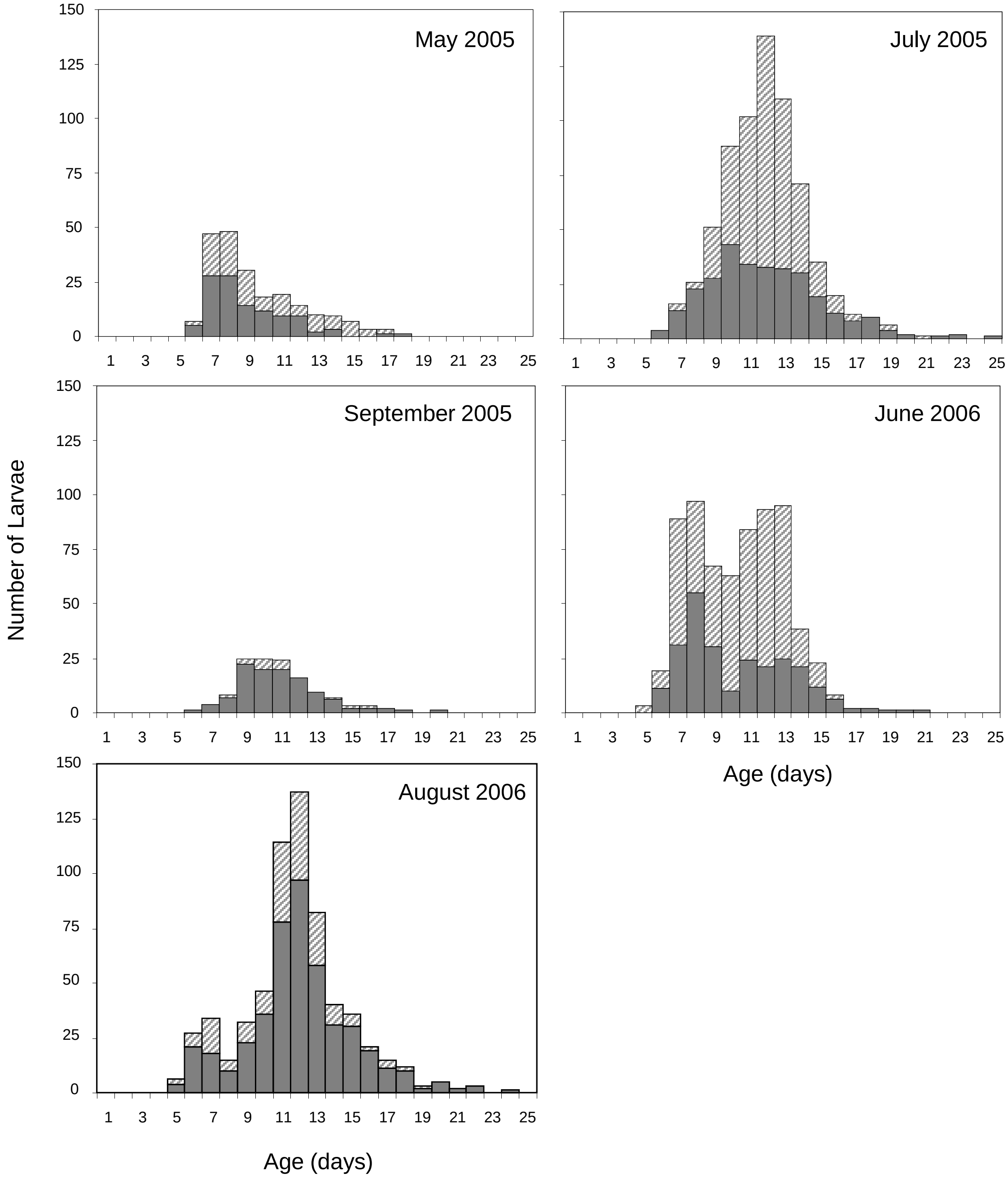

Figure 9

Age-frequency distributions of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006 arranged by survey. Ages determined via otolith microstructure analysis (solid bars) or predicted using age-length key (dashed bars). Note: *n*-values same as Figure 7.

(July 2005: 12.0 ± 3.3 days and August 2006: 12.0 ± 3.1 days) and fish of intermediate age collected in September 2005 (10.9 ± 2.4 days) (Fig. 9).

Growth

Sailfish displayed rapid growth during early life with inter-annual differences detected between 2005 (0.123, 11.6% d^{-1}) and 2006 (0.114, 10.8% d^{-1}) (ANCOVA, slopes, $F_{(1, 1205)} = 21.4$, $p < 0.01$) (Fig. 10). Intra-annual variation in growth was observed in 2005 (ANCOVA, slopes, $F_{(2, 507)} = 5.1$, $p = 0.01$) with larvae collected in September (0.113, 10.7% d^{-1}) displaying slower growth than larvae collected in July (0.127, 11.9% d^{-1}). In contrast, growth was similar between surveys in 2006 (ANCOVA, slopes, $F_{(1, 692)} = 0.7$, $p = 0.39$, power = 0.14) (Fig.10).

Data from July 2005, June 2006, and August 2006 surveys were further analyzed to examine the influence of oceanographic conditions on growth. Growth rates were calculated separately for individuals collected from three different oceanographic features (based on altimetry data) with cyclonic eddies excluded due to low sample sizes within these features (all $n < 5$) (Table 4). Spatial variation in growth was observed during the August 2006 survey (ANCOVA, slopes, $F_{(2, 440)} = 3.4$, $p = 0.03$), with larvae collected within anti-cyclone features (0.105, 10.0% d^{-1}) displaying slower growth than larvae collected in the open ocean (0.117, 11.0% d^{-1}). In contrast, growth was similar across features in July 2005 and June 2006 (ANCOVA, slopes, $F_{(2, 282)} = 0.4$, $p = 0.67$, power = 0.11 and ANCOVA, slopes, $F_{(2, 241)} = 2.5$, $p = 0.09$, power = 0.49, respectively).

The same surveys (July 2005, June 2006 and August 2006) were analyzed for density-dependent differences in growth by separating collection stations into three

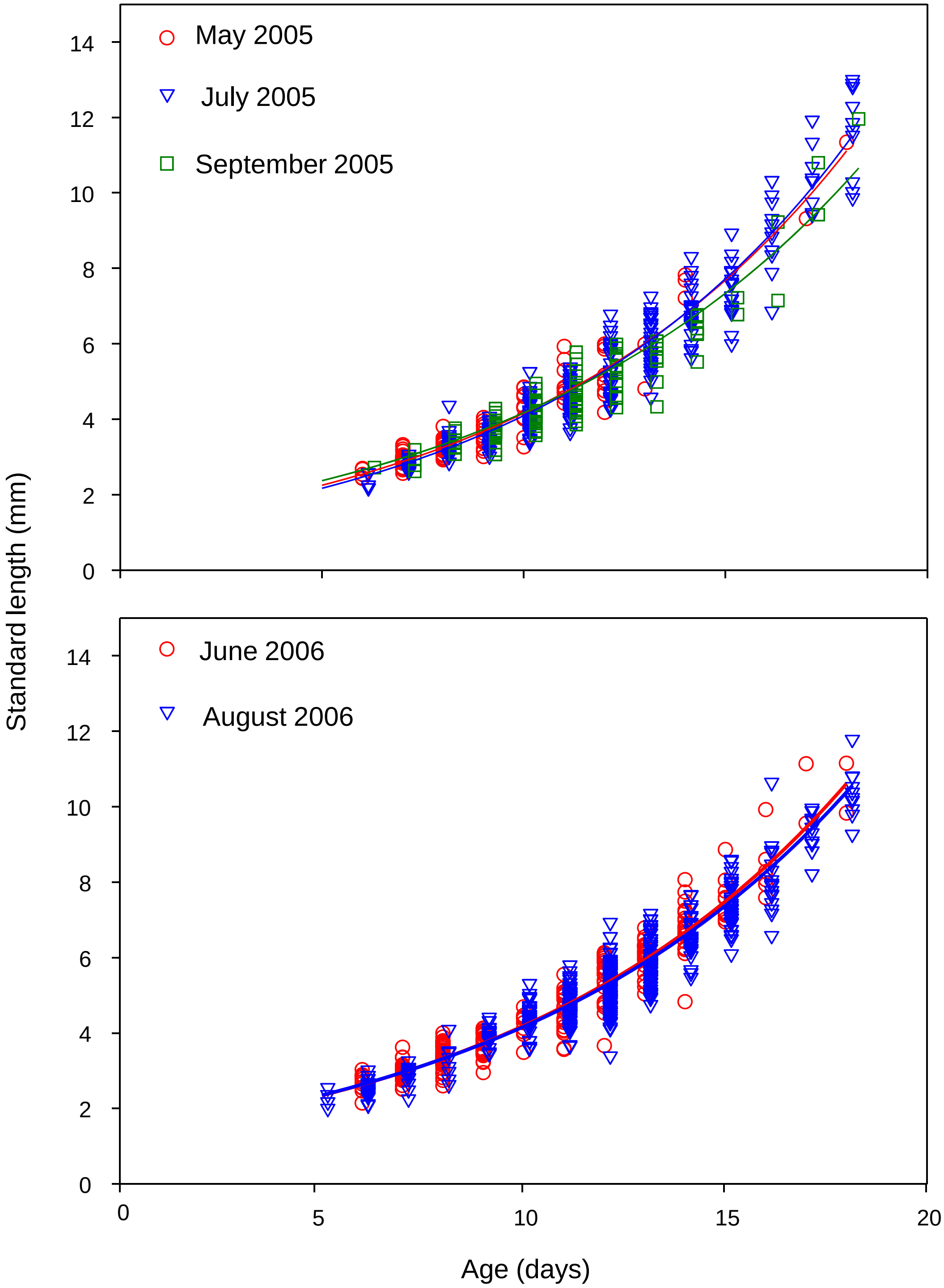

Figure 10

Size-at-age relationships of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006 arranged by year and survey. Age in days estimated from otolith growth increment counts. Growth models are given in Table 4.

Table 4

Exponential growth models arranged by survey and oceanographic feature for sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Number of larvae within each category is given (*n*). * indicates significant growth variation.

