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The Nature and Extent of Species Interactions With the United States Gulf Menhaden Fishery.

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THE NATURE AND EXTENT OF SPECIES INTERACTIONS WITH THE U.S. GULF MENHADEN FISHERY

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ABSTRACT

I employed categorical techniques to explain patchy data on the releasable bycatch in the U.S. Gulf of Mexico menhaden fishery looking for species and areas of potential concern, and potential solutions. For fishing grounds east of the Mississippi River, the odds of observing sets with high bycatch in spring and summer were greater than in the fall. Furthermore, spring bycatch rates were higher east of 89^0 W than in areas west of 93^0 W. Correspondence analysis indicated that the fate of the releasable bycatch could be classified into three major species-fate groupings. From April through August, two distinct bycatch species assemblages separated the fishery at a longitude of 91^0 W. From September through October there was a spatial shift in the species assemblage. Areas west of 93^0 W appeared to have an assemblage distinct from the rest of the fishery. From these analyses, bull sharks emerged as a species for potential concern.

A shark-specific analysis of the bycatch revealed an annual take of approximately 30,000 sharks. Logit analysis indicated that the odds of observing shark bycatch were significantly greater in June-August than September-October. The odds of observing shark bycatch during April-May were also significantly different from September-October, however, these differences were only apparent east of 93^0 W. Stomach analyses of sharks and a consideration of size at age suggests that the fishery is impacting an important nursery ground for a complex assemblage of sharks, for which menhaden is an important forage base.

I describe the spatial and temporal patterns of bottlenose dolphins and brown pelicans associated with the fishery. Dolphins were observed around 19 % of fishing sets and diving and circling pelicans were observed in 23% of sets. These

associations are described by a loglinear model with pelican-season-dolphin, dolphin-season-area, and pelican-season-area terms. Results suggest that while the incidental capture of dolphins in the fishery is extremely low, they are far more frequently observed in the immediate vicinity of the fishing operation. This suggests dolphins may have learned to avoid being captured. However, the extremely low rates of incidental capture may be biologically important given the low population estimates.

CHAPTER 1

INTRODUCTION

The Precautionary Approach to Fisheries Management

Global fisheries resources are currently at high levels of exploitation with the harvest of marine fish having risen from approximately 14 million metric tons (t) in 1950 to about 73 million t in 1994 (FAO, 1997). A recent evaluation of the status of the world's major marine fish stocks indicated that about 35% were overfished with declining landings, while 25% were considered to be at a high level of exploitation (FAO, 1997). As a result, the estimated percentage of exploited fish stocks under management has increased from 0 in 1950 to over 60% in 1994 (FAO, 1997). As fishing pressure, harvest, and the level of management have increased, there has been a movement towards new management and development policies for fisheries resources. One of the major changes has been the application of the precautionary approach to fisheries management (Restrepo et al., 1998). This approach has recently been incorporated into international fisheries agreements (e.g., Article 6 of the Agreement for the implementation of the provisions of the United Nations Convention on Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks) and into Federal regulations (e.g., Magnuson-Stevens Fishery Conservation and Management Act as amended through October 1996).

Under the precautionary approach, a resource conservative philosophy to fisheries management should be taken when information is uncertain, unreliable or inadequate (United Nations, 1995). As described in Article 6 of the UN straddling stock

agreement (United Nations, 1995) to which the United States is a signatory, implementation of the precautionary approach requires :

1) An improved decision-making process for fishery resource conservation and management by collecting and sharing the best available scientific information and the implementation of improved techniques for dealing with risk and uncertainty;

2) Stock specific reference points that are set using the best scientific information and the identification of actions that need to be taken if they are exceeded;

3) Taking into account uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels of distribution of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions; and

4) Develop data collection and research programs to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans which are necessary to ensure the conservation of such species and to protect habitats of special concern.

Fisheries Bycatch

It has been estimated that worldwide 27 million t of fish are discarded annually and that this discard consist of juveniles and species of low commercial value (FAO, 1997). Given the magnitude of discards in world fisheries, the importance of reducing bycatch has been highlighted as a major management concern in ensuring sustainable fisheries resources. Within the United States, the importance of assessing bycatch at

the national level, and its relevance to achieving sustainable fisheries are twofold (NMFS 1997a). First, bycatch increases the uncertainty concerning total fishing mortality which in turn makes assessing the status of stocks more difficult, and thereby affects the setting of optimum yield and overfishing levels. Second, bycatch often precludes other more productive uses of fishery resources.

The United States has recently been a party to two international agreements which specifically identify bycatch reduction as a major goal with broader objectives (NMFS 1997b). These agreements are the Code of Conduct for Responsible Fisheries and the Agreement Relating to the Conservation and Management of Straddling Stocks and Highly Migratory Fish Stocks. Both agreements have bycatch management principles that promote the idea that users of aquatic ecosystems should minimize 1) waste, 2) catch of non-target species of both fish and non-fish species, and, 3) impacts on associated or dependent species (NMFS 1997b).

The overall impact of bycatch is being addressed in many U.S. fisheries; and has resulted in the introduction of regional bycatch regulations (e.g., Ackley 1997;Pautzke 1997), the development of bycatch reduction devices (e.g., Rogers et al. 1997; Watson et al. 1993) and changes to federal fishery management regulations.

Under the Magnuson-Stevens Fishery Conservation and Management Act (as amended through October 1996, Public law 94-265) bycatch is included as a new national standard. In the Act, bycatch is defined as:

> fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch and release fishery management program.

The draft national plan on managing the nation's bycatch (NMFS 1997b) defines bycatch more broadly as "discarded catch plus retained incidental catch and

unobserved mortality". The National Marine Fisheries Service (NMFS) noted that while the Magnuson-Stevens Act definition is to be used in fishery management plans to support National Standard 9 for bycatch (NMFS, 1997b), its broader definition of bycatch was intended to provide a basis for bycatch research, management and planning for the agency. In this dissertation, I use the latter NMFS definition of bycatch.

It has been argued that an ecological approach to fisheries management is essential so as to identify potential problems and solutions which take into account that fisheries are an important component of the ecological system and this type of approach is essential in dealing with bycatch (Condrey and de Silva, in press). Understanding why bycatch species were there at the time the directed catch was made, the role they play within the ecosystem, and how their removal may impact the system are some of the questions that need to be understood (Condrey and de Silva, in press). Without a proper understanding of these types of issues, a true balance between managing the resource and inflicting intentional and unintentional potential negative impacts will not be minimized whether one is dealing with the direct take, bycatch, or other non-lethal species associations. In this dissertation, I use an ecological approach to examine some of these issues concerning bycatch in the U.S. gulf menhaden, *Brevoortia patronus,* fishery.

Having reported on the magnitude and species composition on the menhaden bycatch which is retained (de Silva and Condrey, 1997), I focus in this dissertation on bycatch which is not retained and on non-lethal fishery-species associations that represent the complex interactions the fishery has with the ecosystem in which it operates.

Dissertation Structure

One of the major statistical problems in examining bycatch in the menhaden fishery was its patchy distribution (Condrey, 1994). Chapter 2 of my dissertation deals with the statistical tools used to examine patterns in bycatch. I propose the suitability of using categorical statistical techniques to examine such data, and provide an example of their use in examining patterns in the releasable bycatch of the menhaden fishery. *In addition I focus on the overall releasable bycatch for the fishery looking for* species of potential concern and potential solutions. I identified bull sharks, *Carcharinus leucas,* as a species for potential concern in Chapter 2.

In Chapter 3, I use categorical statistical techniques alongside other methods to examine shark bycatch in the menhaden fishery and discuss the implications of this source of incidental mortality to shark populations in the Atlantic and Gulf of Mexico. I also highlight the suitability of such techniques to look for bycatch patterns in terms of management objectives, and examine flexible alternatives for achieving bycatch reductions for the fishery. In essence, bycatch is simply the interaction a fishery has with other components of the ecosystem within which it operates. While these interactions are considered negative when they result in mortality, the fishery also has other types of interactions with the ecosystem.

In Chapter 4, I examine the positive non-lethal associations the menhaden fishery has with brown pelicans, *Pelecanus occidentalis*, bottlenose dolphins, *Tursiops truncatus*, and other seabirds. I also discuss the incidental capture of bottlenose dolphins in the fishery in relation to dolphin stocks and regulations set forth in the Marine Mammal Protection Act of 1972.

Scientific and common names of fishes and decapod crustaceans used in this dissertation follow those of Robins et al. (1991) and Williams et al. (1989) respectively. The scientific and common names of birds follows those of Lowery (1974). Chapters 2, 3 and 4 have been written in journal style to be submitted to a peer reviewed journal, or where denoted, has been published in a peer reviewed journal.

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CHAPTER 2

DISCERNING PATTERNS IN PATCHY DATA: A CATEGORICAL APPROACH USING GULF MENHADEN, *Brevoortia patronus*, BYCATCH[1]

Introduction

Bycatch analyses

Statistical analyses of fisheries data often require consideration of the patchy distribution of aquatic organisms (e.g., Andrew and Pepperell, 1992). This is especially true when using standard regression and ANOVA techniques as they rely on the assumptions of normality of residuals and homogeneous variances. Often, transformations of the response variable can be used to satisfy these assumptions (Underwood, 1981). However, in some instances suitable transformations may not be successful in stabilizing the error variance and bringing the error distribution close to normal. In such instances nonparametric techniques such as the Kruskal-Wallis one-way ANOVA or ANOVA on the ranked data can be used (Neter et al., 1990). As Underwood (1981) noted, one of the implied assumptions of these methods is the equal variances among treatments. This assumption is sometimes not satisfied when dealing with patchy data. A further problem with such techniques is that one cannot explore significant differences through the use of contrasts or multiple comparison tests, except with the Kruskal-Wallis one-way ANOVA.

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Studies on fisheries bycatch have used a variety of statistical methods. Andrew et al. (1995) used ANOVA with suitable transformations to evaluate the bycatch in an Australian stow net fishery for school prawns and Austin et al. (1994) used the Kruskal-Wallis one-way ANOVA to examine geographical differences in the bycatch of Atlantic menhaden, *Brevoortia tyrannus,* fishery. Hudson (1990), examining the shrimp and fish bycatch assemblages of the Canadian Eastern Arctic, used an intermediate linkage clustering algorithm to examine abundance patterns and species associations among different regions. More unique solutions have been presented by Richards et al. (1994), who proposed the use of a modified generalized logit model to carry out a categorical form of response surface analysis, allowing the estimation of transformation parameters on the explanatory variables along with other parameters. Perkins and Edwards (1996) have used mixture models, consisting of the negative binomial distribution with added zeros, as a solution to analyzing bycatch with many zero observations.

In this paper, we use loglinear and logit models to examine patchy data with bycatch from the gulf menhaden, *Brevoortia patronus,* fishery as an example. Menhaden bycatch can be classified into two groups; 1) bycatch that is pumped directly into the hold with the menhaden is termed automatically retained bycatch; 2) all other bycatch is termed releasable bycatch. In this paper we analyze only releasable bycatch. With the exception of Christmas et al. (1960) and Condrey (1994), previous studies on menhaden bycatch have not taken releasable bycatch into account. Furthermore, all previous work has been qualitative in nature. Our examination of releasable bycatch, however, serves both as an analysis of patchy

data with categorical techniques, and as a quantitative description of a biologically-important portion of the menhaden bycatch.

Species taken as bycatch may be caught because they are associated with the target species or simply because they were encountered on a random basis (Hall, 1996). An analysis of the structure of bycatch species assemblages associated with a fishery can provide valuable information for both management and ecological purposes. Hudson (1990), examining shrimp and fish bycatch assemblages in the Canadian Eastern Arctic, observed three associations that she proposed were related to the origin of the predominant water masses in the region. Harris and Poiner (1991) documented changes in species composition of the demersal fish-fauna over a 20-year period in the Gulf of Carpentaria, Australia; and suggested that increases in the benthopelagic taxa over this period could be partially explained by discard of bycatch in the banana prawn fishery. Because little information on spatial and temporal associations for species assemblages of the menhaden fishery exist, we describe the spatial and temporal associations for these species, together with the fate of these organisms, as a first step in accruing such information. We have used correspondence analysis, a categorical form of ordination, to describe these association patterns.