Survey	Feature	*n*	Growth model
May 2005	All larvae	112	$1.214e^{0.123x}$
July 2005	Anti-cyclone	135	$1.134e^{0.128x}$
	Front	45	$1.290e^{0.122x}$
	Open ocean	108	$1.176e^{0.124x}$
	All larvae	289	$1.149e^{0.127x}$ *
September 2005	All larvae	112	$1.347e^{0.113x}$ *
All 2005	All larvae	513	$1.201e^{0.123x}$ *
June 2006	Anti-cyclone	21	$1.548e^{0.101x}$
	Front	108	$1.255e^{0.120x}$
	Open ocean	118	$1.363e^{0.112x}$
	All larvae	247	$1.316e^{0.116x}$
August 2006	Anti-cyclone	131	$1.515e^{0.105x}$ *
	Front	166	$1.321e^{0.114x}$
	Open ocean	149	$1.283e^{0.117x}$ *
	All larvae	446	$1.335e^{0.114x}$
All 2006	All larvae	693	$1.332e^{0.114x}$ *

larval density categories: < 5.0, 5.0 to 9.0 and > 9.0. Ranges were selected based on natural breaks in data and sample sizes were relatively similar among density categories. Growth rates were statistically similar across density in all three surveys: July 2005 (ANCOVA, slopes, $F_{(2, 283)} = 0.8$, $p = 0.46$, power = 0.18), June 2006 (ANCOVA, slopes, $F_{(2, 244)} = 0.3$, $p = 0.77$, power = 0.09) and August 2006 (ANCOVA, slopes, $F_{(2, 440)} = 1.3$, $p = 0.27$, power = 0.28).

Mortality

Instantaneous daily mortality (Z) over a 10-day interval was statistically similar between 2005 (0.288, 25.0% d^{-1}) and 2006 (0.310, 26.6% d^{-1}) (ANCOVA, slopes, $F_{(1, 46)} = 0.0$, $p = 0.99$, power = 0.05) (Fig. 11, Table 5). Mortality ranged from 0.228 (20.4% d^{-1}) to 0.345 (29.2% d^{-1}) in 2005 surveys with no intra-annual variation observed (ANCOVA, slopes, $F_{(2, 24)} = 2.1$, $p = 0.15$, power = 0.39). Further, mortality rates were statistically similar among survey periods during 2006, ranging from 0.270 (23.7% d^{-1}) in June to 0.304 (26.2% d^{-1}) in August (ANCOVA, slopes, $F_{(1, 16)} = 0.2$, $p = 0.70$, power = 0.07).

Recruitment potential ($G{:}Z$)

Instantaneous weight-specific growth coefficients (G) ranged from 0.347 (41.5% d^{-1}) in 2006 to 0.371 (44.9% d^{-1}) in 2005 and were indexed to mortality to assess temporal variation in recruitment potential (Table 5). Annual estimates of $G{:}Z$ were 1.29 in 2005 and 1.12 in 2006. Temporal variation in recruitment potential was observed with the ratio of $G{:}Z$ highest in early and mid season surveys: May 2005 (1.30), July 2005 (1.66) and June 2006 (1.30). In contrast, G:Z ratios of the final survey in both years were

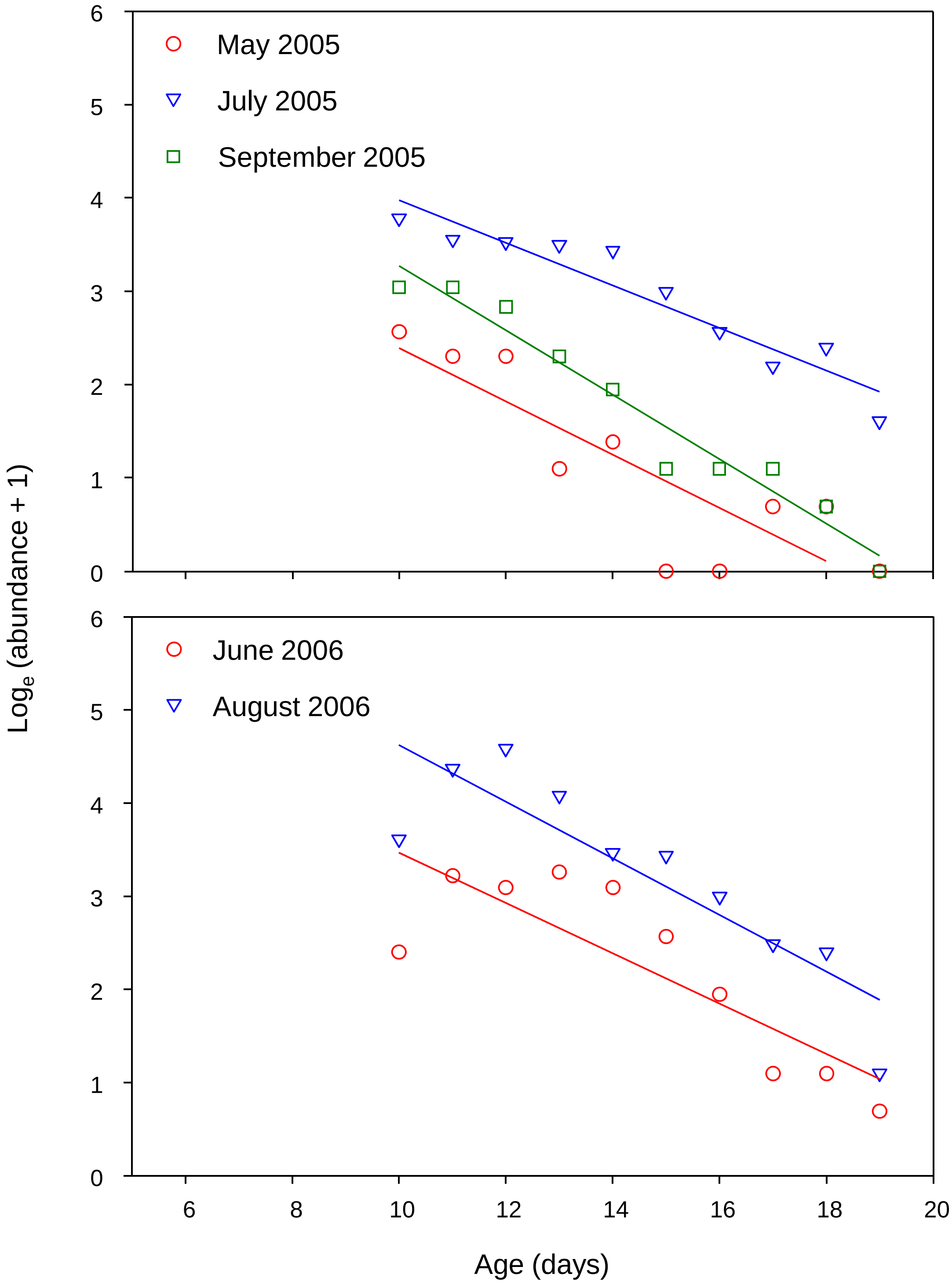

Figure 11

Regression plots of Log$_e$ (abundance + 1) on age for 10-day cohorts of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006 arranged by year and survey. *Z* values (slopes) shown in Table 5.

Table 5

Instantaneous weight-specific growth (*G*) and mortality (*Z*) coefficients of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Percent per day calculated from instantaneous growth and mortality coefficients. The G:Z recruitment index is also shown.

Year	Survey	*G*	% / day	*Z*	% / day	*G:Z*
2005	May	0.371	44.9	0.285	24.8	1.30
	July	0.378	45.9	0.228	20.4	1.66
	September	0.347	41.5	0.345	29.2	1.01
	All surveys	0.371	44.9	0.288	25.0	1.29
2006	June	0.351	42.0	0.270	23.7	1.30
	August	0.347	41.5	0.304	26.2	1.14
	All surveys	0.347	41.5	0.310	26.6	1.12

the lowest: September 2005 (1.01) and August 2006 (1.14), suggesting that late season cohorts have lower survival potential compared to early season cohorts. Still, recruitment indices were > 1.0 for all surveys, and this indicates that all cohorts were gaining biomass during this life stage (Table 5).

Hatch-date distribution

Hatch-date distributions determined using otolith and predicted ages indicated that spawning of sailfish in the northern Gulf ranged from May to September during 2005 and 2006 (Fig. 12). Hatch dates of sailfish peaked in mid-July, with the majority of larvae (56.3% of total sailfish catch) from July spawning and/or hatching events. Percent of total catch from July spawning and/or hatching events was particularly high in 2005 (67.1%) compared to 2006 (47.8%). Since the majority of sailfish were < 20 days of age and sampling was conducted bi-monthly, hatch-date distributions were comprised of multiple modes.

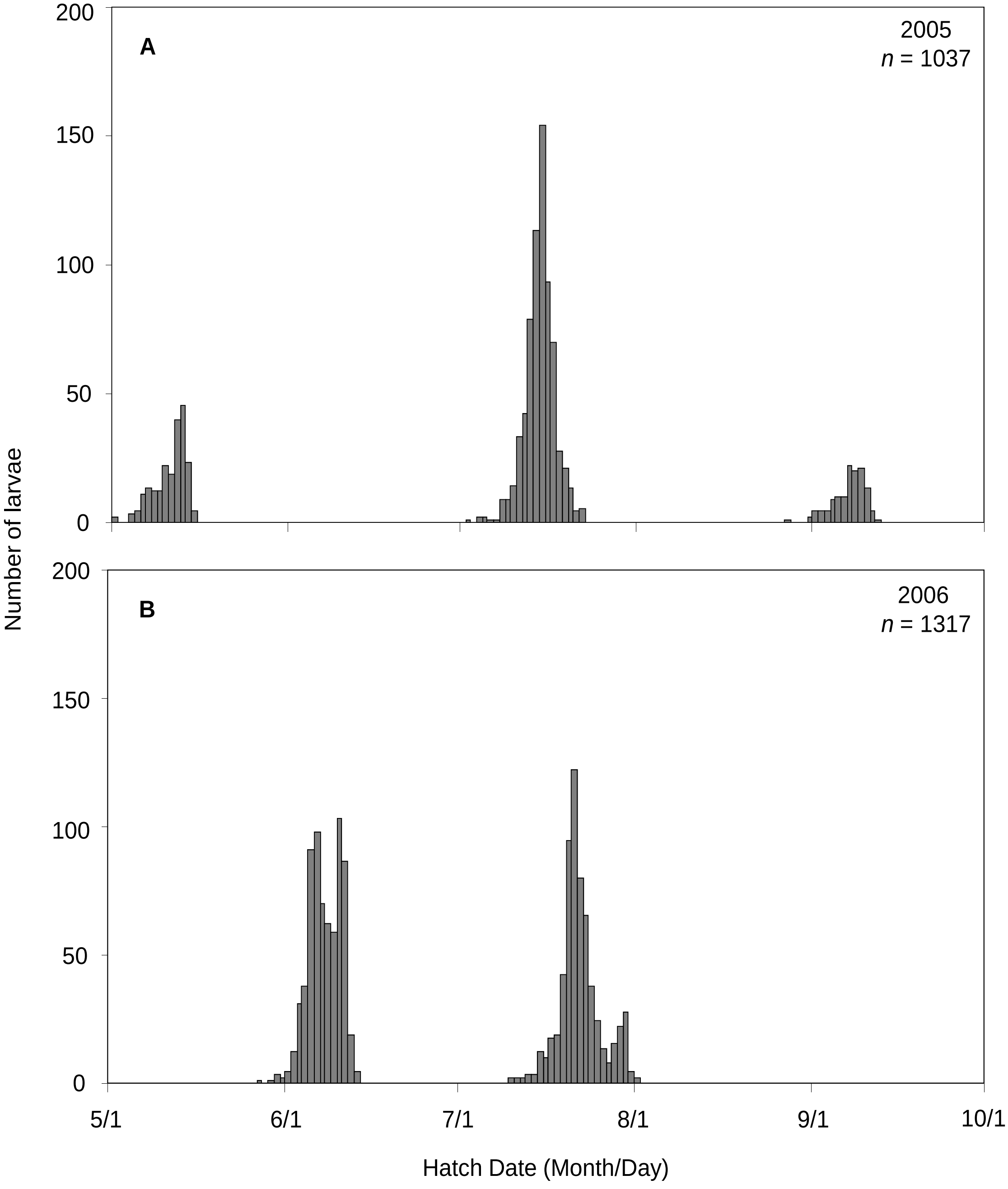

Figure 12

Hatch-date distributions of sailfish larvae collected from the northern Gulf of Mexico in 2005 and 2006. Hatch dates determined by subtracting age from catch date. Otolith-derived ages used when available, remaining ages predicted by applying age-length key.

Discussion

Catch numbers (2,426 larvae; 24.4 larvae hour^{-1}) and densities (1.4 larvae per 1000 m^{-2}) of sailfish larvae from the northern Gulf of Mexico (Gulf) were comparable to or higher than values reported for other putative spawning areas of sailfish. Llopiz and Cowen (2008) collected 452 sailfish during 221 neuston tows (6.1 larvae hour^{-1}) over 2 years in the Straits of Florida, while Post et al. (1997) collected 288 sailfish larvae during 315 tows (27.4 larvae hour^{-1}) over 2 years in the same region. Serafy et al. (2003) collected 99 istiophorid larvae during 67 tows in Exuma Sound, Bahamas (8.9 larvae hour^{-1}), with 90% of the catch being blue marlin. Additionally, sailfish frequency of occurrence from this study (45.0%) corresponds closely to the 41.1% occurrence reported in the Straits of Florida and Bahamas by Luthy (2004), albeit all major Atlantic billfishes (sailfish, white marlin, blue marlin and swordfish) were included by this author. Catch data of sailfish larvae suggests high abundance in the northern Gulf during the summer spawning period; albeit, variations in towing methodology, sampling gear and oceanographic conditions among studies may result in differences in catch rates of larvae. However, similar to catch rates of sailfish larvae, bycatch of adult sailfish was also high in the Gulf, Straits of Florida and Bahamas during the summer spawning period (NMFS, 2008), supporting the premise that these regions may be important spawning grounds of sailfish. In fact, the bycatch of adults from 2000 to 2007 was higher in the Gulf (0.134 sailfish caught per 1000 hooks set) than the western Atlantic (0.058 sailfish per 1000 hooks set) (NMFS, 2008), further highlighting the potential value of this region as a spawning and nursery ground of sailfish.

In the northern Gulf, the density of sailfish larvae was correlated with physicochemical conditions during early summer surveys. Larval density was positively correlated with sea surface temperature during early surveys in both 2005 and 2006 (May and June, respectively), when variability in temperature across oceanographic features was pronounced. Temperature has been shown to influence the distribution of larvae in coastal and open ocean systems, and higher densities are often found in the vicinity of well developed sea-surface temperature fronts (Sabates, 1990; Grimes and Finucane, 1991; Lamkin, 1997). Elevated abundances of pelagic larvae have also been linked to intermediate salinity levels in areas where low and high salinity water bodies converge (Lang et al., 1994; Hanisko and Lyczkowski-Shultz, 2003; Bakun, 2006). Even though a strong gradient was not observed, significant spatial variation in salinity was observed across oceanographic features during 4 of 5 surveys with sailfish density correlated with salinity during certain surveys. Further, larval density has been observed to be correlated with depth, and certain species are more abundant in deeper waters (Ditty et al., 2004; Zarrad et al., 2006; Serafy et al., 2007). Thus, increased densities of sailfish larvae in the deeper slope waters of the northern Gulf (June 2006) are not surprising; albeit larvae were more abundant in shelf waters during certain surveys as well (July 2005). Environmental parameters analyzed in this study do not explain all of the observed variation in larval density and, as such, inclusion of additional biotic (e.g. chlorophyll levels, prey abundance) and abiotic (e.g. current speed) factors, which have been shown to affect the distribution and abundance of larvae (Grimes and Finucane, 1991; Govoni and Grimes, 1992; Cowen et al., 1993), will likely further clarify the primary determinants of sailfish distribution and abundance in the northern Gulf.

Elevated densities of sailfish larvae were observed within mesoscale frontal features associated with the Loop Current over the course of all surveys. Increased larval densities have been observed at frontal features created by riverine discharge and/or converging oceanic currents in temperate and tropical oceans (Richards et al., 1993; Hare et al., 2001; Hoffmeyer et al., 2007; Richardson, 2007). Despite the fact that several studies have reported peak catches along frontal features, the mechanisms responsible for elevated densities in these regions are poorly understood. Two theories provide plausible explanations for the reoccurring pattern of aggregation in these features. First, Cushing's match/mismatch hypothesis suggests that adult spawning should be timed with peak production of larval food sources, thereby increasing larval survival potential (Cushing, 1990). Advancing this hypothesis, recent studies have observed elevated primary productivity and increased densities of planktonic food sources within frontal features (Govoni et al., 1989; Sabates, 1990; Grimes and Finucane, 1991). This suggests that increased larval feeding opportunities at fronts lead to increased growth and higher survival in such features (Grimes and Finucane, 1991; Biggs, 1992; Brandt, 1993). Second, it has been hypothesized that elevated abundances at fronts is the result of transport via currents that accumulate larvae at convergent features (Govoni et al., 1989; Govoni and Grimes, 1992; Cowen et al., 1993). Larvae spawned throughout the Gulf and nearby Caribbean Sea have been shown to aggregate over time within Loop Current frontal features (Hanisko and Lyczkowski-Shultz, 2003;

Bakun, 2006), suggesting that oceanographic processes may partly explain elevated larval abundances in the region. While the precise mechanisms driving observed variations in larval abundance are not fully understood, the consistent collection of larvae within the western margin of the Loop Current indicates that these features may serve as important early life habitat of sailfish in the northern Gulf.

Sailfish larvae displayed rapid growth during the early life interval with intra- and inter-annual variation observed. Growth rates for 2005 ($g = 0.123$) and 2006 ($g = 0.114$) were slightly lower than those reported for sailfish in the Straits of Florida by Luthy et al. (2005) ($g = 0.137$) and Richardson (2007) ($g = 0.130$). Minimal differences in growth between studies are not entirely unexpected because the timing of collections and physicochemical conditions between the two regions were comparable. Straits of Florida sampling was conducted between April and September in waters ranging from 26.1°C to 30.6°C and salinity from 34.0 to 36.7 ppt (Luthy et al., 2005), which is comparable to conditions in the Gulf between May and September (26.4 °C to 30.4 °C and 35.2 to 36.5 ppt, this study). Further, observed growth rates for sailfish were similar to those of other istiophorids in waters adjacent to the Gulf. Growth rates of blue marlin from Exuma Sound, Bahamas range from $g = 0.098$ (Serafy et al., 2003) to 0.125 (Sponaugle et al., 2005), and from $g = 0.089$ (Sponaugle et al., 2005) to 0.114 (Richardson, 2007) in the Straits of Florida. Similar to sailfish studies, blue marlin collections were from areas in close proximity to the Gulf with similar sea surface temperature (26 – 30°C) and salinity (35.8 – 36.8 ppt) to the Gulf during the same sampling period. Thus, comparable growth rates observed here suggests that certain species within the family Istiophoridae possess relatively similar growth trajectories during early life even though adult sizes are markedly different (Wilson et al., 1991; Chiang et al., 2006).

Growth rates of sailfish in the northern Gulf varied temporally, and seasonal and/or annual variation in the growth of pelagic species' is often positively associated with temperature (Rilling and Houde, 1999; Sponaugle et al., 2006). While sea surface temperature varied among sampling periods in the northern Gulf, corresponding variations in growth were not detected. In fact, growth of sailfish larvae during the warmest months (July 2005 and August 2006) was highly variable (g = 0.114 – 0.127, August and July, respectively) despite similar mean sea surface temperatures across these surveys (30.4 and 30.1°C, respectively). In addition, growth during May 2005 was the second highest among all surveys even though mean temperature was lowest (26.4°C). Still, 92.0% of sailfish larvae collected in May were from frontal features which were observed to have the highest sea surface temperature of any feature encountered (26.9°C). While many studies have reported positive associations between growth and temperature (Rilling and Houde, 1999; Sponaugle et al., 2006; Power and Attrill, 2007), other studies have observed that alternate biotic factors (e.g. prey availability, larval density) were stronger determinants of growth (Jenkins et al., 1991; Lang et al., 1994; Wexler et al., 2007). This suggests that high temperatures alone may not influence growth, thus corroborating the findings observed here.

Despite elevated densities of larvae within frontal features in certain surveys, variations in sailfish growth across oceanographic features were observed in only one survey. Similarities in growth rates across oceanographic features is surprising given the fact that frontal features often display increased primary productivity (Grimes and Finucane, 1991; Richards et al., 1993), and rapid growth during early life has been linked to primary productivity and prey availability in fish larvae (de Vries et al., 1990; Rilling and Houde, 1999; Wexler et al., 2007). Prior studies on distribution and abundance of zooplankton and ichthyoplankton have defined frontal features using sea surface temperature and salinity gradients (Govoni et al., 1989; Grimes and Finucane, 1991; Hare et al., 2001), subsurface temperature gradients (Richards et al., 1993; Lamkin, 1997) and surface current vectors (Lane et al., 2003). The lack of finite definitions for oceanographic features, combined with the complexity of the pelagic environment, suggests that identification of frontal features may vary depending on the methodology employed. However, using the same istiophorid collection data and classification scheme for oceanographic features as this study, Tidwell (2008) observed significant differences in diet composition of istiophorid larvae across oceanographic features with a single genus of copepod (*Evadne*) consumed within anti-cyclones at twice the rate of any other feature. Further, the slower growth observed within anti-cyclones in this study is supported by recent work in the northern Gulf which has observed lower chlorophyll and zooplankton levels within anti-cyclones, suggesting that oligotrophic conditions exist within the anti-cyclones (Biggs, 1992; Samuel Dorado, Texas A&M University – Galveston, pers. comm.). These observations support my approach for classifying oceanographic features and suggest that reduced productivity or prey availability within anti-cyclones is likely responsible for reduced growth of sailfish collected in this feature.