The fishery

The U.S. Gulf of Mexico menhaden fishery has existed since the late 1800's (Nicholson, 1978) and is the second largest fishery in tonnage in the United States (US Department of Commerce, 1996). Estimates of menhaden landings for the 1994 fishing season were approximately 0.7 million metric tons (t) (Leard et al., 1995). Although gulf menhaden is the primary clupeid sought, finescale menhaden, *B.*

gunteri, yellowfin menhaden, *B. smithi*, and Atlantic thread herring ,*Opisthonema oglinum*, are occasionally taken opportunistically (Leard et al., 1995).

Schools of menhaden are located visually by the senior crew aboard the vessel or with the help of spotter planes. A purse seine, deployed from a pair of small (12.2 m) purse seine boats, is used to encircle the school. Once the school is encircled, the bottom of the net is drawn closed to hold the catch. The seine is then retrieved mechanically by each purse seine boat until the fish are confined into a small section of the net. The catch is then pumped into the refrigerated hold of a larger (43 to 61 meter) carrier vessel. The number of times the purse net is set each day depends on the availability and size of schools. Schools contain from 3 to 100 t of menhaden (Leard et al., 1995). Once the hold of a vessel is full, or a trip is otherwise complete, the menhaden are transported to one of the processing plants located from Moss Point, MS to Cameron, LA. Although the fishing area extends from Apalachicola, FL to Freeport, TX, more than 86% of the menhaden caught from 1990 to 1994 were taken off Louisiana (Leard et al., 1995).

Materials and Methods

Loglinear and logit models

As reviewed in Agresti (1990) and Freeman (1987), loglinear and logit models are special cases of the Generalized Linear Models introduced by Nelder and Wedderburn (1972). Agresti (1990) summarizes a Generalized Linear Model as " a linear model for a transformed mean of a variable having a distribution in the natural exponential family".

Loglinear models describe association patterns among categorical variables. Using this approach, cell counts in a contingency table are modeled in terms of

association among the variables. Loglinear models may be viewed as analogous to correlation analysis where cell counts in a loglinear contingency table are treated as independent Poisson variables.

In a $I \times J$ table where $N= IJ$ cells consisting of n multinomial samples, let n_k denote the count of the k th cell, and let $m_k = E(n_k)$ represent the expected value where $k= 1.....N$. The probabilities $\{\pi_{ij}\}$ for that multinomial distribution form the joint distribution of two categorical responses. These two responses are statistically independent when $\pi_{ij}= \pi_{i+}\, \pi_{+j}$. for all i and j.

If there is a dependence between the two variables, then all expected values of each cell (m_{ij}) are > 0. The loglinear model for this two way table can be written as:

$$\log\ m_{ij} = \mu + \lambda_i^x + \lambda_j^y + \lambda_{ij}^{xy}\ ,$$

where $\mu = \sum_i \sum_j \log\ m_{ij} / IJ$;

$\lambda_i^x = \sum_j \log\ m_{ij} / J - \mu$;

$\lambda_j^y = \sum_i \log\ m_{ij} / I - \mu$; and

$\lambda_{ij}^{xy} = \log\ m_{ij} - \lambda_i^x - \lambda_j^y + \mu$.

This model perfectly describes any set of positive expected frequencies and is referred to as the saturated model. The right hand side of this equation resembles the formula for the cell means ANOVA. The parameters $\{\lambda_i^x\}$ and $\{\lambda_j^y\}$ are deviations about a mean and $\sum_i \lambda_{ij}^{xy} = \sum_j \lambda_{ij}^{xy} = \sum_i \lambda_i^x = \sum_j \lambda_j^y = 0$. This model can also be described in the notation form as [XY].

A saturated loglinear model always expresses a given table of categorical data perfectly. This model has the maximum achievable log likelihood because it is the most general model, with as many parameters as observations. However, it is possible

that a simpler model may provide a fit as statistically good as the saturated model. How well this model fits is represented by the scaled deviance, a function of twice the difference in the log likelihoods of the saturated model and the simpler model. In addition to testing the fit of a model, one can use the deviance to diagnose lack of fit through residual analysis.

For example, consider a three-dimensional saturated model with variables X, Y, and Z. For this model [XYZ], $\log\ m_{ijk} = \mu + \lambda_i^x + \lambda_j^y + \lambda_k^z + \lambda_{ij}^{xy} + \lambda_{ik}^{xz} + \lambda_{jk}^{yz} + \lambda_{ijk}^{xyz}$. When $\lambda_{ijk}^{xyz} = 0$ there is no three-factor interaction, and the association between two variables is identical at each level of the third variable and reduces to the loglinear model [XY XZ YZ]. Further, if $\lambda_{ijk}^{xyz} = 0$ and $\lambda_{jk}^{yz} = 0$, then Y and Z are conditionally independent for any given level of X [XY XZ]. Similarly if $\lambda_{ijk}^{xyz} = 0$, $\lambda_{jk}^{yz} = 0$ and $\lambda_{ik}^{xz} = 0$ then Z is jointly independent of X and Y [XY Z]. Finally if $\lambda_{ijk}^{xyz} = 0$, $\lambda_{jk}^{yz} = 0$, $\lambda_{ik}^{xz} = 0$ and $\lambda_{ij}^{xy} = 0$, then X, Y, and Z are mutually independent [X Y Z]. With these criteria and beginning with a saturated model, we used a stepwise model selection procedure with deviance in the form of the G^2 test statistic to find a simpler model that has a fit as good as the saturated model. This enables one to explore multi-dimensional tables to find simpler representations of the information contained therein.

Another advantage of loglinear models is that when one of the variables can be modeled as a response, and the others as explanatory variables, certain loglinear models are equivalent to logit models with categorical explanatory variables. Such logit models enable us to study the problem of interest in a manner analogous to ANOVA.

Many categorical response variables have only two categories. The response can be classified either as a success or a failure. The Bernoulli distribution, which belongs to the natural exponential family, forms the basis of the logit model. For such

a dichotomous variable, the probability of observing response 0 can be defined as $P(Y=0)=\pi$, and the probability of observing response 1, $P(Y=1)=1-\pi$. The link function for this model , $\log \pi_i/(1-\pi_i)$, is known as the logit and is equivalent to the log odds.

Consider the following example, where we examine the presence or absence of bycatch in two areas. In this example (Table 2.1), the 2 x 2 table has rows i_1 *(area 1)*, and i_2 (*area 2*) and columns j_1 (*presence of bycatch*) and j_2 *(absence of bycatch)*. The counts in the cells of the table are the number of units of effort (individual sets) observed in each category.

In this case the odds, Ω_{i1}, of observing j_1 (*presence of bycatch*) given you are in category i_1 *(area 1)* is computed as the ratio of the conditional probabilities of observing a set with bycatch to that of observing a set with no bycatch in *area 1* :

$$\{\pi_{j1|i1}/\pi_{j2|i1}\} \text{ is } 0.4/0.6= 0.67$$

Similarly, the odds, $\Omega_{i2,}$ of observing j_1 *(presence of bycatch)* given you are in category i_2 (*area 2*) is computed as the ratio of the conditional probabilities of observing a set with bycatch to that of observing a set with no bycatch in *area 2*:

$$\{\pi_{j1|i2}/\pi_{j2|i2}\} = 0.33/0.67= 0.5.$$

The odds ratio, θ, is computed as

$$\Omega_{i1}/\ \Omega_{i2} \text{ is } 0.67/0.5 =1.34$$

Thus, the odds of observing response j_1 *(presence of bycatch)* is 1.34 times more likely for row i_1 *(area 1)* than for row i_2 *(area 2)*. An odds ratio of 1 indicates that you are equally likely to observe response j_1*(presence of bycatch)* for row i_1 *(area 1)* and row i_2 *(area 2)*, indicating independence between the rows and columns of the table.

Table 2.1. Hypothetical example used to explain odds ratios and conditional probabilities. $\pi_{j1|i}$ is the conditional probability of observing bycatch given a particular area. $\pi_{j2|i}$ is the conditional probability of observing no bycatch given a particular area.

	Bycatch			Conditional Probabilities	
	Presence -(j_1)	Absence -(j_2)	Total Sets	$\pi_{j1\|i}$	$\pi_{j2\|i}$
Area A -(i_1)	4	6	10	0.40	0.60
Area B -(i_2)	2	4	6	0.33	0.67
Total	6	10	16		

The logit model has two forms. One form occurs where the explanatory variables are continuous and is the logistic regression model. The second occurs where the explanatory variables are categorical. The logistic regression model is analogous to a regression model, whereas the second type is analogous to an ANOVA model.

For the previous example, a model with a single categorical explanatory factor (*area*), the logit form of the model is:

$$\text{Log}\,(\pi_{j1|i} / \pi_{j2|i}) = \alpha + \beta_i^{Area},$$

where α is the mean of the logits; and

β_i^{Area} is the deviation from the mean for row *i*.

β_i describes the effects of the factor on the response. For this model the higher β_i gets, the higher the logit in row *i*, and the higher the value of $\pi_{j1|i.}$ The constraints on this model are $\Sigma\ \beta_i = 0$. In this case the right hand side of the equation resembles the cell means model of a one-way ANOVA. This logit model would be equivalent to $\log(m_{ij1}) - \log(m_{ij2}) = 2\lambda_i^{Area} + 2\lambda_{j1}^{Bycatch} + 2\lambda_{ij1}^{AreaBycatch}$ in loglinear form.

Bycatch sampling and data set description

Bycatch from the gulf menhaden fishery was sampled April through October 1995 by two to three onboard samplers on a total of twenty-seven week-long trips aboard vessels operating from menhaden processing plants in the U.S. Gulf of Mexico. To maximize coverage of the Gulf, samplers boarded vessels from ports in the western, central, and eastern regions in a given week as often as possible. During each sampling trip, all sets made by the vessel were alternatively sampled, either for releasable bycatch, or automatically retained bycatch. For all sets sampled, the presence of dolphins in the vicinity was also noted by the observers. In addition, the

boat captains visually estimated catch, in standard menhaden (1,000 standard menhaden [~305 kg]) and recorded the latitude and longitude of a set location. The location was used to identify in which National Marine Fisheries Service (NMFS) statistical zone (Figure 2.1) the set was made (after Kutkuhn, 1962).

To collect releasable bycatch data, samplers observed the purse seine from the time it was brought alongside the carrier ship, throughout the pumping procedure, until the net was emptied and cleaned. During this time, the species, number, and fate of the releasable bycatch were recorded. The seven categories of bycatch fate were: gilled in the net (gilled); kept by the crew for consumption (kept) ; released with no apparent harm (released healthy); released seriously injured or dead (released dead); released after being bruised or after being kept in the set for a long time (released disoriented); collected by the crew from the net or deck and put into the hold (caught and put in hold); and observed in the net but fate unknown (unknown).

Preliminary statistical analysis

For the variables bycatch number, bycatch percentage, and estimated catch, we calculated a series of commonly used statistical descriptors. These were the mean, standard deviation, 95% confidence intervals, median, skewness, and kurtosis. In addition, we also calculated the winsorized mean and its standard deviation (SAS Institute Inc., 1993).

We initially attempted to examine spatial and temporal patterns in the bycatch with a two-way ANOVA model. For the analysis, data were classified into season (S) consisting of three groups: spring (April through June), summer (July through August), and fall (September through October). Adjacent NMFS zones (Figure 2.1) were combined to form four area groups (A): 11-12, 13-14, 15-16, and 17-18.