No evidence of density-dependence on growth was observed for sailfish larvae during any survey in the northern Gulf, which corresponds to studies that have observed no effect of density on growth during the early life interval for fish larvae (Hewitt et al., 1985; Economou, 1991; McGurk et al., 1993). Similarly, Cowen et al. (2000) noted that grazing pressure by larval fishes on their planktonic food sources is likely to be insignificant due to the rapid replenishment rate of zooplankton prey. Further, the diet of istiophorid larvae is dominated by zooplankton prey until approximately 9 – 10 mm SL (16 – 17 days) (Llopiz and Cowen, 2008; Tidwell, 2008). Thus, density-dependent growth during the early life interval may be uncommon, which corroborates findings presented here.

Although intra- and inter-annual variations in mortality were insignificant, losses were substantial throughout the early life interval examined ($Z = 0.23 – 0.35$). Daily instantaneous mortality rates reported here are 10 – 45% lower than mortality values for sailfish and blue marlin larvae from the Straits of Florida and Exuma Sound, Bahamas (Richardson, 2007). Additionally, losses reported here are comparable to other pelagic larvae such as bluefin tuna, *Thunnus thynnus* ($Z = 0.20$; Rooker et al., 2007), yellowfin tuna, *Thunnus albacares* ($Z = 0.33$; Lang et al., 1994) and the suborder scombroidei which includes tunas, billfishes and barracudas, *Sphyraena sp.* ($Z = 0.34$; Houde and Zastrow, 1993). Age-specific mortality is often used to assess changes in recruitment potential and survival over the course of the early life interval (Leak and Houde, 1987;

Anderson, 1988; Houde, 2002) as mortality may be up to 7 times higher during the egg and early larval stages compared to the juvenile stage (Bailey and Houde, 1989; Houde, 1997; Rilling and Houde, 1999). Decreases in mortality are attributed to reductions in predator success as a result of increasing predator evasion with larval size (Folkvord and Hunter, 1986; Bailey and Houde, 1989; Leggett and DeBlois, 1994). Here, stage-specific mortality comparisons were limited for sailfish due to the lack of samples from early stage larvae (< 6 days). Additionally, mortality estimates for the late larval and early juvenile stages (> 20 days) were not calculated due to concerns that gear avoidance behavior may influence catch numbers of larger individuals, which can affect estimates of mortality (Houde, 1987).

Many studies have shown that predation is a major cause of mortality during the early life interval of pelagic species (Bailey and Houde, 1989; Leggett and DeBlois, 1994; Houde, 2002) and predation-mediated mortality is probably responsible for the high loss of sailfish larvae during the life stage investigated. Although information regarding predation on istiophorids is rather limited, recent studies indicate that istiophorids are preyed upon by dolphinfish (Oxenford and Hunte, 1999) as well as conspecifics (Llopiz and Cowen, 2008). In fact, Tidwell (2008) reported that the most common larval fish taxa present in the stomachs of sailfish and blue marlin used in this study were istiophorids, which represented approximately 28% of the total piscine prey. Thus, cannibalism or predation pressure by other istiophorids appears to represent an important source of mortality for sailfish during early life.

Weight-specific growth (*G*) and mortality (*Z*) estimates were used to determine a recruitment potential index (*G:Z*) of sailfish larvae, and observed ratios were greater than 1.0 for all cohorts, indicating conditions were likely favorable for growth, mortality and recruitment. Houde and Zastrow (1993) observed that the mean *G:Z* ratio for marine species during the larval stage is 0.89, with a *G:Z* ratio of 0.96 for larvae in the suborder scombroidei; however, indices range from 0.26 to 2.42 for larvae of upwelling and shelf species (Houde and Zastrow, 1993), suggesting wide-ranging recruitment potential for pelagic fishes. Recruitment indices for sailfish ranged from 1.01 to 1.66, with the highest value observed for the July 2005 period. Variations in *G:Z* often coincide with temperature and prey availability (Sogard, 1997; Rilling and Houde, 1999, Cowan and Shaw, 2002), and the highest reported value for sailfish was observed when sea surface temperature was greatest and density within frontal features was at the highest level.

Hatch dates of larval sailfish from the present study indicate that spawning is protracted in the northern Gulf, with peak spawning activity during mid summer. To date, sailfish spawning has not been documented in the northern Gulf, but sailfish are known to have protracted spawning in other regions of the Atlantic and Pacific. Spawning occurs from May to September in the western North Atlantic (de Sylva and Breder, 1997) and from April to September in the eastern Pacific (Chiang et al., 2006), corresponding to the spawning range observed in this study. Additionally, studies suggest that peak spawning occurs in mid to late summer as increased frequencies of mature ovaries have been observed in sailfish landed in July and August (de Sylva and Breder, 1997; Chiang et al., 2006; Richardson, 2007).

CHAPTER III

SUMMARY AND CONCLUSIONS

Number, frequency of occurrence and density of sailfish larvae observed in the Gulf were greater than those reported from other putative istiophorid spawning grounds in the Caribbean Sea and the Straits of Florida. Similar to catch rates of sailfish larvae, adult biomass appears to be high in the Gulf during the summer spawning period, supporting the premise that this region may be an important spawning ground of sailfish. Spatial and temporal variations in sailfish distribution and abundance were observed with increased larval catches correlated with temperature and depth during early season surveys, albeit only 30 to 45% of the variability in density was explained by environmental parameters examined. Additionally, frontal features were encountered during less than one-third of sampling stations, yet nearly half of all sailfish were collected within frontal features. This suggests that oceanographic conditions, particularly frontal features associated with the Loop Current, influence the distribution and abundance of sailfish larvae in the northern Gulf.

Sailfish larvae displayed rapid growth throughout the early life interval with temporal and spatial variation observed. Intra- and inter-annual variation in growth was observed with faster growth for 2005 cohorts and highest for the mid season cohort of 2005. Spatial variation in growth was also observed with decreased growth observed within anti-cyclonic features during certain surveys, which supports previous research that suggests anti-cyclones are oligotrophic features. No density-dependent influence on growth was observed for any cohort.

Daily mortality rates were substantial (20 to 29% d^{-1}), suggesting that sailfish suffer large losses during early life. This observation emphasizes the importance of rapid growth during the most vulnerable early life stages. Recruitment indices suggest that all sailfish cohorts were gaining biomass during early life, though mid season cohorts contributed more to annual recruitment. Hatch-date and catch distributions were protracted in the northern Gulf with peak spawning activity observed in July. The highest recruitment potential was also observed in July, suggesting that peak adult spawning activity occurs when conditions for larval growth, survival and recruitment are optimal.

Questions remain as to the specific factors responsible for observed variation in distribution and growth as well as the extent of spawning in the northern Gulf. However, high larval densities and rapid growth during early life, in combination with high recruitment potential, suggests that larvae spawned and/or hatched in the northern Gulf contribute to adult populations. This study provides strong evidence that the northern Gulf serves as viable spawning and/or nursery habitat of sailfish.

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APPENDIX A

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
1-1	5/17/2005	750	27.00	-94.00	24.50	35.50	6.80	8.09
1-2	5/17/2005	955	27.00	-93.87	25.28	35.78	6.88	8.18
1-3	5/17/2005	1100	27.00	-93.73	25.17	34.80	6.85	8.22
1-4	5/17/2005	1202	27.00	-93.60	25.56	34.66	6.80	8.15
1-5	5/17/2005	1325	27.00	-93.47	25.81	34.97	6.83	8.13
1-6	5/17/2005	1425	27.00	-93.33	25.87	35.21	6.90	8.21
1-7	5/17/2005	1535	27.00	-93.20	25.57	35.53	7.01	7.79
1-8	5/17/2005	1635	27.00	-93.07	25.85	35.23	7.18	8.15
1-9	5/17/2005	1742	27.00	-92.93	26.14	34.79	7.29	8.17
1-10	5/17/2005	1842	27.00	-92.80	25.40	35.68	7.15	8.02
1-11	5/18/2005	725	27.00	-92.67	25.20	35.85	10.82	8.24
1-12	5/18/2005	1008	27.00	-92.53	25.09	35.46	6.47	8.24
1-13	5/18/2005	1112	27.00	-92.40	25.12	35.64	6.61	8.22
1-14	5/18/2005	1213	27.00	-92.27	25.46	35.68	6.38	8.17
1-15	5/18/2005	1314	27.00	-92.13	25.57	35.61	6.60	7.85
1-16	5/18/2005	1420	27.00	-92.00	26.13	35.60	6.59	7.57
1-17	5/18/2005	1525	27.00	-91.87	25.96	35.75	6.77	7.51
1-18	5/18/2005	1630	27.00	-91.73	26.40	35.43	6.71	7.91
1-19	5/18/2005	1730	27.00	-91.60	26.29	35.71	6.93	8.02
1-20	5/18/2005	1833	27.00	-91.47	26.15	34.24	7.00	8.08
1-21	5/19/2005	810	27.00	-91.33	26.45	36.05	6.78	8.25
1-22	5/19/2005	915	27.00	-91.20	26.72	34.89	6.84	8.25
1-23	5/19/2005	1020	27.00	-91.07	27.03	35.98	6.77	8.25
1-24	5/19/2005	1127	27.00	-90.93	26.86	35.99	6.70	8.23
1-25	5/19/2005	1240	27.00	-90.80	27.15	35.56	6.79	8.23
1-26	5/19/2005	1345	27.00	-90.67	27.71	35.85	6.30	8.08
1-27	5/19/2005		27.00	-90.53	27.82	36.03	6.87	7.62
1-28	5/19/2005	1555	27.00	-90.40	27.70	35.96	7.02	7.68
1-29	5/19/2005	1710	27.00	-90.27	27.74	36.10	6.81	7.91
1-30	5/19/2005	1825	27.00	-90.13	27.03	35.55	7.03	7.92
1-31	5/20/2005		28.00	-90.00	27.17	36.22	6.33	8.21
1-32	5/20/2005	855	28.00	-90.13	27.88	36.07	6.69	7.98
1-33	5/20/2005	1000	28.00	-90.27	28.02	36.10	7.73	8.06
1-34	5/20/2005	1100	28.00	-90.40	28.13	36.08	7.06	8.07
1-35	5/20/2005	1200	28.00	-90.53	28.04	35.97	7.01	8.01
1-36	5/20/2005	1305	28.00	-90.67	27.81	35.94	9.20	8.18
1-37	5/20/2005	1405	28.00	-90.80	28.04	35.56	6.71	8.14
1-38	5/20/2005	1507	28.00	-90.93	27.85	36.33	6.76	8.22
1-39	5/20/2005	1610	28.00	-91.07	27.84	35.79	7.46	8.22
1-40	5/20/2005	1720	28.00	-91.20	27.59	36.23	6.67	8.23
1-41	5/20/2005	1820	28.00	-91.33	27.16	36.45	6.65	8.21
1-42	5/21/2005	810	28.00	-91.47	25.99	36.23	8.92	8.18
1-43	5/21/2005	910	28.00	-91.60	26.14	35.36	7.43	7.86
1-44	5/21/2005	1010	28.00	-91.73	26.27	36.45	7.05	5.63

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
1-45	5/21/2005	1120	28.00	-91.87	25.93	36.03	6.96	7.25
1-46	5/21/2005	1220	28.00	-92.00	26.03	36.37	6.69	7.82
1-47	5/21/2005		28.00	-92.13	26.01	35.19	6.93	7.99
1-48	5/21/2005	1419	28.00	-92.27	26.35	34.34	7.02	8.11
1-49	5/21/2005	1530	28.00	-92.40	26.36	34.03	7.10	8.11
1-50	5/21/2005	1640	28.00	-92.53	26.24	35.15	7.18	8.16
1-51	5/21/2005	1745	28.00	-92.67	25.79	35.30	7.53	8.16
1-52	5/22/2005	735	28.00	-92.80	25.28	34.54	8.82	8.17
1-53	5/22/2005	845	28.00	-92.93	25.35	34.84	7.52	7.97
1-54	5/22/2005	950	28.00	-93.07	25.75	34.78	6.58	7.87
1-55	5/22/2005	1050	28.00	-93.20	25.80	34.70	6.50	6.80
1-56	5/22/2005	1150	28.00	-93.33	26.11	34.07	7.38	6.74
1-57	5/22/2005	1300	28.00	-93.47	26.28	34.16	7.35	7.78
1-58	5/22/2005	1440	28.00	-93.60	26.65	34.39	6.72	7.99
1-59	5/22/2005	1550	28.00	-93.73	26.60	34.86	6.64	8.06
1-60	5/22/2005	1710	28.00	-93.87	26.54	34.48	6.98	8.14
2-1	7/23/2005	820	27.00	-94.00	29.31	35.55	6.69	8.10
2-2	7/23/2005	930	27.00	-93.87	29.42	35.63	6.59	8.10
2-3	7/23/2005	1035	27.00	-93.73	29.53	35.61	6.63	8.12
2-4	7/23/2005	1145	27.00	-93.60	29.64	35.78	6.58	8.10
2-5	7/23/2005	1300	27.00	-93.47	29.81	35.81	6.51	7.96
2-6	7/23/2005	1500	27.00	-93.33	29.86	35.89	6.55	7.43
2-7	7/23/2005	1610	27.00	-93.20				
2-8	7/23/2005	1715	27.00	-93.07	30.14	36.01	8.93	7.24
2-9	7/23/2005	1825	27.00	-92.93	30.04	36.03	10.30	8.00
2-10	7/23/2005	1940	27.00	-92.80	29.86	35.99	10.21	8.10
2-11	7/24/2005	710	27.00	-92.67	29.63	35.90	10.42	8.09
2-12	7/24/2005	815	27.00	-92.53	29.52	36.01	10.00	8.17
2-13	7/24/2005	920	27.00	-92.40	29.57	36.01	10.30	8.15
2-14	7/24/2005	1032	27.00	-92.27	29.72	35.98	6.40	8.14
2-15	7/24/2005	1135	27.00	-92.13	29.85	36.06	6.42	8.12
2-16	7/24/2005	1245	27.00	-92.00	29.95	36.07	6.19	7.99
2-17	7/24/2005	1430	27.00	-91.87	30.53	36.16	8.03	7.56
2-18	7/24/2005	1535	27.00	-91.73	30.73	36.17	10.50	7.76
2-19	7/24/2005	1650	27.00	-91.60	31.56	36.19	6.51	7.74
2-20	7/24/2005	1800	27.00	-91.47	31.10	36.30	6.53	7.95
2-21	7/25/2005	715	27.00	-91.33	29.70	36.07	6.64	8.10
2-22	7/25/2005	830	27.00	-91.20	29.81	36.15	6.22	8.15
2-23	7/25/2005	935	27.00	-91.07	29.76	36.10	6.23	8.11
2-24	7/25/2005	1050	27.00	-90.93	29.74	35.94	6.28	8.03
2-25	7/25/2005	1205	27.00	-90.80	30.17	36.02	6.20	8.13
2-26	7/25/2005	1315	27.00	-90.67	30.34	36.09	6.18	8.02
2-27	7/25/2005	1430	27.00	-90.53	30.59	36.12	6.18	8.02
2-28	7/25/2005	1540	27.00	-90.40	30.36	36.12	6.26	8.01

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
2-29	7/25/2005	1650	27.00	-90.27	30.48	36.13	6.17	7.95
2-30	7/25/2005	1800	27.00	-90.13	30.35	36.07	6.17	7.84
2-61	7/25/2005	706	27.00	-90.00	29.92	36.02	6.28	8.07
2-31	7/26/2005	840	28.00	-90.00	30.01	36.05	6.36	8.04
2-32	7/26/2005	1014	28.00	-90.13	30.21	36.09	6.38	8.01
2-33	7/26/2005	1215	28.00	-90.27	30.22	36.07	6.44	7.92
2-34	7/26/2005	1325	28.00	-90.40	30.43	36.16	6.41	7.88
2-35	7/26/2005	1450	28.00	-90.53	31.90	36.21	6.29	7.96
2-36	7/26/2005	1600	28.00	-90.67	32.51	36.08	6.18	8.04
2-37	7/26/2005	1707	28.00	-90.80	30.40	36.21	6.35	8.02
2-38	7/26/2005	1811	28.00	-90.93	31.76	36.16	6.23	7.98
2-39	7/26/2005	1918	28.00	-91.07	31.36	36.18	6.20	8.07
2-40	7/27/2005	700	28.00	-91.20	30.51	33.75	6.24	8.11
2-41	7/27/2005	820	28.00	-91.33	30.57	33.76	6.27	8.09
2-42	7/27/2005	935	28.00	-91.47	30.68	33.78	6.24	7.85
2-43	7/27/2005	1050	28.00	-91.60	31.01	33.09	6.16	7.93
2-44	7/27/2005	1200	28.00	-91.73	31.09	33.80	6.50	7.71
2-45	7/27/2005	1315	28.00	-91.87	31.69	33.73	6.46	7.79
2-46	7/27/2005	1434	28.00	-92.00	30.87	33.88	6.47	7.96
2-47	7/27/2005	1536	28.00	-92.13	30.70	34.86	6.46	7.84
2-48	7/27/2005	1639	28.00	-92.27	31.05	35.32	6.34	8.05
2-49	7/27/2005	1741	28.00	-92.40	30.71	33.78	6.47	8.01
2-50	7/28/2005	730	28.00	-92.53	29.74	34.88	6.26	8.00
2-51	7/28/2005	922	28.00	-92.67	30.10	35.13	6.39	7.91
2-52	7/28/2005	1031	28.00	-92.80	30.15	35.52	6.38	7.80
2-53	7/28/2005	1144	28.00	-92.93	30.66	34.91	6.39	7.95
2-54	7/28/2005	1250	28.00	-93.07	30.70	33.58	6.35	7.95
2-55	7/28/2005	1400	28.00	-93.20	30.92	32.15	6.43	7.89
2-56	7/28/2005	1515	28.00	-93.33	30.99	32.84	6.44	7.96
2-57	7/28/2005	1620	28.00	-93.47	31.22	32.35	6.19	7.77
2-58	7/28/2005	1725	28.00	-93.60	31.18	32.99	6.31	7.99
2-59	7/28/2005	1835	28.00	-93.73	31.05	32.38	6.23	8.07
2-60	7/25/2005	1915	28.00	-93.87	30.10	36.15	6.15	8.07
2-62	7/28/2005	1945	28.00	-94.00	30.88	32.10	6.31	8.10
3-1	9/16/2005	1115	27.00	-94.00	29.77	36.73	6.16	8.12
3-2	9/16/2005	1223	27.00	-93.87	30.10	36.84	5.88	8.02
3-3	9/16/2005	1335	27.00	-93.73	30.74	37.13	4.87	7.99
3-4	9/16/2005	1450	27.00	-93.60	30.39	36.96	5.91	7.93
3-5	9/16/2005	1602	27.00	-93.47	31.74	36.98	5.07	7.64
3-6	9/16/2005	1715	27.00	-93.33	30.65	36.90	6.27	7.52
3-7	9/16/2005	1823	27.00	-93.20	30.86	36.69	6.20	7.91
3-8	9/16/2005	1930	27.00	-93.07	30.27	36.70	5.92	8.08
3-9	9/17/2005	710	27.00	-92.93	29.53	36.87	5.71	8.16
3-10	9/17/2005	825	27.00	-92.80	29.43	36.67	5.75	8.17

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
3-11	9/17/2005	932	27.00	-92.67	29.60	36.64	5.79	8.16
3-12	9/17/2005	1034	27.00	-92.53	29.85	36.65	5.81	8.12
3-13	9/17/2005	1150	27.00	-92.40	29.95	36.64	5.88	8.05
3-14	9/17/2005	1313	27.00	-92.27	30.02	36.64	6.55	8.02
3-15	9/17/2005	1410	27.00	-92.13	30.36	36.65	6.40	7.96
3-16	9/17/2005	1506	27.00	-92.00	30.14	36.55	6.28	8.03
3-17	9/17/2005	1607	27.00	-91.87	30.14	36.59	6.30	7.98
3-18	9/17/2005	1703	27.00	-91.73	29.88	36.58	6.42	7.92
3-19	9/17/2005	1758	27.00	-91.60	29.81	36.65	6.41	7.80
3-20	9/18/2005	700	27.00	-91.47	29.60	36.56	6.46	8.08
3-21	9/18/2005	740	27.00	-91.33	29.35	36.77	6.11	8.17
3-22	9/18/2005	850	27.00	-91.20	29.50	36.65	6.59	8.13
3-23	9/18/2005	945	27.00	-91.07	29.75	36.67	6.63	8.04
3-24	9/18/2005	1050	27.00	-90.93	29.79	36.64	6.66	8.03
3-25	9/18/2005	1145	27.00	-90.80	29.80	36.69	6.66	7.90
3-26	9/18/2005	1245	27.00	-90.67	29.95	36.76	6.74	6.86
3-27	9/18/2005	1345	27.00	-90.53	29.87	36.65	6.77	7.22
3-28	9/18/2005	1450	27.00	-90.40	29.79	36.68	6.44	7.74
3-29	9/18/2005	1600	27.00	-90.27	29.84	36.83	6.38	7.68
3-30	9/18/2005	1705	27.00	-90.13	29.80	36.82	6.29	7.76
3-61	9/18/2005	1810	27.00	-90.00	29.74	36.80	6.24	8.03
3-31	9/19/2005	650	28.00	-90.00	28.60	36.75	6.48	8.15
3-32	9/19/2005	806	28.00	-90.13	28.65	36.64	6.50	8.16
3-33	9/19/2005	910	28.00	-90.27	28.65	36.60	6.56	8.03
3-34	9/19/2005	1015	28.00	-90.40	29.21	35.69	6.70	6.18
3-35	9/19/2005	1115	28.00	-90.53	29.19	36.02	6.72	6.41
3-36	9/19/2005	1220	28.00	-90.67	29.36	34.80	6.33	6.46
3-37	9/19/2005	1320	28.00	-90.80	29.50	34.66	6.58	7.69
3-38	9/19/2005	1422	28.00	-90.93	29.69	34.59	6.47	7.98
4-1	6/15/2006	810	27.00	-94.00	28.16	36.20	6.57	8.30
4-2	6/15/2006	915	27.00	-93.87	28.16	33.18	6.76	8.27
4-3	6/15/2006	1017	27.00	-93.73	28.28	36.36	6.63	8.25
4-4	6/15/2006	1120	27.00	-93.60	28.40	36.24	6.65	8.22
4-5	6/15/2006	1217	27.00	-93.47	28.45	36.27	6.65	8.20
4-6	6/15/2006	1317	27.00	-93.33	28.56	36.24	6.68	8.17
4-7	6/15/2006	1410	27.00	-93.20	28.53	36.24	6.70	8.07
4-8	6/15/2006	1520	27.00	-93.07	28.69	36.16	6.73	7.93
4-9	6/15/2006	1610	27.00	-92.93	28.65	36.18	6.65	8.17
4-10	6/15/2006	1710	27.00	-92.80	28.52	36.15	6.63	8.28
4-11	6/15/2006	1805	27.00	-92.67	28.53	36.11	6.64	8.29
4-12	6/16/2006	700	27.00	-92.53	28.27	36.07	6.61	8.34
4-13	6/16/2006	805	27.00	-92.40	28.17	35.98	6.50	8.23
4-14	6/16/2006	905	27.00	-92.27	28.13	35.91	6.37	8.17
4-15	6/16/2006	1005	27.00	-92.13	28.19	35.89	6.48	8.20