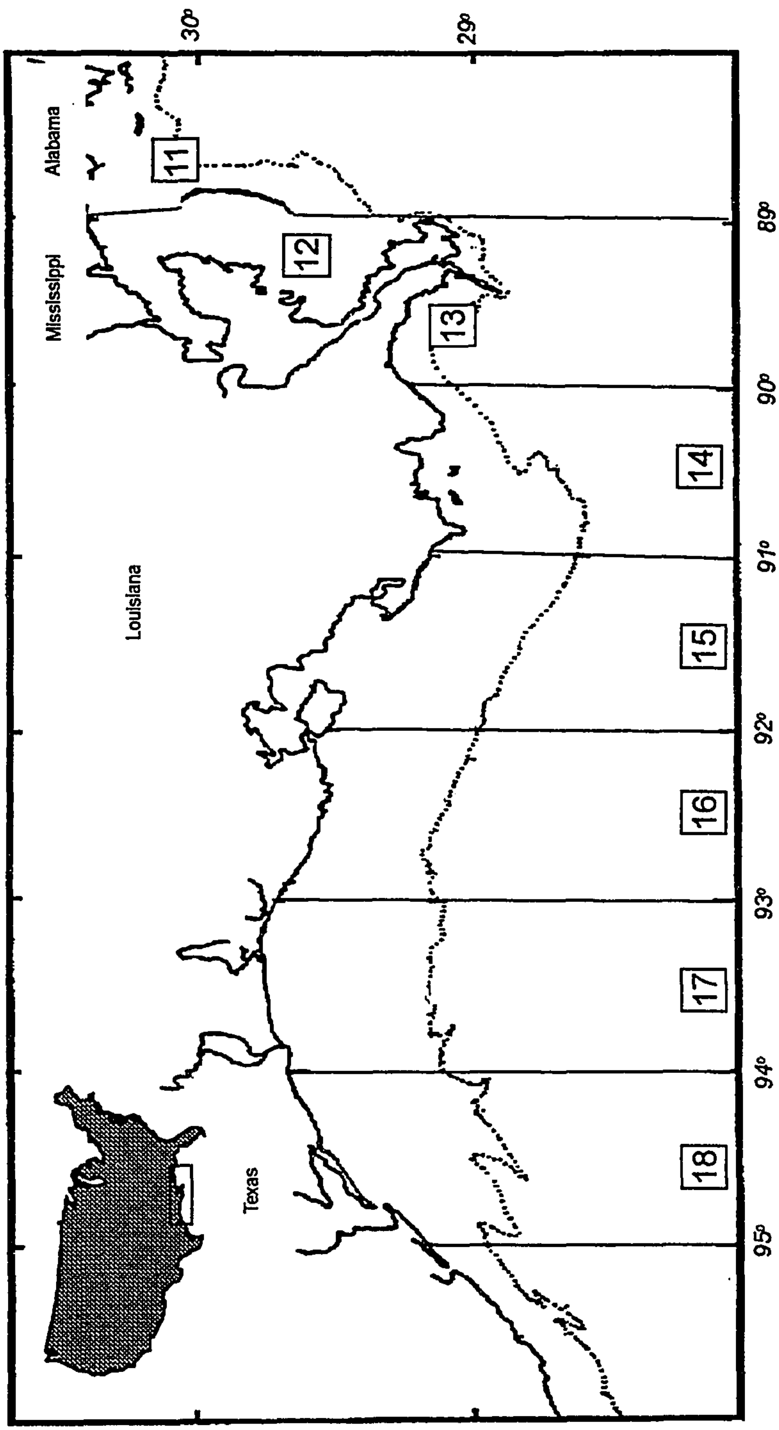

Figure 2.1. Map encompassing the extent of the U.S. gulf menhaden fishery along the Texas to Alabama coasts.

Bycatch patterns were examined with two response variables: 1) bycatch numbers; and 2) bycatch percentage ([bycatch number/total catch]x100). For each of these two response variables, spatial and temporal patterns were examined by using the ANOVA model with season, area, and their interaction term as independent variables. Based on the results of the untransformed models, these models were also re-examined using the log and square root transformations for both response variables. In addition, we also used an arcsine transformation, 2 arcsin √ (bycatch/menhaden catch), suggested by Neter et al. (1990) for transformation of proportions. Using residual plots, the Shapiro-Wilk test for normality and a modified Levene's test for homogenous variances (Neter et al., 1990), all seven models were examined to determine if model assumptions were met.

Spatial and temporal patterns in bycatch

For our analysis using loglinear and logit models with categorical explanatory variables, we used a four- way contingency table with a unit of effort (the set) as the count. Our main interest was to: 1) examine the spatial and temporal patterns in bycatch; and 2) determine if the presence of dolphins in the vicinity when the set was made might be an indicator of bycatch patterns.

Exploratory analysis with loglinear and logit models

To examine bycatch as a response of interest with categorical models, a new dichotomous categorical variable, bycatch, based on the median bycatch percentage, was created. Each set was classified, as high bycatch if the bycatch rate of the set was greater than the median value of all sets, or as low bycatch, if the bycatch rate of the set was less than or equal to the median bycatch of all the sets. We used the median rate as it is a robust measure of central tendency. In deciding on possible

criteria for defining this variable, more extreme conditions, such as bycatch rates greater than the 75th percentile, were considered. However, by choosing more extreme values, we increased the number of sparse cells, and this affected the validity of the G^2 test statistic.

In analyzing contingency tables, it is necessary that the number of cell counts with zero frequencies be low (a minimum expected value of 1 is satisfactory as long as < 20% of cells have counts of 5 or less) for the test statistic to be valid (Agresti 1990). To reduce the number of cells with zero frequencies, months and zones were combined generating two new variables, season (S) and area (A), corresponding to those used in the ANOVA. The presence of dolphins was used as a dichotomous variable, dolphins (D).

To identify the most appropriate and simplest loglinear model for the data using the variables season, area, bycatch, and dolphins, we employed a stepwise backward solution procedure commencing with the saturated loglinear model (Agresti 1990). Here the saturated model is denoted as [SABD] where S stands for season, A for area, B for bycatch, and D for dolphins, and the model includes all possible interactions up to and including the four-way interaction. Because the saturated model would naturally provide the best fit, we were interested in determining if a simpler model could be found that would also satisfy the criteria of a logit model with bycatch as the response variable. The standardized residuals of the resulting model were then examined to ensure that lack of fit was not a problem.

Contrasts

For the logit form of the selected model, we constructed a series of contrasts that might help to explain the nature of these potential interactions. The contrasts of interest had two general forms:

1 Given a specific area, were the odds of observing a set with high bycatch the same between any two different seasons. This results in three unique contrasts for each area (spring vs summer, spring vs fall, summer vs fall) and a total of 12 contrasts.

Let F_{ij} be the logit of high bycatch for season *i* and area *j* and F_{hj} be the logit of high bycatch for season *h* and area *j*.

The hypotheses being tested were

$$H_0: \; F_{ij} - F_{hj} = 0$$

where $F_{ij} = \alpha + \beta_i^{S} + \beta_j^{A} + \beta_{ij}^{SA}$;

$F_{hj} = \alpha + \beta_h^{S} + \beta_j^{A} + \beta_{hj}^{SA}$;and

h and *i* = spring, summer, fall such that $h \neq i$ for each *j*, and *j*= Area 11-12, Area 13-14, Area 15-16, Area 17-18.

2 Given a specific season, were the odds of observing a set with high bycatch the same between any two different areas. This results in six unique contrasts for a given season and a total of 18 contrasts (11-12 vs 13-14, 11-12 vs 15-16, 11-12 vs 17-18,.....,15-16 vs 17-18).

Let F_{ij} be the logit of high bycatch for season *i* and area *j* and F_{ik} be the logit of high bycatch for season *i* and area *k*.

The hypotheses being tested were:

$$H_0: \; F_{ij} - F_{ik} = 0$$

where $F_{ij} = \alpha + \beta_i^S + \beta_j^A + \beta_{ij}^{SA}$;

$F_{ik} = \alpha + \beta_i^S + \beta_k^A + \beta_{ik}^{SA}$; and

j and k = area 11-12, area 13-14, area 15-16, and area 17-18 such that $j \neq k$ for each i where i = spring, summer, fall.

For these contrasts, which represented all possible pairwise contrasts, an overall type I error level of 0.10 was adjusted by the total number of contrasts (30) and only P-values less than 0.0033 were considered significant. The statistical significance of the contrasts were based on the Wald Chi-Square test statistic (SAS Institute Inc., 1993). The estimated odds ratios for the conditions associated with the hypotheses were calculated from the parameter estimates given by the analysis.

Bycatch species associations

To examine the association between species and fates of the releasable bycatch, we used correspondence analysis on a species-by-fate table for all seasons and areas combined. Area and species associations of the releasable bycatch were also examined for each of the three seasons with correspondence analysis on species-by-area tables.

For all correspondence analyses, we defined two groups of species. The first group, consisting of those species that were common in terms of number and occurrence, was used in the main table. Releasable bycatch species falling into this group had a minimum of 230 individuals and were found in at least 30% of the sets. The second group of species consisted of releasable bycatch that were less common; these were species for which a minimum of 30 individuals were observed, which occurred in at least 4% of the sets, and did not meet our criteria for well represented species. These species were included as supplementary variables in our analysis

(Greenacre, 1984). Supplementary variables are represented as points in the joint row and column space, but are not used in determining the locations of the active rows and columns of the table. Species included in the main and supplementary table accounted for 97% of the total number of organisms observed during the study period. Species which did not meet these criteria were not used in the analyses.

Results

Preliminary statistical analysis

A total of 15,579 bycatch organisms representing 62 species or taxonomic groups were observed as releasable bycatch in 257 sets. The estimated catch of standard menhaden per set ranged from 5,000 to 500,000 with a median, mean and standard deviation of 50,000, 67,000 and ±61,000, respectively. Skewness and kurtosis values, of 2.5 and 10.7 indicated that the distribution of the estimated menhaden catch was positively skewed (Figure 2.2).

The number of bycatch observed in each set ranged from 0 to 1,600 organisms, with a median, mean, and standard deviation of 15, 61 and ±153, respectively. The winsorized mean and standard deviation values were 53 and 6.9 respectively. The 95% confidence interval of the mean was between 41.8 and 79.3. The distribution of bycatch organisms was strongly positively skewed (5.9), and sharply peaked with a kurtosis value of 47.2 (Figure 2.3).

The bycatch percentage (Figure 2.4) ranged from 0 to 4% with a median, mean and standard deviation of 0.033%, 0.168% and ±0.48, respectively. The winsorized mean bycatch percentage and standard deviation were 0.14 % and 0.02, respectively.

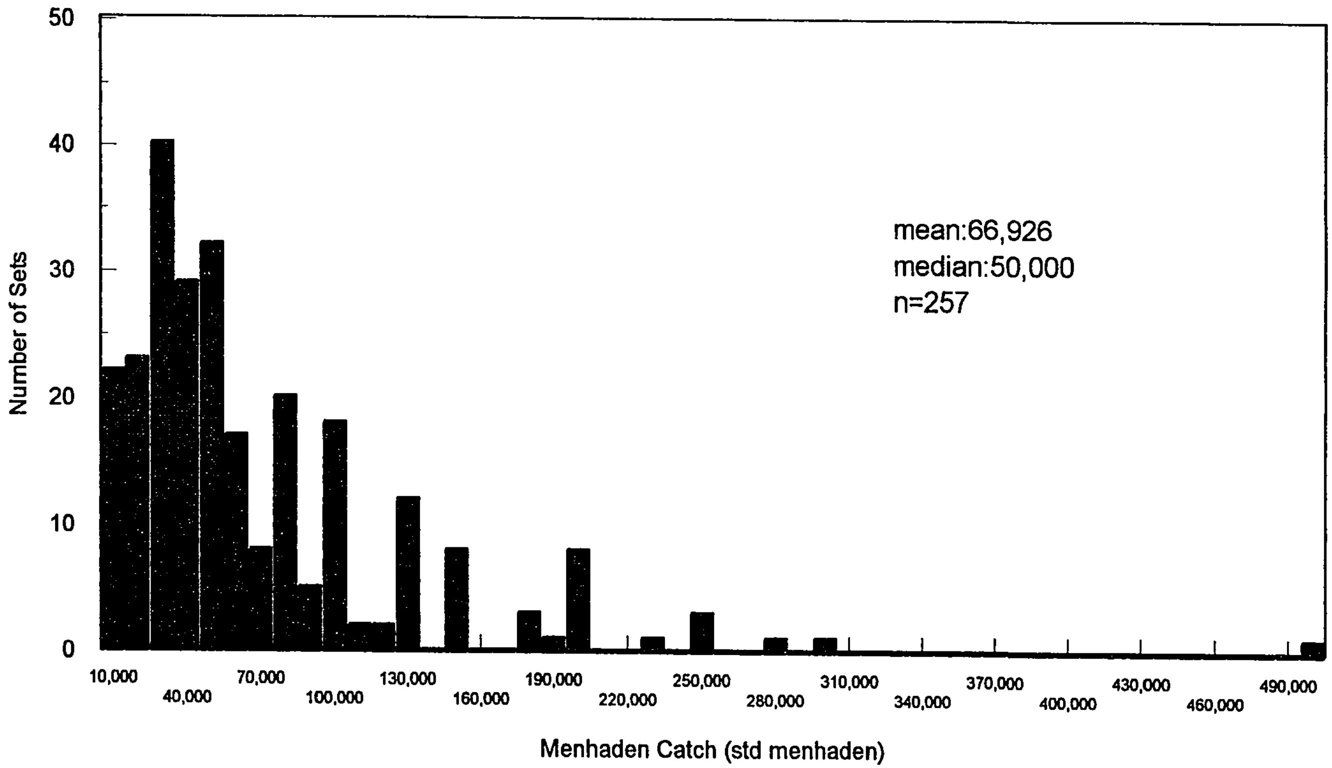

Figure 2.2. Distribution of menhaden catch sampled during the 1995 gulf menhaden fishing season. std= standard (1,000 standard menhaden ~ 305 kg).