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
4-16	6/16/2006	1105	27.00	-92.00	28.22	35.74	6.48	8.16
4-17	6/16/2006	1145	27.00	-91.92	28.21	35.88	6.52	8.17
4-18	6/16/2006	1320	27.00	-91.73	28.22	35.59	6.63	8.14
4-19	6/16/2006	1415	27.00	-91.60	28.24	35.79	6.56	8.00
4-20	6/16/2006	1505	27.00	-91.47	28.26	35.66	6.65	7.80
4-21	6/16/2006	1555	27.00	-91.33	28.27	35.68	6.73	7.26
4-22	6/16/2006	1647	27.00	-91.20	28.22	35.76	6.70	7.83
4-23	6/16/2006	1739	27.00	-91.07	28.17	35.75	6.73	7.80
4-61	6/17/2006	700	27.00	-90.00	28.35	35.55	6.56	8.30
4-63	6/17/2006	812	27.00	-89.87	28.44	35.45	6.55	8.26
4-64	6/17/2006	914	27.00	-89.73	28.25	35.56	6.51	8.21
4-65	6/17/2006	1012	27.00	-89.60	28.25	35.46	6.51	8.19
4-66	6/17/2006	1128	27.00	-89.47	28.34	35.45	6.56	8.15
4-67	6/17/2006	1248	27.00	-89.33	28.51	35.60	6.56	8.08
4-68	6/17/2006	1353	27.00	-89.20	28.92	35.68	6.56	8.00
4-69	6/17/2006	1450	27.00	-89.07	29.10	35.62	6.68	6.64
4-70	6/17/2006	1552	27.00	-88.93	29.79	35.60	6.57	7.15
4-71	6/17/2006	1600	27.00	-88.80	29.38	35.54	6.67	6.76
4-72	6/17/2006	1610	27.00	-88.67	29.34	35.52	6.59	7.31
4-73	6/18/2006	705	27.13	-88.67	28.53	35.50	6.51	8.24
4-74	6/18/2006	814	27.27	-88.67	28.54	35.50	6.48	7.99
4-75	6/18/2006	912	27.40	-88.67	28.51	35.57	6.44	7.94
4-76	6/18/2006	1000	27.53	-88.67	28.54	35.55	6.47	7.83
4-77	6/18/2006	1052	27.67	-88.67	28.50	35.55	6.52	7.84
4-78	6/18/2006	1150	27.80	-88.67	28.61	35.55	6.54	7.79
4-79	6/18/2006	1247	27.93	-88.67	28.74	35.57	6.51	7.87
4-80	6/18/2006	1412	27.93	-88.80	29.31	35.61	6.49	7.97
4-81	6/18/2006	1530	27.93	-88.93	29.59	35.61	6.45	7.79
4-82	6/18/2006	1645	27.93	-89.07	30.31	35.85	6.52	7.95
4-83	6/18/2006	1750	27.93	-89.20	29.80	35.73	6.49	8.02
4-84	6/18/2006	1900	27.93	-89.33	29.96	35.90	6.42	8.09
4-85	6/19/2006	703	27.93	-89.47	28.54	35.87	6.44	8.24
4-86	6/19/2006	805	27.93	-89.60	28.11	35.92	6.18	8.17
4-87	6/19/2006	904	27.93	-89.73	28.43	35.87	6.51	8.17
4-88	6/19/2006	1008	27.93	-89.87	28.65	35.76	6.38	6.31
4-89	6/19/2006	1114	27.93	-90.00	28.86	35.61	6.64	4.48
4-90	6/19/2006	1329	27.93	-90.27	29.04	35.88	6.37	7.77
4-91	6/19/2006	1523	27.93	-90.53	29.66	35.89	6.21	7.88
4-92	6/19/2006	1725	27.93	-90.80	29.05	35.58	6.09	7.93
4-93	6/20/2006	710	27.93	-91.07	28.49	36.05	6.73	8.16
4-94	6/20/2006	835	27.93	-91.33	28.47	36.05	6.56	8.06
4-95	6/20/2006	935	27.93	-91.60	28.45	35.98	6.68	7.60
4-96	6/20/2006	1040	27.93	-91.87	28.55	35.90	6.73	5.70
4-97	6/20/2006	1150	27.93	-92.13	28.67	35.96	6.73	7.06
4-98	6/20/2006	1345	27.93	-92.40	28.98	35.98	6.63	7.74

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
4-99	6/20/2006	1532	27.93	-92.67	29.01	36.00	6.48	7.99
4-100	6/20/2006	1732	27.93	-92.93	28.87	36.18	6.76	8.11
5-1	7/31/2006	758	27.00	-89.47	30.02	36.38	5.59	8.11
5-2	7/31/2006	859	27.00	-89.60	29.99	36.39	5.46	8.11
5-3	7/31/2006	947	27.00	-89.73	30.07	36.41	5.33	7.99
5-4	7/31/2006	1045	27.00	-89.87	30.12	36.47	5.07	7.78
5-5	7/31/2006	1224	27.00	-90.00	30.48	36.47	6.72	7.82
5-6	7/31/2006	1315	27.00	-90.13	30.79	36.53	6.34	8.04
5-7	7/31/2006	1420	27.00	-90.27	31.06	36.50	6.35	8.09
5-8	7/31/2006	1527	27.00	-90.40	30.85	36.41	6.91	8.12
5-9	7/31/2006	1627	27.00	-90.53	30.71	36.35	6.04	8.11
5-10	7/31/2006	1727	27.00	-90.67	30.65	36.33	5.86	8.16
5-11	7/31/2006	1823	27.00	-90.80	30.40	36.26	6.12	8.12
5-12	8/1/2006	800	27.00	-90.93	29.90	36.22	12.55	8.06
5-13	8/1/2006	910	27.00	-91.07	29.55	35.97	12.84	6.41
5-14	8/1/2006	1015	27.00	-91.20	29.79	36.02	12.73	6.47
5-15	8/1/2006	1120	27.00	-91.33	29.85	36.25	12.23	6.98
5-16	8/1/2006	1223	27.00	-91.47	29.93	36.41	9.57	7.49
5-17	8/1/2006	1325	27.00	-91.60	30.02	36.39	9.64	7.67
5-18	8/1/2006	1420	27.00	-91.73	30.14	36.37	9.61	7.75
5-19	8/1/2006	1520	27.00	-91.87	30.11	36.37	9.62	7.87
5-20	8/1/2006	1612	27.00	-92.00	30.06	36.36	9.08	7.94
5-21	8/1/2006	1734	27.17	-92.00	30.05	36.40	9.50	7.97
5-22	8/1/2006	1847	27.33	-92.00	29.92	36.31	9.43	8.03
5-23	8/2/2006	700	27.50	-92.00	29.75	36.47	9.22	8.15
5-24	8/2/2006	745	27.50	-91.87	29.75	36.38	9.27	8.09
5-25	8/2/2006	845	27.50	-91.73	29.72	36.34	9.40	8.06
5-26	8/2/2006	940	27.50	-91.60	29.74	36.32	9.41	7.99
5-27	8/2/2006	1040	27.50	-91.47	29.82	36.28	9.48	7.93
5-28	8/2/2006	1134	27.50	-91.33	29.68	36.17	9.52	7.94
5-29	8/2/2006	1245	27.50	-91.20	29.90	36.26	9.44	8.00
5-30	8/2/2006	1330	27.50	-91.07	30.01	36.32	9.42	8.01
5-31	8/2/2006	1420	27.50	-90.93	30.05	36.36	9.44	7.80
5-32	8/2/2006	1517	27.50	-90.80	30.17	36.39	9.30	7.67
5-33	8/2/2006	1615	27.50	-90.67	30.16	36.39	9.42	7.24
5-34	8/2/2006	1700	27.50	-90.53	29.96	35.99	9.52	7.79
5-35	8/3/2006	702	27.50	-90.40	29.58	36.00	6.09	8.17
5-36	8/3/2006	755	27.50	-90.27	29.61	36.02	7.50	8.20
5-37	8/3/2006	855	27.50	-90.13	29.59	35.59	7.79	8.14
5-38	8/3/2006	958	27.50	-90.00	29.97	36.16	8.03	8.09
5-39	8/3/2006	1307	27.50	-89.87	30.00	36.17	9.22	7.89
5-40	8/3/2006	1343	27.50	-89.80	29.98	36.18	9.12	7.94
5-41	8/3/2006	1426	27.50	-89.73	29.87	36.17	9.06	8.06
5-42	8/3/2006	1503	27.50	-89.67	29.85	36.13	9.29	7.45

Station #	Date	Time	Latitude	Longitude	Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg/L)	pH
5-43	8/3/2006	1600	27.50	-89.53	29.96	36.19	9.39	7.06
5-44	8/3/2006	1730	27.67	-89.53	30.05	36.13	9.20	8.05
5-45	8/3/2006	1859	27.83	-89.53	29.82	35.98	9.21	8.14
5-46	8/4/2006	735	28.00	-89.53	29.93	36.50	7.94	8.13
5-46A	8/4/2006	850	28.00	-89.67	29.92	36.45	7.98	8.07
5-47	8/4/2006	938	28.00	-89.77	29.69	35.68	7.74	7.39
5-48	8/4/2006	1030	28.00	-89.87	29.93	36.14	7.85	6.50
5-49	8/4/2006	1135	28.00	-90.00	30.12	36.38	8.70	5.42
5-50	8/4/2006	1233	28.00	-90.13	30.21	36.43	8.34	7.60
5-51	8/4/2006	1333	28.00	-90.27	30.20	36.35	8.20	7.77
5-52	8/4/2006	1436	28.00	-90.40	30.16	36.18	8.24	7.93
5-53	8/4/2006	1555	28.00	-90.53	30.18	36.40	8.26	7.94
5-54	8/4/2006	1655	28.00	-90.67	30.23	36.39	8.34	7.92
5-55	8/4/2006	1815	28.00	-90.80	30.16	36.45	8.29	7.85
5-56	8/4/2006	1910	28.00	-90.93	30.10	36.40	8.24	8.00
5-57	8/5/2006	705	28.00	-91.07	29.87	36.46	5.44	8.23
5-58	8/5/2006	806	28.00	-91.20	29.83	36.42	7.88	7.99
5-59	8/5/2006	921	28.00	-91.33	29.91	36.46	7.58	8.08
5-59A	8/5/2006	929	28.00	-91.33	29.91	36.46	7.58	8.08
5-60	8/5/2006	1042	28.00	-91.47	30.19	36.47	7.72	6.18
5-61	8/5/2006	1144	28.00	-91.60	30.17	36.54	7.15	7.39
5-62	8/5/2006	1240	28.00	-91.73	30.46	36.51	7.70	7.55
5-63	8/5/2006	1336	28.00	-91.87	30.51	34.16	7.69	7.68
5-64	8/5/2006	1428	28.00	-92.00	30.40	34.17	7.74	7.83