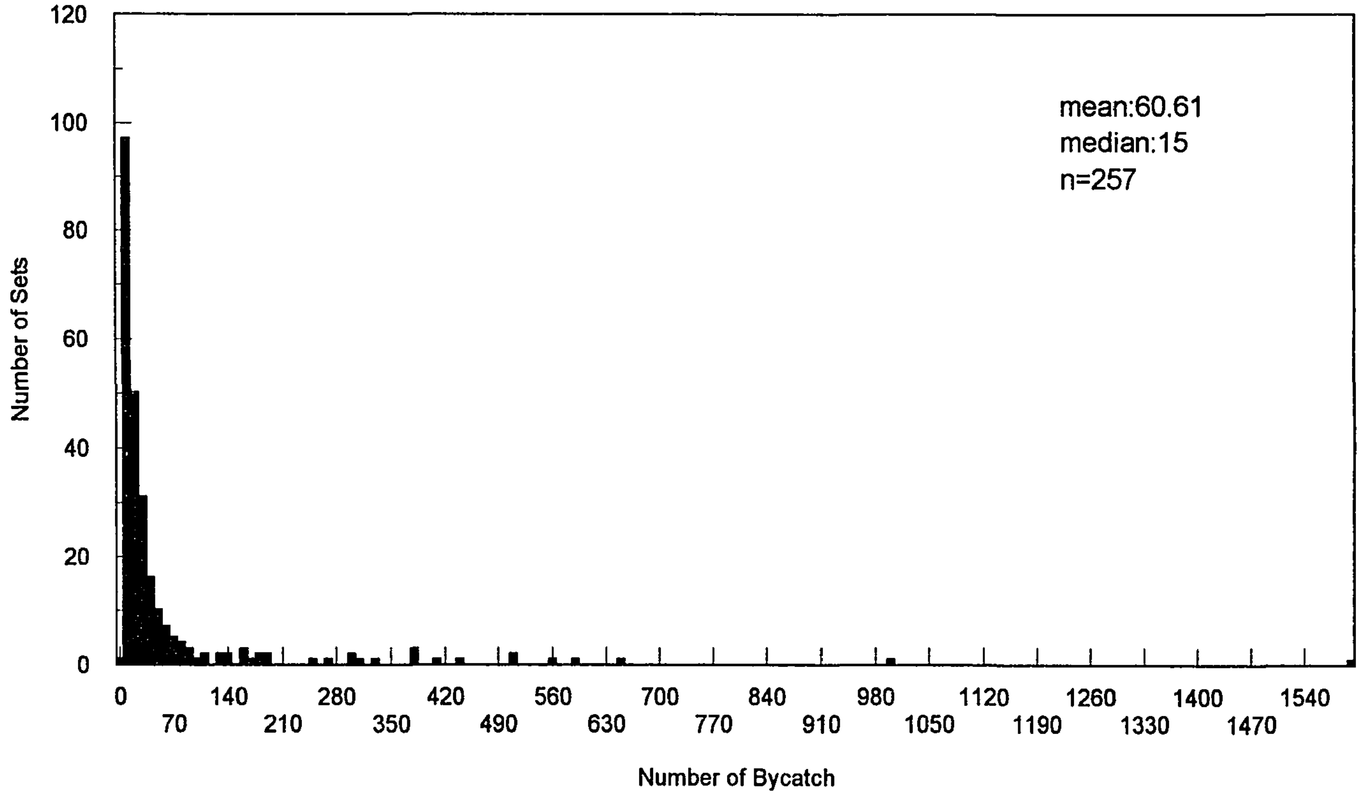

Figure 2.3. Distribution of bycatch sampled during the 1995 gulf menhaden fishing season.

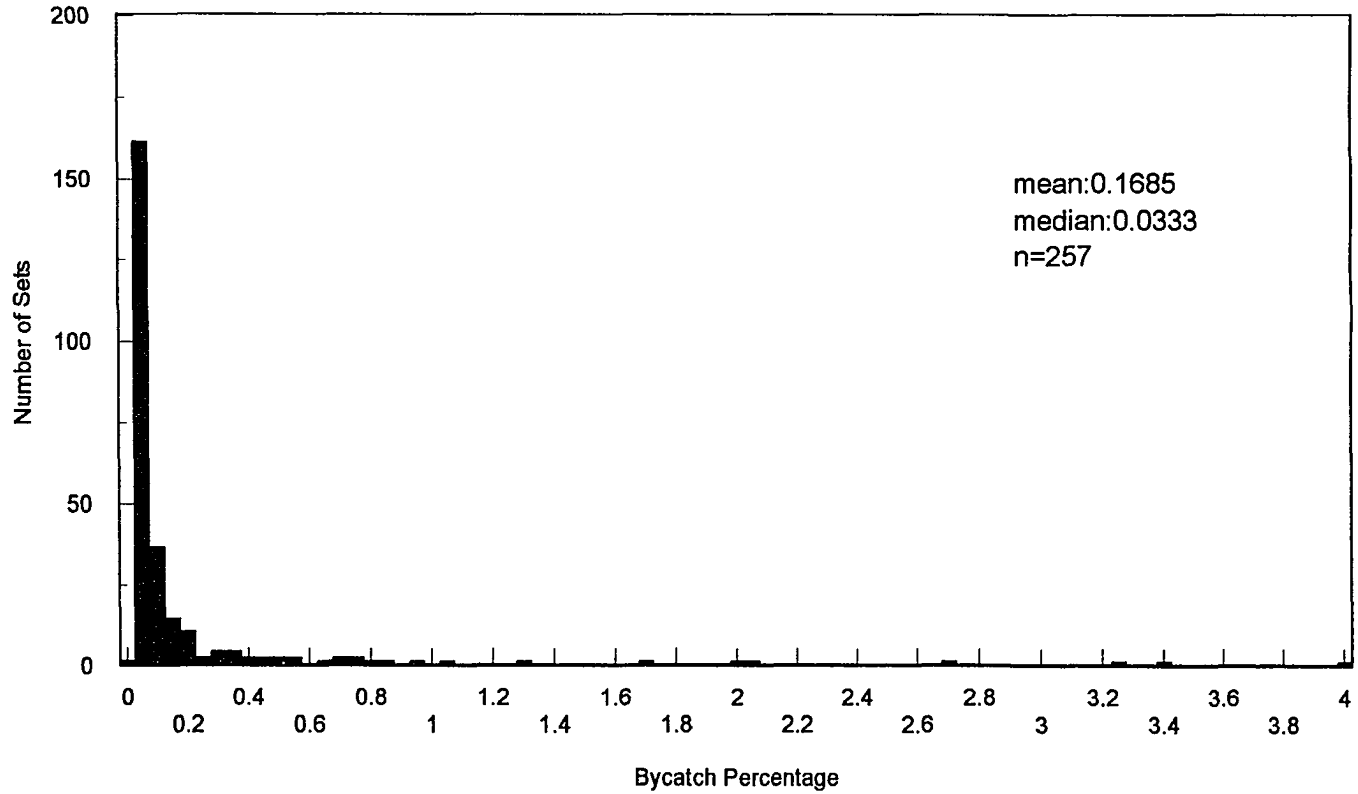

Figure 2.4. Distribution of the bycatch percentage in fishing sets sampled during the 1995 gulf menhaden fishing season.

The 95% confidence interval of the mean was between 0.11 and 0.22%. The distribution of the bycatch percentage was also found to be positively skewed (5.4) and strongly peaked (32.7).

Analysis of variance using bycatch, bycatch percentage, and their respective transformations, together with the arcsine transformation, did not meet model assumptions. In all cases, the modified Levene's test indicated that the variances were non-homogeneous, and both the residual plots and Shapiro-Wilk test indicated that the assumption of normality of residuals were not met. For example, for the response log (bycatch percentage +1), the residuals of the model were not normally distributed (Shapiro-Wilk W= 0.678, P < W= 0.0001) and the residual plot indicated non-homogenous variances. Furthermore, a modified Levine's test indicated that the variances were non-homogeneous (F= 6.21, df= 11, df-error= 245, P > F= 0.0001). These characteristics suggest that our transformations were not successful in sufficiently stabilizing the error variance and bringing the distribution of the error terms close enough to normality so as to meet the robustness properties of the standard inference procedures.

Spatial and temporal patterns in bycatch

Exploratory analysis using loglinear models

With the backward selection procedure, loglinear models [SAB SAD DB] and [SAB SAD] (as defined in Table 2.2) satisfied the criteria for a logit model and had a good fit (Table 2.2). The simplest of these models, [SAB SAD], was selected; this loglinear model corresponds to the logit model with categorical explanatory variables of the form:

Table 2.2. Summary statistics of loglinear models examined through the stepwise selection procedure. Models with fits as good as the saturated model are marked ns. (A=area, B=bycatch, D=dolphins, S=season). Models are presented hierarchically from most complex to simplest.

Loglinear Model	df	G^2	P value
Model without the four-way interaction term			
ADB SDB SAB SAD	6	11.64	0.0706
Selected models with 3 three-way interaction terms			
ADB SDB SAB	12	26.58	0.0089
ADB SDB SAD	12	27.62	0.0063
SDB SAB SAD^{ns}	9	13.41	0.1449
SAB SAD ADB	14	27.90	0.0147
Selected models with 2 three-way interaction terms and 1 two-way interaction term			
SDB SAB DA	15	29.38	0.0144
SAB SAD DB^{ns}	11	15.65	0.1547
Selected models with 2 three-way interaction terms			
SAB SAD^{ns}	12	17.82	0.1213
SDB SAB	18	45.83	0.0003
Selected models with 1 three-way and 2 two-way interaction terms			
SAB SD AD	18	34.89	0.0097
SAD SB AB	18	34.30	0.0116

$$\log\frac{\pi_{high|ik}}{\pi_{low|ik}}=\alpha+\beta_i^A+\beta_k^S+\beta_{ik}^{AS} \qquad (1)$$

here $\pi_{high|ik}$= the probability of observing a set with high bycatch given area i and season k ;and

$\pi_{low|ik}$= the probability of observing a set with low bycatch given area i and season k.

This model, in loglinear and logit forms, had a G^2=17.82 with 12 df and a P- value= 0.1213. Examination of the standardized residuals of the logit form revealed that none of the residuals had an absolute value greater than 1.45, and thus showed no evidence of lack of fit.

For the logit model there was a significant interaction between season and area, (Wald Chi-Square (χ^2)= 14.65, df= 6, P= 0.0232). This interaction is reflected in the plot of probabilities of high (greater than 0.033%) bycatch for the area-season combinations (Figure 2.5).

Contrasts

The contrasts of the odds of high bycatch between seasons for a given area indicate that the hypothesis of spring and summer seasons being the same for all four areas could not be rejected. Wald χ^2 values are presented in Table 2.3. The contrasts of the spring and fall seasons suggest that the only significant differences between these two seasons existed for area 11-12 (Wald χ^2 df=1 P>χ^2= 0.0015). When the summer and fall seasons were contrasted, a significant difference between seasons was observed only for area 11-12 (Wald χ^2 df= 1 P>χ^2= 0.0024).

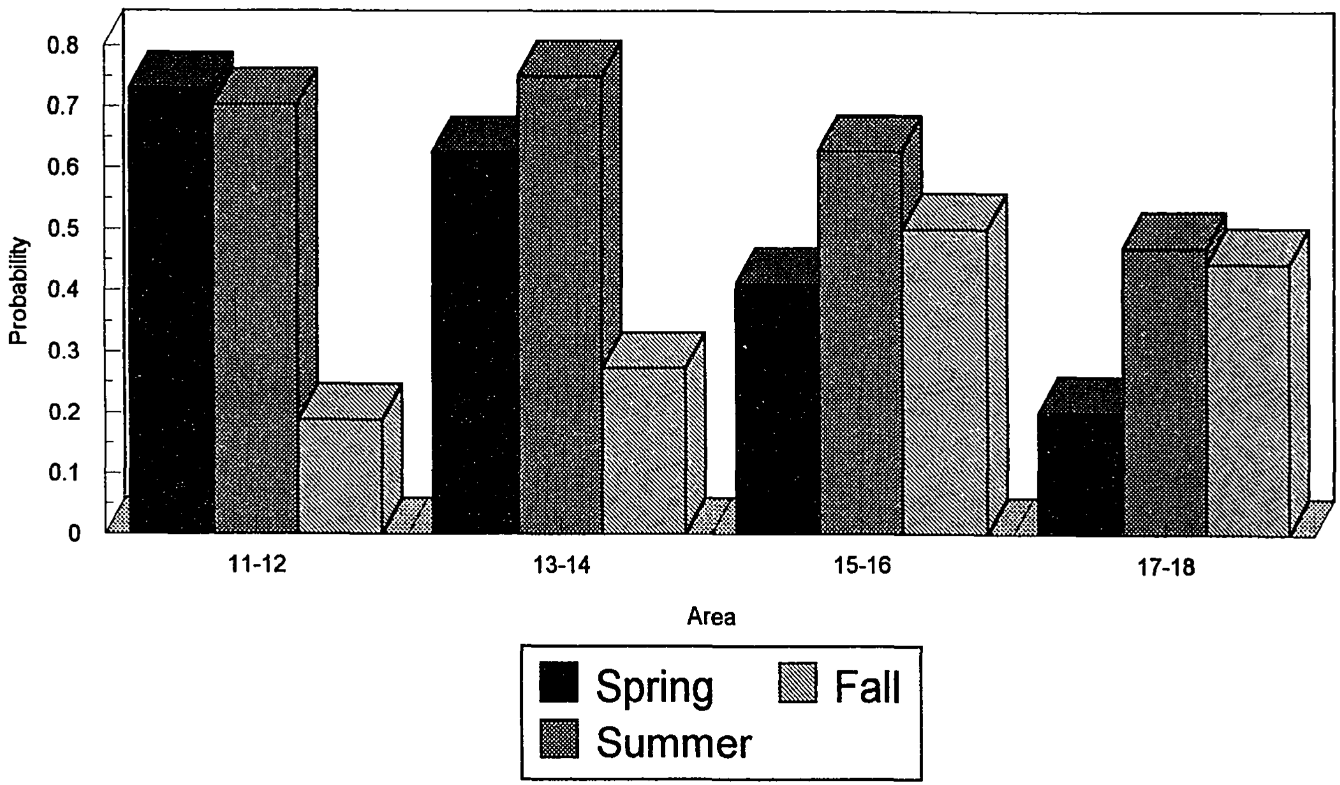

Figure 2. 5. Probabilitites of observing a set with high bycatch (>0.033%) for area-season combinations.

Table 2.3. Estimated odds ratios and Wald chi-square values for contrasts for observing high bycatch between seasons, given a set was made in a certain area. For example, the odds of observing high bycatch is 11.761 times greater during the spring season than the fall season for area 11-12. * indicates a ratio significantly different from 1. Wald χ^2 values are in parenthesis. For all contrasts Wald χ^2 df=1.

Season	Area	Spring	Fall
Fall	11-12	11.761* (10.03)	
Summer	11-12	1.142 (0.05)	0.097* (9.25)
Fall	13-14	4.444 (2.24)	
Summer	13-14	0.555 (0.19)	0.125 (2.41)
Fall	15-16	0.699 (0.48)	
Summer	15-16	0.414 (4.29)	0.592 (0.97)
Fall	17-18	0.312 (2.11)	
Summer	17-18	0.218 (2.47)	0.899 (0.02)

For contrasts of the odds of high bycatch between areas for a given season, significant differences between area 11-12 and 17-18 in the spring season were observed (Wald χ^2= 9.29 df= 1 P>χ^2= 0.0023). All other contrasts between areas for the spring, summer and fall seasons were not significant contrasts (Table 2.4).

The estimated odds ratios for the conditions associated with the hypotheses are also given in Tables 2.3 and 2.4. Only estimated odds ratios of contrasts for the rejected hypotheses of no difference are examined in detail.

If a fishing boat was in area 11-12, the odds of observing a set with high bycatch are about 11.8 times higher if a boat was fishing in the spring rather than the fall. Also, if a fishing boat was in area 11-12, the odds of observing a set with high bycatch are about 0.1 times (or approximately 10.3 times lower) in the fall than in the summer. It appears that for area 11-12, the odds of observing a set with high bycatch in the fall are significantly lower than in the spring or summer.

The third significant contrast indicated that for a vessel fishing in the spring, the odds of observing a set with high bycatch is about 10.8 times higher in area 11-12 than in area 17-18.

Refining the final model

We were interested, on the basis of our contrasts, in determining if a model with simpler dichotomous classes for areas and seasons would provide as good a statistical fit as this "full model" (Eq. 1). We compared three potential models which had one or both of these variables with reduced classes against the full model (Table 2.5). For these models we classified area into two groups; 1) east of the Mississippi River; and 2) west of the Mississippi River. Season was also classified into two groups;

Table 2.4. Estimated odds ratios and Wald chi-square values for contrasts for observing high bycatch between areas, given a set was made in a certain season. For example, the odds of observing high bycatch is 1.628 times greater in area 11-12 than area 13-14. * indicates a ratio significantly different from 1. Wald χ^2 values are in parenthesis. For all contrasts χ^2 df=1.

Season	Area	11-12	13-14	15-16
Spring				
	13-14	1.628 (0.33)		
	15-16	3.877 (6.64) 2.380 (1.23)		
	17-18	10.857* (9.29)	6.666 (3.79)	2.799 (2.13)
Summer				
	13-14	0.791 (0.04)		
	15-16	1.407 (0.42)	1.777 (0.23)	
	17-18	2.671 (2.33)	3.374 (0.94)	1.898 (1.22)
Fall				
	13-14	0.615 (0.27)		
	15-16	0.230 (3.63)	0.375 (1.50)	
	17-18	0.288 (2.43)	0.468 (0.84)	1.250 (0.12)

Table 2.5. Comparison of reduced logit models to full model. Diff=difference between full model and reduced model.

	Likelihood Ratio Statistics			Model Comparisons		
	df	G^2	$P > G^2$	Diff df	Diff G^2	P Values
Full Model Season= Apr-Jun, Jul-Aug, Sep-Oct Area= 11-12, 13-14, 15-16, 17-18	12	17.82	0.1213			
Reduced Model I Season=Apr-Jun, Jun-Aug, Sep-Oct Area=11-12, 13-18	6	9.76	0.1352	6	8.06	0.237
Reduced Model II Season=Apr-Aug, Sep-Oct Area= 11-12, 13-14, 15-16, 17-18	8	9.99	0.2659	4	7.83	0.098
Reduced Model III Season= Apr-Aug, Sep-Oct Area=11-12, 13-18	4	7.54	0.1100	8	10.28	0.246

1) early --sets sampled April through August; and 2) late -- sets sampled September through October.

All three reduced models provided a fit as good as our full model (Table 2.5); therefore, we chose the model that had reduced classes for season and area because it was the simplest. Four contrasts of interest were examined:

1) Test for seasonal differences in the odds of observing a set with high bycatch given the set was sampled east of the Mississippi River;

2) Test for seasonal differences in the odds of observing a set with high bycatch given the set was sampled west of the Mississippi River;

3) Test for area differences in the odds of observing a set with high bycatch given the set was sampled in the early season; and

4) Test for area differences in the odds of observing a set with high bycatch given the set was sampled in the late season.

The contrasts were written similarly to those for the 'full model'. For the four contrasts, the overall type 1 error level of 0.1 was adjusted by the number of contrasts and an alpha level less than 0.025 was considered significant.

Of the four contrasts, two were significant. The first indicated that in areas east of the river, the odds of observing a set with high bycatch was significantly different between sets sampled in the early season and sets sampled in the late season (Wald χ^2, df= 1, $P > \chi^2 = 0.0007$). The odds of observing a set with high bycatch east of the river in the early season was 11 times greater than the odds of observing a set with high bycatch in the late season. The second significant contrast indicated that for sets sampled in the early season, the odds of observing a set with high bycatch east of the river was significantly different from the odds of observing a set with high bycatch west

of the river (Wald χ^2 ,df= 1, P> χ^2= 0.0047). In the early season, the odds of observing a set with high bycatch east of the river was 2.7 times greater than observing a set with high bycatch west of the river during the same period.

Bycatch species associations

Of the 62 species or taxonomic groups observed, 20 occurred in two or fewer sets. The most frequently occurring species were Atlantic cutlassfish, *Trichiurus lepturus* (44% of sets), Atlantic croaker, *Micropogonias undulatus* (38% of sets), Spanish mackerel, *Scomberomorus maculatus* (36% of sets), sand seatrout, *Cynoscion arenarius* (35% of sets), and gafftopsail catfish, *Bagre marinus* (34% of sets). In terms of total abundance (Table 2.6), Atlantic croaker, sand seatrout, and Atlantic bumper, *Chloroscombrus chrysurus,* accounted for 71% of the total releasable bycatch.

Species included in the main table were Atlantic croaker, sand seatrout, crevalle jack, *Caranx hippos*, gafftopsail catfish, Spanish mackerel, and Atlantic cutlassfish (Table 2.6). Species included as supplementary variables were striped mullet, *Mugil cephalus*, unidentified requiem sharks, gulf butterfish, *Peprilus burti*, cownose ray, *Rhinoptera bonasus*, spotted seatrout ,*Cynoscion nebulosus*, Atlantic bumper, blacktip shark ,*Carcharhinus limbatus*, red drum ,*Sciaenops ocellatus*, unidentified penaeid shrimp, hardhead catfish, *Arius felis*, brown shrimp, *Penaeus aztecus* , cabbagehead jellyfish, *Stomolophus meleagris*, bull shark ,*Carcharhinus leucas,* and unidentified tonguefish (Soleidae) (Table 2.6).

The fate of releasable bycatch

Correspondence analysis on the fate-by-species table for the entire fishing season indicated that the first two axes explained 97% of the total inertia (conceptually

Table 2.6. Species used in correspondence analyses. (M) signifies species used in main table and (S) in supplementary table (see materials and methods). Areas 11-12,13-14, etc. are shown under each season. Counts are number of organisms observed. Unid.=unidentified.