APPENDIX B

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
1-1	1131	-24.836	Cyclone	0	0.00	0	0
1-2	1252	-27.062	Cyclone	0	0.00	0	0
1-3	1237	-27.062	Cyclone	0	0.00	0	0
1-4	1291	-27.614	Cyclone	0	0.00	0	0
1-5	1201	-27.614	Cyclone	0	0.00	0	0
1-6	1370	-22.678	Cyclone	0	0.00	0	0
1-7	1290	-22.678	Cyclone	0	0.00	0	0
1-8	1450	-16.398	Cyclone	0	0.00	0	0
1-9	1271	-16.398	Cyclone	0	0.00	0	0
1-10	1509	-8.618	Open Ocean	0	0.00	0	0
1-11	1567	-7.767	Open Ocean	0	0.00	0	0
1-12	1448	-0.796	Open Ocean	0	0.00	0	0
1-13	1880	-0.796	Front	0	0.00	0	0
1-14	1480	6.134	Front	0	0.00	0	0
1-15	2004	6.134	Front	0	0.00	0	0
1-16	1462	13.804	Front	0	0.00	0	0
1-17	1630	18.592	Anti-cyclone	0	0.00	0	0
1-18	1646	18.592	Anti-cyclone	1	0.26	0	0
1-19	2011	21.175	Anti-cyclone	0	0.00	0	0
1-20	1773	21.175	Anti-cyclone	0	0.00	0	0
1-21	2090	18.954	Anti-cyclone	0	0.00	0	0
1-22	1687	18.954	Anti-cyclone	5	0.99	0	1
1-23	2003	15.068	Front	0	0.00	0	0
1-24	1682	15.068	Front	1	0.21	0	0
1-25	1661	9.143	Front	4	0.91	0	0
1-26	1614	9.143	Front	1	0.23	0	1
1-27	1516	6.562	Open Ocean	0	0.00	0	0
1-28	2261	6.562	Open Ocean	1	0.21	0	0
1-29	1836	7.988	Open Ocean	1	0.19	0	0
1-30	2380	7.988	Open Ocean	0	0.00	0	0
1-31	548	14.716	Front	75	10.44	0	0
1-32	568	13.127	Front	48	7.94	0	8
1-33	458	13.127	Front	20	3.18	0	0
1-34	492	13.689	Front	9	1.45	0	2
1-35	394	13.689	Front	27	4.68	0	1
1-36	243	15.445	Front	7	1.44	0	0
1-37	249	15.445	Front	3	0.58	0	0
1-38	183	19.170	Anti-cyclone	1	0.19	0	0
1-39	147	19.170	Anti-cyclone	8	1.42	0	1
1-40	147	19.760	Anti-cyclone	0	0.00	0	0
1-41	201	19.760	Anti-cyclone	0	0.00	0	0
1-42	143	20.388	Anti-cyclone	0	0.00	0	0
1-43	198	20.388	Anti-cyclone	0	0.00	0	0
1-44	119	15.536	Front	0	0.00	0	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m2)	Blue Marlin	White Marlin
1-45	121	15.536	Front	0	0.00	0	0
1-46	123	10.699	Front	0	0.00	0	0
1-47	107	4.948	Front	0	0.00	0	0
1-48	138	4.948	Open Ocean	0	0.00	0	0
1-49	130	0.328	Open Ocean	0	0.00	0	0
1-50	112	0.328	Open Ocean	0	0.00	0	0
1-51	117	-3.725	Open Ocean	0	0.00	0	0
1-52	110	-3.392	Open Ocean	0	0.00	0	0
1-53	108	-6.992	Open Ocean	0	0.00	0	0
1-54	109	-6.992	Open Ocean	0	0.00	0	0
1-55	101	-9.703	Open Ocean	0	0.00	0	0
1-56	105	-9.703	Open Ocean	0	0.00	0	0
1-57	104	-9.479	Open Ocean	0	0.00	0	0
1-58	97	-9.479	Open Ocean	0	0.00	0	0
1-59	97	-7.989	Open Ocean	0	0.00	0	0
1-60	85	-7.989	Open Ocean	0	0.00	0	0
2-1	1131	-7.834	Open Ocean	0	0.00	0	0
2-2	1252	-8.580	Open Ocean	0	0.00	0	0
2-3	1237	-8.580	Open Ocean	0	0.00	0	0
2-4	1291	-8.405	Open Ocean	0	0.00	0	0
2-5	1201	-8.405	Open Ocean	0	0.00	0	0
2-6	1370	-8.031	Open Ocean	0	0.00	0	0
2-7	1290	-8.031	Open Ocean	0	0.00	0	0
2-8	1450	-9.111	Open Ocean	0	0.00	0	0
2-9	1271	-9.111	Open Ocean	0	0.00	0	0
2-10	1509	-10.635	Cyclone	0	0.00	0	0
2-11	1567	-10.907	Cyclone	1	0.23	0	0
2-12	1448	-10.143	Cyclone	0	0.00	0	0
2-13	1880	-10.143	Cyclone	1	0.24	0	0
2-14	1480	-3.567	Front	0	0.00	0	0
2-15	2004	-3.567	Front	1	0.18	0	0
2-16	1462	8.440	Front	0	0.00	0	0
2-17	1630	22.063	Anti-cyclone	0	0.00	0	0
2-18	1646	22.063	Anti-cyclone	0	0.00	0	0
2-19	2011	32.084	Anti-cyclone	0	0.00	0	0
2-20	1773	32.084	Anti-cyclone	0	0.00	0	0
2-21	2090	35.197	Anti-cyclone	160	22.56	1	0
2-22	1687	35.197	Anti-cyclone	0	0.00	0	0
2-23	2003	37.381	Anti-cyclone	5	0.73	0	0
2-24	1682	37.381	Anti-cyclone	3	0.38	1	0
2-25	1661	37.211	Anti-cyclone	0	0.00	0	0
2-26	1614	37.211	Anti-cyclone	2	0.27	1	0
2-27	1516	39.583	Anti-cyclone	0	0.00	0	0
2-28	2261	39.583	Anti-cyclone	1	0.20	4	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
2-29	1836	38.999	Anti-cyclone	0	0.00	8	0
2-30	2380	38.999	Anti-cyclone	0	0.00	1	0
2-61	2424	36.143	Anti-cyclone	0	0.00	1	0
2-31	548	-6.578	Front	18	2.78	4	0
2-32	568	-4.873	Front	1	0.10	0	0
2-33	458	-4.873	Front	0	0.00	0	0
2-34	492	-5.718	Front	1	0.12	0	0
2-35	394	-5.718	Front	289	51.35	0	0
2-36	243	-8.194	Open Ocean	3	0.52	0	0
2-37	249	-8.194	Open Ocean	116	23.02	0	0
2-38	183	-10.093	Cyclone	1	0.16	0	0
2-39	147	-10.093	Cyclone	0	0.00	0	0
2-40	147	-9.798	Open Ocean	1	0.16	1	0
2-41	201	-9.798	Open Ocean	6	1.22	0	0
2-42	143	-8.362	Open Ocean	23	4.87	0	0
2-43	198	-8.362	Open Ocean	2	0.38	0	0
2-44	119	-7.126	Open Ocean	2	0.45	0	0
2-45	121	-7.126	Open Ocean	0	0.00	0	0
2-46	123	-6.462	Open Ocean	2	0.37	1	0
2-47	107	-5.778	Open Ocean	0	0.00	0	0
2-48	138	-5.778	Open Ocean	1	0.16	0	0
2-49	130	-4.880	Open Ocean	16	2.61	0	0
2-50	112	-4.715	Open Ocean	13	2.66	0	0
2-51	117	-3.506	Open Ocean	49	9.73	0	0
2-52	110	-3.506	Open Ocean	1	0.29	1	0
2-53	108	-1.630	Open Ocean	14	2.80	0	0
2-54	109	-1.630	Open Ocean	3	0.53	0	0
2-55	101	-1.325	Open Ocean	1	0.14	0	0
2-56	105	-1.325	Open Ocean	1	0.20	0	0
2-57	104	-1.777	Open Ocean	2	0.35	0	0
2-58	97	-1.777	Open Ocean	2	0.35	0	0
2-59	97	-2.486	Open Ocean	1	0.21	0	0
2-60	85	-2.486	Open Ocean	7	1.02	0	0
2-62	82	-2.276	Open Ocean	5	0.97	0	0
3-1	1131	-9.510	Open Ocean	0	0.00	0	0
3-2	1252	-6.931	Open Ocean	0	0.00	0	0
3-3	1237	-6.931	Open Ocean	1	0.15	0	0
3-4	1291	-3.355	Open Ocean	0	0.00	0	0
3-5	1201	-3.355	Open Ocean	0	0.00	0	0
3-6	1370	0.406	Open Ocean	6	0.67	0	0
3-7	1290	0.406	Open Ocean	23	3.06	3	0
3-8	1450	3.219	Front	0	0.00	20	0
3-9	1271	3.626	Front	0	0.00	78	0
3-10	1509	4.829	Front	1	0.16	17	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
3-11	1567	4.829	Front	0	0.00	4	0
3-12	1448	5.902	Front	1	0.15	0	0
3-13	1880	5.902	Front	0	0.00	4	0
3-14	1480	5.882	Front	3	0.54	1	0
3-15	2004	5.882	Front	1	0.20	0	0
3-16	1462	5.290	Front	0	0.00	9	0
3-17	1630	3.461	Front	0	0.00	0	0
3-18	1646	3.461	Front	0	0.00	19	0
3-19	2011	2.296	Front	0	0.00	18	0
3-20	1773	1.307	Front	1	0.17	21	0
3-21	2090	0.369	Open Ocean	0	0.00	2	0
3-22	1687	0.369	Open Ocean	0	0.00	12	0
3-23	2003	1.116	Open Ocean	5	0.86	1	0
3-24	1682	1.116	Open Ocean	1	0.21	3	0
3-25	1661	0.650	Open Ocean	0	0.00	0	0
3-26	1614	0.650	Open Ocean	20	3.46	0	0
3-27	1516	-0.048	Open Ocean	23	4.51	0	0
3-28	2261	-0.048	Open Ocean	25	4.52	0	0
3-29	1836	0.211	Open Ocean	0	0.00	0	0
3-30	2380	0.211	Open Ocean	0	0.00	0	0
3-61	2424	1.235	Open Ocean	16	2.99	1	0
3-31	548	-1.473	Open Ocean	3	0.45	0	0
3-32	568	-3.413	Open Ocean	1	0.19	0	0
3-33	458	-3.413	Open Ocean	1	0.17	0	0
3-34	492	-7.013	Open Ocean	0	0.00	0	0
3-35	394	-7.013	Open Ocean	0	0.00	0	0
3-36	243	-10.956	Cyclone	2	0.39	0	0
3-37	249	-10.956	Cyclone	0	0.00	0	0
3-38	183	-14.921	Cyclone	0	0.00	0	0
4-1	1131	-12.518	Cyclone	0	0.00	0	0
4-2	1252	-5.530	Open Ocean	1	0.20	0	0
4-3	1237	-5.530	Open Ocean	0	0.00	0	0
4-4	1291	5.636	Front	0	0.00	0	0
4-5	1201	5.636	Front	0	0.00	0	0
4-6	1370	15.511	Front	0	0.00	0	0
4-7	1290	15.511	Front	0	0.00	0	0
4-8	1450	22.630	Anti-cyclone	0	0.00	0	0
4-9	1271	22.630	Anti-cyclone	0	0.00	0	0
4-10	1509	26.577	Anti-cyclone	0	0.00	0	0
4-11	1567	26.577	Anti-cyclone	0	0.00	0	0
4-12	1448	26.436	Anti-cyclone	0	0.00	0	0
4-13	1880	26.436	Anti-cyclone	0	0.00	0	0
4-14	1480	23.833	Anti-cyclone	0	0.00	0	0
4-15	2004	23.833	Anti-cyclone	0	0.00	0	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
4-16	1462	19.865	Anti-cyclone	0	0.00	0	0
4-17	1687	19.865	Anti-cyclone	0	0.00	0	0
4-18	1646	13.876	Front	1	0.23	0	0
4-19	2011	8.791	Front	0	0.00	0	0
4-20	1773	8.791	Front	0	0.00	0	0
4-21	2090	4.320	Open Ocean	0	0.00	1	0
4-22	1687	4.320	Open Ocean	0	0.00	0	0
4-23	2003	1.469	Open Ocean	5	1.27	3	0
4-61	2424	17.706	Anti-cyclone	79	18.29	4	4
4-63	2373	15.925	Front	4	0.69	0	0
4-64	2332	15.925	Front	121	20.59	2	4
4-65	2408	15.544	Front	3	0.55	0	0
4-66	2531	15.544	Front	24	4.89	2	0
4-67	2542	14.372	Front	68	11.07	0	0
4-68	2487	14.372	Front	133	22.04	0	0
4-69	2326	14.989	Front	36	7.08	0	1
4-70	2232	14.989	Front	22	4.21	0	0
4-71	2212	14.790	Front	26	4.72	0	0
4-72	2234	14.790	Front	14	2.56	1	1
4-73	2245	5.339	Front	4	0.78	0	0
4-74	2349	5.339	Front	3	0.57	1	0
4-75	2199	-2.645	Open Ocean	31	5.83	0	1
4-76	1918	-2.645	Open Ocean	3	0.52	2	3
4-77	1739	-6.940	Open Ocean	2	0.38	0	0
4-78	1867	-6.940	Open Ocean	0	0.00	1	1
4-79	1951	-8.519	Open Ocean	8	1.50	0	2
4-80	1697	-8.519	Open Ocean	6	1.03	0	0
4-81	1496	-8.004	Open Ocean	62	8.67	1	4
4-82	1268	-8.004	Open Ocean	1	0.21	0	0
4-83	1394	-6.175	Open Ocean	9	1.81	0	0
4-84	1302	-6.175	Open Ocean	9	1.79	0	0
4-85	1009	-3.729	Open Ocean	12	1.81	0	0
4-86	987	-3.729	Open Ocean	0	0.00	0	0
4-87	936	-2.996	Open Ocean	0	0.00	0	0
4-88	828	-2.996	Open Ocean	0	0.00	0	0
4-89	635	-4.368	Open Ocean	0	0.00	0	0
4-90	638	-8.481	Open Ocean	1	0.18	0	0
4-91	504	-14.752	Cyclone	1	0.19	0	0
4-92	423	-20.232	Cyclone	0	0.00	0	0
4-93	279	-23.637	Cyclone	0	0.00	0	0
4-94	324	-21.852	Cyclone	0	0.00	0	0
4-95	294	-19.487	Cyclone	1	0.21	0	0
4-96	171	-15.496	Cyclone	1	0.21	0	0
4-97	166	-12.203	Cyclone	0	0.00	0	1
4-98	113	-12.215	Cyclone	0	0.00	0	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
4-99	179	-12.245	Cyclone	0	0.00	0	0
4-100	146	-11.700	Cyclone	0	0.00	0	0
5-1	2531	14.837	Front	1	0.25	1	0
5-2	2408	14.837	Front	0	0.00	0	0
5-3	2332	19.856	Anti-cyclone	0	0.00	1	0
5-4	2373	19.856	Anti-cyclone	0	0.00	0	0
5-5	2424	25.102	Anti-cyclone	0	0.00	0	0
5-6	2386	28.547	Anti-cyclone	3	0.64	4	0
5-7	1848	28.547	Anti-cyclone	1	0.21	7	0
5-8	2239	29.763	Anti-cyclone	1	0.25	3	0
5-9	1530	29.763	Anti-cyclone	0	0.00	2	0
5-10	1579	35.722	Anti-cyclone	1	0.21	0	0
5-11	1668	35.722	Anti-cyclone	38	9.17	1	0
5-12	1660	40.173	Anti-cyclone	57	10.19	1	0
5-13	2003	40.173	Anti-cyclone	53	9.16	1	1
5-14	1687	39.424	Anti-cyclone	46	9.08	0	0
5-15	2090	39.424	Anti-cyclone	3	0.43	0	0
5-16	1773	37.245	Anti-cyclone	2	0.48	0	0
5-17	2011	37.245	Anti-cyclone	0	0.00	0	0
5-18	1646	31.341	Anti-cyclone	0	0.00	0	0
5-19	1630	31.341	Anti-cyclone	0	0.00	0	0
5-20	1462	26.092	Anti-cyclone	0	0.00	0	0
5-21	1530	13.144	Front	0	0.00	0	0
5-22	942	13.144	Front	0	0.00	0	0
5-23	762	3.339	Front	0	0.00	1	0
5-24	822	9.944	Front	0	0.00	0	0
5-25	971	9.944	Front	0	0.00	0	0
5-26	1146	14.856	Front	0	0.00	0	0
5-27	965	14.856	Front	0	0.00	0	0
5-28	1056	15.909	Front	0	0.00	0	0
5-29	1164	15.909	Front	0	0.00	0	0
5-30	1332	13.792	Front	0	0.00	0	0
5-31	1131	13.792	Front	0	0.00	0	0
5-32	1028	8.812	Front	0	0.00	0	0
5-33	1309	8.812	Front	0	0.00	0	0
5-34	1040	9.640	Front	114	4.95	3	0
5-35	1148	12.805	Front	41	7.54	2	0
5-36	1202	13.467	Front	23	8.17	0	0
5-37	1125	13.467	Front	20	3.80	0	0
5-38	1169	14.618	Front	2	0.04	218	0
5-39	1295	13.418	Front	0	0.00	50	0
5-40	1374	13.418	Front	0	0.00	27	0
5-41	1372	13.418	Front	0	0.00	14	0
5-42	1608	13.418	Front	0	0.00	1	0

Station #	Ocean depth (m)	Sea Surface Height (cm)	Feature	Sailfish	Sailfish density (no. / 1000m^2)	Blue Marlin	White Marlin
5-43	1850	11.616	Open Ocean	0	0.00	2	0
5-44	1332	1.892	Open Ocean	0	0.00	4	0
5-45	1148	1.892	Open Ocean	31	5.79	1	0
5-46	979	-5.035	Open Ocean	0	0.00	0	0
5-46A	751	-1.414	Open Ocean	0	0.00	0	0
5-47	796	-1.414	Open Ocean	3	0.61	0	0
5-48	711	-1.414	Open Ocean	0	0.00	0	0
5-49	557	-0.087	Open Ocean	6	1.25	0	0
5-50	568	-1.113	Open Ocean	0	0.00	0	0
5-51	458	-1.113	Open Ocean	38	8.01	0	0
5-52	460	-4.101	Open Ocean	28	6.73	0	0
5-53	394	-4.101	Open Ocean	4	1.16	0	0
5-54	243	-8.342	Open Ocean	0	0.00	0	0
5-55	249	-8.342	Open Ocean	4	0.99	0	0
5-56	183	-9.465	Open Ocean	4	1.17	0	0
5-57	147	-9.850	Open Ocean	16	4.36	1	0
5-58	147	-7.092	Open Ocean	33	8.17	0	0
5-59	201	-7.092	Open Ocean	39	9.53	1	0
5-59A	201	-7.092	Open Ocean	0	0.00	0	0
5-60	132	-5.468	Open Ocean	4	0.90	0	0
5-61	192	-5.468	Open Ocean	3	0.70	0	0
5-62	119	-5.668	Open Ocean	12	2.69	0	0
5-63	121	-5.668	Open Ocean	3	0.66	0	0
5-64	123	-8.412	Open Ocean	0	0.00	0	0

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