Species	Spring				Summer				Fall				Total
	11-12	13-14	15-16	17-18	11-12	13-14	15-16	17-18	11-12	13-14	15-16	17-18	
Atlantic croaker (M)	132	20	50	1	554	1,604	1,732	212	40	97	51	612	5,105
sand seatrout (M)	104	26	17	0	813	1,500	572	2	91	91	197	53	3,466
gafftopsail catfish (M)	255	70	72	24	161	0	96	48	8	28	33	1	796
Atlantic cutlassfish (M)	41	28	209	22	5	1	53	55	7	0	13	36	470
crevalle jack (M)	71	12	133	17	5	0	31	9	22	41	8	0	349
Spanish mackerel (M)	22	11	34	33	29	0	56	33	0	7	6	10	241
Atlantic bumper (S)	0	0	0	0	0	0	2,166	330	0	0	1	0	2,497
striped mullet (S)	344	31	0	0	511	0	0	0	0	9	0	0	895
red drum (S)	21	0	34	0	23	0	24	6	0	12	9	116	245
hardhead catfish (S)	36	5	3	0	100	3	38	3	12	1	3	2	206
tonguefish spp. (S)	0 0	2	0	0	0	1	0	0	0	200	1	0	204
blacktip shark (S)	37	0	54	1	20	0	19	52	0	0	0	1	184
cownose ray (S)	27	2	26	0	3	0	4	7	0	0	1	0	70
brown shrimp (S)	0	0	1	2	0	0	39	0	0	0	10	13	65
cabbagehead jellyfish (S)	0	0	5	12	0	0	33	0	1	0	4	6	61
unid. requiem sharks (S)	0	0	23	2	3	0	16	0	0	6	1	6	57
spotted seatrout (S)	2	8	0	0	31	0	0	0	0	0	0	0	41
gulf butterfish (S)	2	0	3	0	0	0	6	3	0	0	0	26	40
bull shark (S)	5	0	0	0	31	0	2	0	0	0	0	1	39
unid. penaeid shrimp (S)	0	0	1	9	5	0	0	0	1	0	0	16	32
Others (not used in CA)	80	5	86	11	147	5	56	24	13	8	72	9	516
Column Total	1,179	218	753	134	2,441	3,113	4,944	784	195	300	609	909	15,579

similar to variance) and offered a good representation of the fate-species associations. From the two-dimensional plot (Figure 2.6) we discerned three major and one minor groupings.

Species primarily associated with being released dead or disoriented were unidentified requiem sharks, red drum, crevalle jack, and bull sharks. Species secondarily associated with being released dead or disoriented were cownose rays and blacktip sharks. These last two species were primarily associated with being released healthy and appeared to form their own minor grouping.

The second group, species primarily associated with being gilled, were Atlantic croaker, sand seatrout, and unidentified tonguefish. Other species that were associated with being gilled were unidentified penaeid shrimp, Atlantic cutlassfish, gulf butterfish, and Atlantic bumper. These four species were also associated with the third group, species actively put into the hold, kept by the crew, and, to a lesser extent those whose fate was unknown. Other species associated with this third group were hardhead catfish, brown shrimp, Spanish mackerel, gafftopsail catfish, striped mullet, and the cabbagehead jellyfish.

Temporal and spatial patterns of bycatch species

Correspondence analysis of area-by-species for spring indicated that the first two axes explained 97% of the inertia and offered a good representation of species-area associations. From the two dimensional plot (Figure 2.7), we discerned three major groupings. The first axis separated the eastern areas of the fishery (zone groups 11-12 and 13-14) from the western areas (zone group 15-16 and 17-18). The second axis also separated zone groups 15-16 from zone group 17-18.

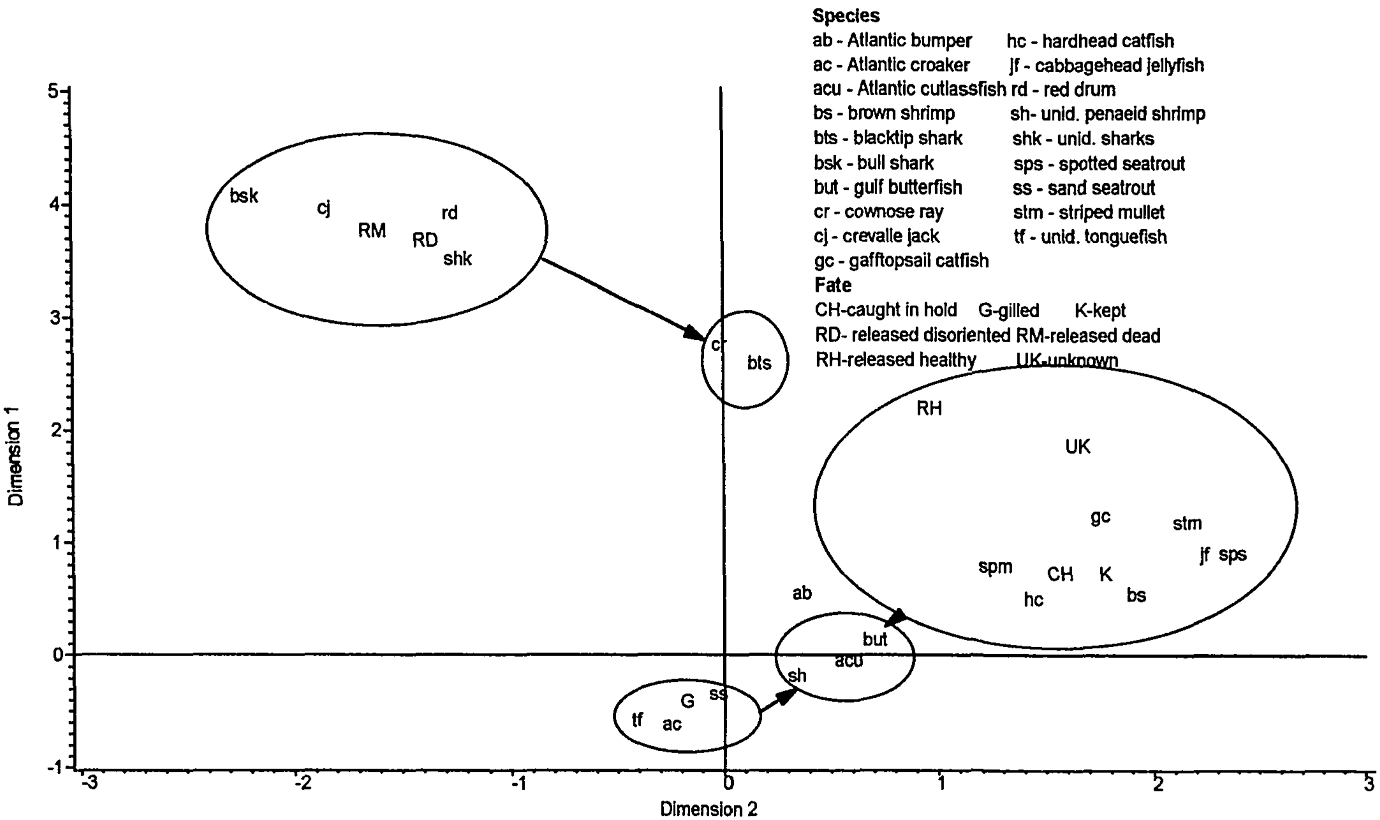

Figure 2.6. Correspondence analysis plot for species-fate associations -1995 fishing season. Species and fate included within circles respresent species-fate groups discussed in text. Arrowheads mark secondary species associated with groups.

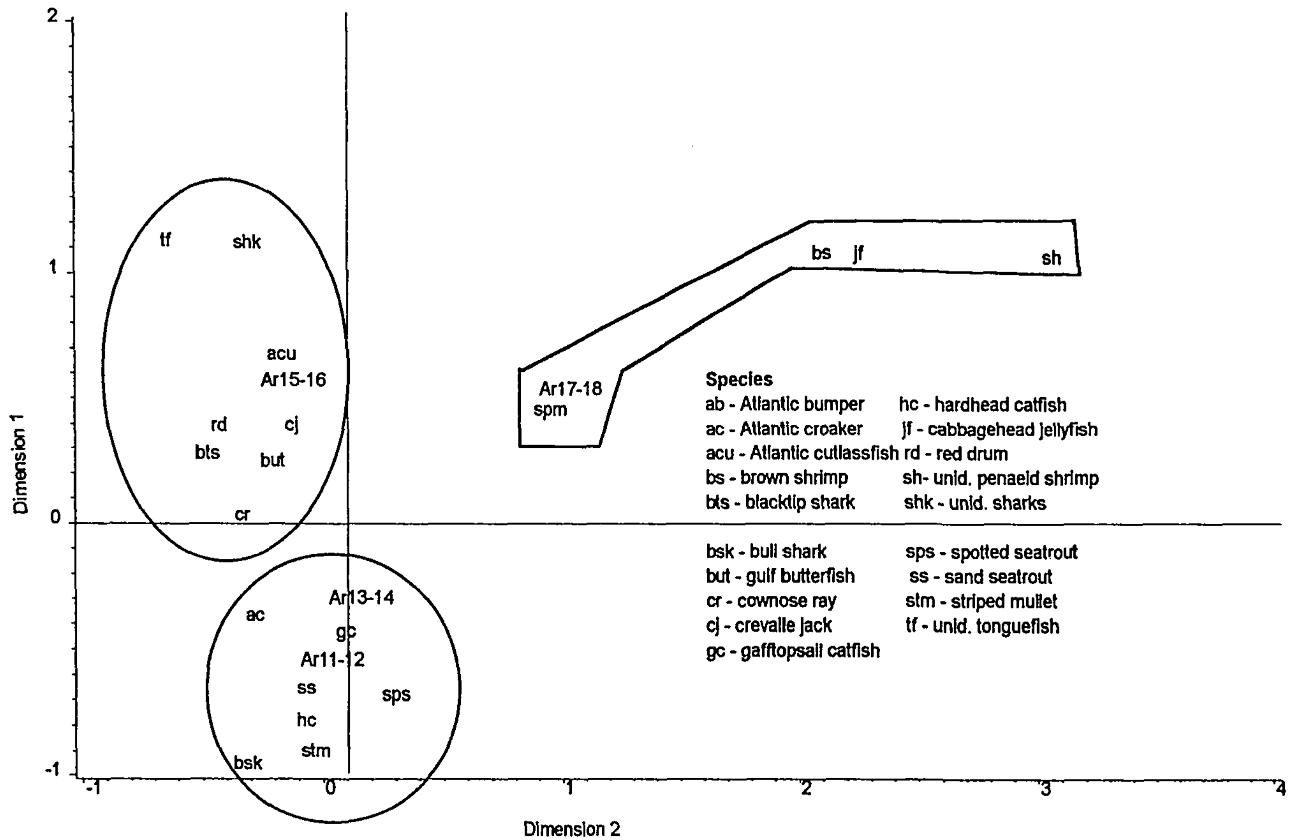

Figure 2.7. Correspondence analysis plot for species-area associations (spring) - 1995 fishing season. Species and areas enclosed within circles and polygon represent species-area groups discussed in text.

The eastern areas were associated with Atlantic croaker, gafftopsail catfish, sand seatrout, hardhead catfish, bull shark, striped mullet, and spotted seatrout.

Zone group 15-16 was primarily associated with unidentified tonguefish, red drum, crevalle jack, blacktip shark, unidentified requiem sharks, gulf butterfish, and Atlantic cutlassfish. Zone group 17-18 was associated with Spanish mackerel, brown shrimp, cabbagehead jellyfish, and unidentified shrimp

For the summer, correspondence analysis indicated that two axes accounted for 94% of total inertia. As in spring, three major species area groupings were observed (Figure 2.8). Notable differences in these grouping were that zone group 15-16 appeared to be closer to the eastern groups (13-14 and 11-12). Furthermore, group 13-14 was separated further from zone group 11-12.

Zone groups 11-12 and 13-14 were primarily associated with sand seatrout and, to a lesser extent, Atlantic croaker. In addition, zone group 11-12 was also associated with bull shark, striped mullet, spotted seatrout, unidentified shrimp and hardhead catfish.

Zone group 15-16 was also associated with Atlantic croaker. Other species associated with this area were cabbagehead jellyfish, brown shrimp, unidentified tonguefish, Atlantic bumper, unidentified requiem sharks, gulf butterfish, and crevalle jack. Zone group 17-18 was associated with Spanish mackerel, Atlantic cutlassfish, cownose ray, blacktip shark, red drum, and gafftopsail catfish. Secondarily associated species with this area were gulf butterfish and crevalle jack.

The first two axes of the fall analysis explained 97% of the total inertia, once again presenting a good fit of the table. By fall two major groupings were observed

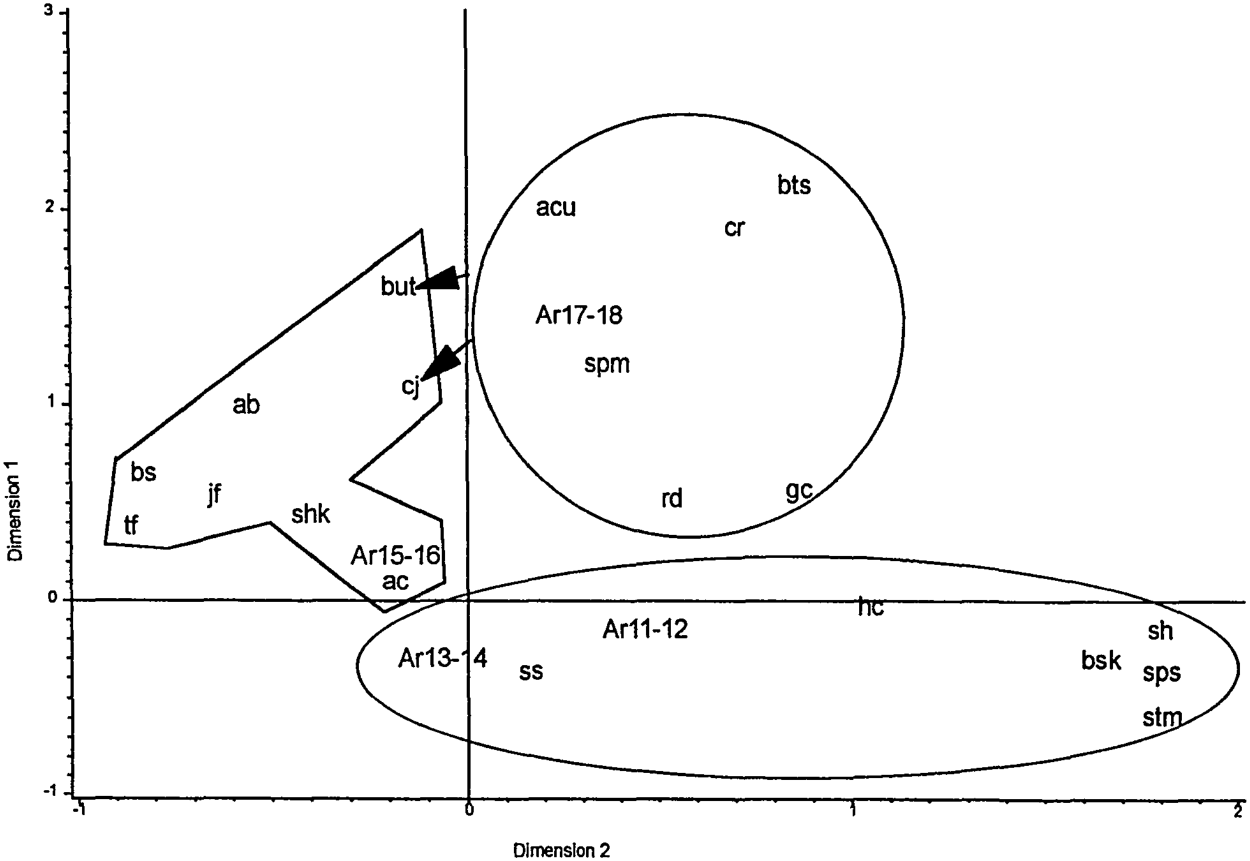

Figure 2.8. Correspondence analysis plot for species-area associations (summer) - 1995 fishing season. Species and areas enclosed within circles and polygon represent species-area groups discussed in text. Arrowheads identify secondary species associations with group.

(Figure 2.9). Areas from zone group 11-12 to 15-16 formed one group and were separated from the most westerly zone group 17-18.

Zone group 17-18 was primarily associated with Atlantic croaker, red drum, bull shark, blacktip shark, gulf butterfish, unidentified shrimp, and, to a lesser extent, cabbagehead jellyfish, brown shrimp, spotted seatrout, Spanish mackerel, and unidentified requiem sharks.

Zone groups 11-12 to 15-16 were associated with hardhead catfish, gafftopsail catfish, sand seatrout, and to a lesser degree, Spanish mackerel. In addition zone group 13-14 was also associated with crevalle jack and striped mullet and zone group 15-16 with cownose ray, unidentified tonguefish, and Atlantic bumper.

Discussion

Bycatch studies of the menhaden industry were conducted in 1894 on the Atlantic menhaden fishery (Christmas et al., 1960) and 1948 in the U.S. Gulf of Mexico (Miles and Simmons, 1950). Automatically retained bycatch percentage estimates have ranged from 0.05% (Dunham, 1972) to 3.90% (Christmas et al., 1960), by number, and 1.0% (Condrey, 1994) to 2.80% (Christmas et al., 1960), by weight. However, these values are based on bycatch retained in the fish hold. No estimates of the releasable bycatch are available. Based on our analysis, releasable bycatch estimates for the U.S. Gulf of Mexico menhaden fishery range from 0.033% (median) to 0.17% (mean) by number and reflect the strong positively skewed distribution of the bycatch. Values based on the winsorized mean are intermediate to those of the mean and median, and are associated with a lower standard deviation than that for the mean.

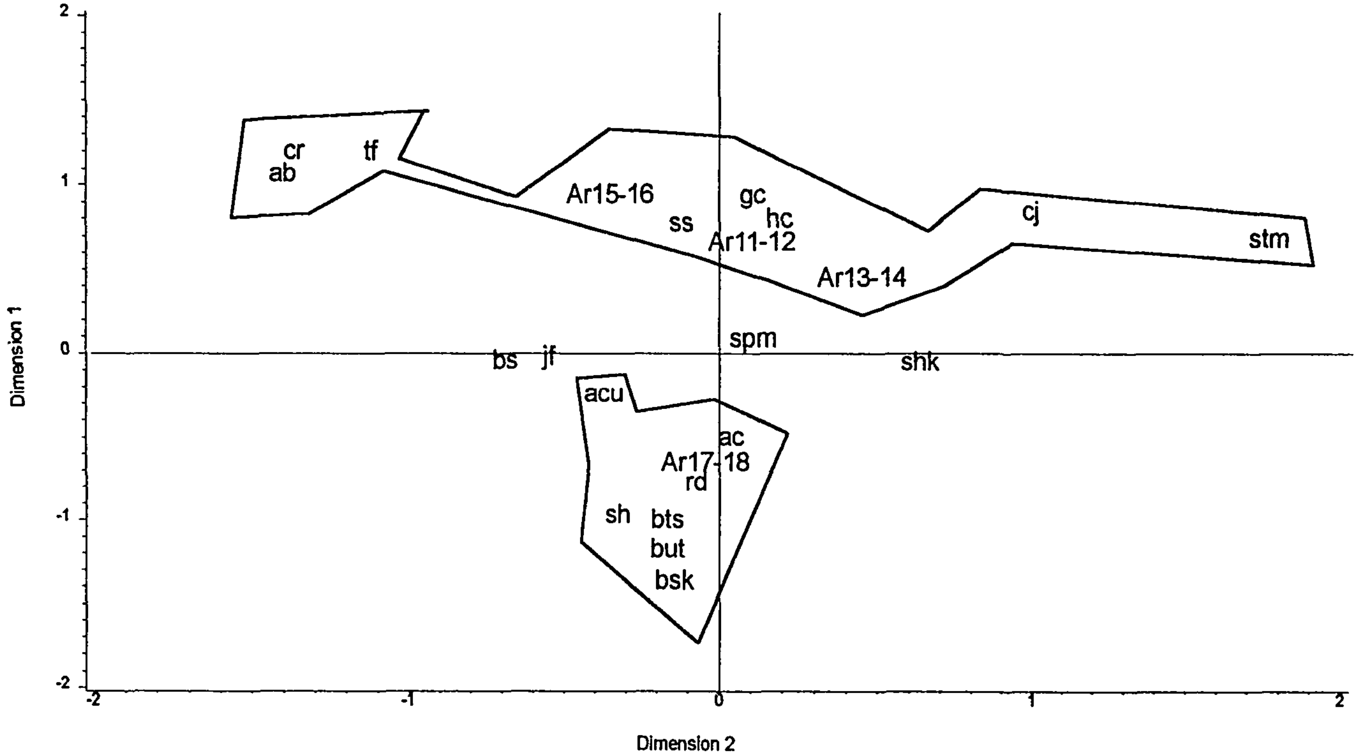

Figure 2.9. Correspondence analysis plot for species-area associations (fall) - 1995 fishing season. Species and areas enclosed within polygons represent species-area groups discussed in text.

As a result of the patchy distribution of menhaden bycatch, examination of the relationship of bycatch to other factors is made more complex. Even after the transformation of our data, we were not successful in stabilizing the error variance and bringing the error distribution close to normal. Because we could not find a suitable transformation, our solution to examining such data would be to convert the variable of interest into a categorical variable and to use categorical techniques in analyzing the data. In our case, the use of loglinear models to identify statistically important interactions was found to be a useful tool in exploring such data. This solution can be considered to fall between studies that can use ANOVA techniques (e.g., Andrew et al., 1995) and those based on the modified negative binomial model as used by Perkins and Edwards (1996).

Legendre (1987) noted that the responses of living organisms to environmental change is nonlinear and in instances nonmonotonic. As loglinear models are insensitive to the shape of the relationship among the variables, Legendre (1987) noted that they are well suited to examining nonmonotically related variables. A further advantage of this type of analysis is that because biological variables respond to interacting environmental variables, they can be used to examine such relationships in detail. By using loglinear models we can include a set of potential interactions in our saturated model, and through a stepwise selection procedure, find those interactions that are statistically important. In our study, bycatch was the issue of interest and the variable that we treated as a response. In effect, we were trying to find factors that could explain the bycatch, and we used loglinear models to find a suitable model that was associated with occurrences of bycatch greater than the median level for the fishery.

By using both loglinear models and logit models with categorical explanatory variables we have used the loglinear model for model selection and the logit model for a detailed examination of the model of our choice in a manner analogous to ANOVA.

Using the stepwise selection procedure, [SAB SAD] was found to be the most suitable loglinear model. We had hypothesized that the presence/absence of dolphins in the fishing area could indicate the presence of high bycatch. Had this been true, the presence/absence of dolphins in the vicinity could have been used by fishermen to avoid setting nets in certain areas. However, an association between dolphins and bycatch was found not to exist.

At first glance the issue of bycatch in the Gulf of Mexico menhaden fishery may seem to be negligible, given the low bycatch percentage. However, the fishery had the second highest annual U.S. commercial landings of 742,000 metric tons in 1995 (U.S. Dept. of Commerce, 1996). Further, given the strong positively skewed distribution of releasable bycatch, a small percentage of the total fishing effort would account for much of the take. By structuring our analysis around bycatch rates that were greater than the median, we have attempted to identify areas-seasons of potential concern in the fishery (hot spots). One of the solutions for reducing bycatch in the fishery is to identify such groupings, thereby, offering the industry a tool to manage their take of bycatch by minimizing fishing effort in these "hot spots" during certain times.

Our philosophy has been that consideration of all bycatch as a single entity is not the best approach. Although we felt the need to address the total bycatch in our first analysis, we also wanted to take individual taxa into consideration. We approached this multi-species aspect of our study using correspondence analysis, which we used to identify the commonly associated species or taxonomic groups in

the different zones and areas, as well as different fates. Our results suggest that this approach can have general appeal in identifying not only areas and species of concern, but also in suggesting approaches to solutions. For example, our hot spot fishing zone and season was east of the Mississippi River between April-August. This hot spot was associated with the bycatch of Atlantic croaker, sand seatrout, hardhead catfish, spotted seatrout, and bull sharks. Of these, Atlantic croaker and sand seatrout were the most commonly occurring species in the releasable bycatch and associated with being gilled. If a reduction in the mortality of these species in the menhaden bycatch were necessary, our study suggests it would require gear modification in the purse seine. A species associated with our hot spot, more likely to require attention, is the bull shark, given it's life history characteristics. Species-fate associations indicated that bull sharks were primarily associated with being released dead. If a reduction in the mortality of bull sharks as menhaden bycatch were mandated, solutions should be centered around reducing the number of sharks released dead. Rester (1996) has suggested that this could be achieved through the modifications to the fish pumping equipment for fish one meter in length or larger.

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CHAPTER 3

PROFILE OF SHARKS ASSOCIATED WITH THE U.S. GULF MENHADEN FISHERY AND THEIR RELEVANCE TO SHARK POPULATIONS IN THE ATLANTIC AND GULF OF MEXICO

Introduction

Our philosophy on bycatch and the management of fisheries

The importance of fisheries bycatch and its inclusion into management policies has recently received much attention (Alverson and Hughes, 1995). However, the systematic evaluation of the importance of bycatch mortality in relation to other sources of mortality and its impact on the population dynamics of a species is not widespread (Alverson and Hughes, 1995). Alverson and Hughes (1995) noted that for certain fisheries there was evidence to suggest that discard mortalities alone may at times approach and even exceed catch mortality. From a management perspective, the need to take into account discard mortality is necessary to ensure the rational management of a stock.

Our philosophy concerning bycatch has been that while there is a preliminary need to address a particular fishery's total bycatch, there is a much greater need for a consideration of the individual bycatch species. We have argued this consideration should search for ecological relationships, species/area/season combinations of potential concern (hot spots) and potential solutions that are both meaningful for the species affected and flexible enough to enhance the likelihood of industry acceptance. We have also argued that categorical statistical techniques are appropriate for this approach not only because they enable us to examine patchy data, but because they

can help us find flexible industry-acceptable solutions (de Silva and Condrey, 1998; Condrey and de Silva, in press).

In our initial analysis of the releasable bycatch of the U.S. Gulf of Mexico gulf menhaden, *Brevoortia patronus,* fishery (de Silva and Condrey, 1998), we used loglinear models and correspondence analyses to identify hot spots. Bull sharks, *Carcharhinus leucas*, emerged as one possible hot spot because they were associated with an area-season of higher than normal bycatch and were also associated with being released dead.

Bull sharks were of the most concern to us, since their basic life history features of slow growth, late maturity, low fecundity, and highly migratory nature make them highly susceptible to overfishing. In addition, bull sharks are also apex predators, who play a major role in the exchange of energy between the upper trophic levels (Wetherbee et al., 1990) and, therefore, their overfishing can have far-reaching ecosystem-level implications (e.g., Lemonick, 1997).

Based on our initial observations on bull sharks and the presence of at least 11 species of sharks in our menhaden bycatch study, we believe an examination of sharks in the menhaden bycatch was warranted. In addition, we felt this analysis was also relevant given the overfished status of large coastal sharks, the fully-fished status of small coastal sharks, and that shark bycatch in the menhaden fishery has not been addressed in the Shark Management Plan (NMFS,1993) or by the Shark Evaluation Workshops (NMFS, 1996a). For this analysis we decided against a single-species-specific analysis and began a shark specific analysis. Springer (1967) hypothesized that "species of sharks within a geographic area make up a segment of a single interacting system of many species of sharks". Given these complex interactions, the

patchy distribution of shark bycatch and our lack of detailed biological information on those sharks observed, a species specific analysis was not considered to be appropriate.

Shark management in the Atlantic and Gulf of Mexico

Increasing fishing pressure on, and concerns about the status of, sharks led to the recent implementation of the Federal Fishery Management Plan for Atlantic sharks (Plan), its Shark Evaluation Workshops (Workshop), and Amendment 1 to the Plan (NMFS ,1993; NMFS,1994; NMFS, 1996a; NMFS, 1996b). While neither the plan nor workshops have taken all sources of bycatch mortality into account in the population models, the importance of reducing juvenile mortality as an effective method of enhancing rebuilding has been discussed (NMFS, 1996a). However, information on the survival rates of juveniles in nursery habitats is for the most part unknown, and collecting this information has been highlighted in the workshop recommendations (NMFS, 1996a).

The 1994 Workshop identified large coastal sharks as being overfished and pelagic and small coastal shark groups as being fully fished. The 1996 Workshop recommended a 50% or more reduction in fishing mortality for large coastal sharks. In response to these recommendations, quotas for large coastal and pelagic sharks were initially capped at 1994 levels (NMFS, 1996a). In 1996 further restrictions were placed on the take of sharks and the proposed Amendment 1 to the Plan was released for review.

The restrictions reclassified five sharks from large coastal sharks to prohibited species, halved the permitted commercial quota for the remaining large coastal sharks

into two semiannual quotas of 642 t, and reduced the recreational bag limit. In addition, a semiannual quota of 880 t was established for small coastal sharks (NMFS, 1997a).

Amendment 1 was proposed to address the fundamental flaw in the fishery, its open-access nature which has resulted in excess harvest capability. To discourage any growth in the permitted bycatch fishery, a four-shark limit on daily landings per vessel was proposed.

The gulf menhaden fishery and sharks associated with the fishery

The gulf menhaden fishery is the second largest fishery by landings in the U.S. with a value of $ 54 million (U.S. Dept. of Commerce, 1997) and operates almost exclusively within state management jurisdictions (Leard et al., 1995). The association of sharks as part of the bycatch in this fishery has been documented as early as 1948 (Knapp, 1949) and in at least four other studies (Christmas et al., 1960; Dunham, 1972; Guillory and Hutton, 1982 and; Condrey, 1994) . However, much of this work related to specific fishing areas and/or times.

Sharks have long been a mechanical problem in the gulf menhaden fishery. If sharks enter the stream of menhaden being transported from the purse seine into the hold of the carrier vessel, they can clog the pumping operation, damage pumping gear, and result in loss of days fished and functional equipment. In attempting to reduce this damage, the industry has developed two devices known as the large fish deflector and hose cage to reduce their take of large bycatch species. Rester (1996) evaluated these two devices and suggested that the hose cage could possibly be modified to achieve a 50% increase in large fish greater than 1 m being released alive.

The large fish deflector was found to prevent large fish from entering the hold but resulted in high mortality of those fish.

In order to promote the better management of sharks, information on the sources of incidental shark mortality is necessary. In the northcentral Gulf of Mexico, a few studies on shark bycatch in other commercial and recreational fisheries, such as that for the tuna longline fishery (Russell, 1993) and shrimp fishery (NMFS, 1996a) have been conducted. In this paper, we provide a description of sharks associated with the gulf menhaden fishery, their fates, distribution with respect to where the fishery operates and provide estimates of the number of sharks caught by the fishery. No information on the spatial and temporal patterns of shark bycatch in the gulf menhaden fishery is currently available. Patterns in the shark bycatch, once identified, may offer the industry a tool to help reduce their take of sharks by enabling them to modify their fishing practices accordingly. In this paper, we also suggest possible approaches to reducing shark bycatch in a manner that could be acceptable to the industry based on our philosophy on bycatch and its management. The approaches to reducing shark bycatch for the fishery are based on two of the proposed management restrictions which are categorical and rigid in nature: a) a 50% reduction in fishing mortality and b) a four shark/vessel-day landing limit in the permitted bycatch fishery.

<u>Relationship of sharks to menhaden schools</u>

For the large bycatch species, such as sharks, one of the factors for observing such occurrences could be when a 'feeding school' of these predators are caught with the menhaden. It has been observed that the shape of the fish school may be a reflection of the presence of predators. Parrish (1992) noted that large schools of fish are probably less likely to be affected by predation than smaller schools. As predators

attack a school of fish, the school will be broken into two or more subgroups. Furthermore, predators finding a school may stay with it, positioning themselves on the edge of the school. While the importance of schooling fishes as a forage base for sharks has been documented (Compagno, 1984b), the role gulf menhaden schools may play as a forage base for sharks in the northcentral Gulf of Mexico is not well documented (Leard et al., 1995).

Materials and Methods

Sampling protocol

The gulf menhaden fishing season operates from the second week in April through the last week of October. We sampled bycatch aboard commercial menhaden fishing vessels during 51 trips made during the 1994 and 1995 fishing seasons over the temporal and spatial range of the fishery (Figure 2.1). Samples were collected June through October of 1994 and April through October of 1995. Sampling was performed on vessels from five of the six plants operating in the region. Approximately 50% of the fleet was sampled over the two fishing seasons and the overall yearly sampling effort represented 2% of the effort by the fishery. Sampling effort was distributed among ports in the western, central, and eastern regions of the gulf to maximize the possibility of obtaining a gulf-wide distribution of effort.

Fishing sets made were sampled by alternatively using one of two procedures: one for the automatically retained bycatch (bycatch which automatically entered the hold through the loading chute) and the other for releasable bycatch (all other bycatch).

Since sharks were primarily observed in the releasable bycatch, except for one blacktip shark encountered in the automatically retained bycatch samples, we confine

this analysis to the releasable sets, approximately 50% of our total sampling effort. During these sets, samplers observed the hardened net during pumping and recorded the identity, estimated total length (m), fate, and numbers of bycatch observed. Bycatch fate was classified as follows: 1) caught and released overboard; 2) caught and put into the hold; 3) gilled; 4) kept by the crew; 5) released disoriented; 6) released healthy; and 7) released dead.

Sharks were identified in the field using Boschung's (1978) guide to sharks in the Gulf of Mexico. This was supplemented with guides by Hoese and Moore (1977) and Robins and Ray (1986). Releasable bycatch was studied without disrupting ordinary fishing practices. This sometimes meant our observers did not have sufficient time and/or opportunity to identify portions of the releasable bycatch. Sharks observed during such instances were classified as unidentified sharks. For one set observed during 1994 a total of 148 sharks were encountered. Of these only two were identified. However, photographs of a portion of this catch (76 sharks) were taken (Figure 3.1). The photographs were used to supplement identification and estimate their size based on a float of known size also depicted in the picture.

During the 1995 fishing season, sharks that were landed on the deck during pumping of all sets were examined in greater detail whenever possible. In addition to identification of species, total length (TL in mm), fork length, (FL in mm) and weight (kg) were also recorded. Stomach contents were examined in situ and identified to species where possible. The contents were weighed and numerated and empty stomachs recorded. Description of the stomach contents follow methods used by Cortes and Gruber (1990) with our results being presented for each species as:

Figure 3.1. Photograph of a portion of sharks classified as unidentified in the set that contained 148 sharks.

1) percentage occurrence, calculated as the number of stomachs containing a particular food item as a percentage of the total number of stomachs containing food; 2) percentage number, calculated as the number of prey items in each category as a percentage of total number of items; and 3) percentage weight, calculated as the wet weight of the prey category expressed as a percentage of total weight. Graphical representations of the diets of sharks are presented using the method suggested by Cortes (1997).

Species composition is presented in terms of occurrence and abundance. Length classes of 50 cm (TL) intervals were used to examine the length-frequency distribution for the six most numerically abundant species/groups and the unidentified requiem sharks. Classes were designated by the lower value of the class (e.g., fish ≥100 cm and < 150 cm are classed as 100 cm).

__Statistical analysis__

Estimates and 95% confidence intervals (CI) for the mean number of sharks were calculated for each year. In addition, bootstrap estimates of the mean number of sharks per set and 95% CI of the mean using the percentile method (Mooney and Duval 1993) were also calculated for 1994 and 1995. For each year 1000 bootstrap replicates were performed.

Estimates of the total number of sharks $\hat{T}$ caught in the menhaden fishery for 1994 and 1995 were calculated as:

$$\hat{T}=N\bar{y}=\frac{N\sum_{i=1}^{n}y_i}{n}$$

where N = total number of sets made by the fishery for year;

n = number of fishing sets sampled; and

y = number of sharks caught in a set and i denotes the set (Scheaffer et al., 1986).

Variance of total sharks $(\hat{V})$ was estimated separately for each of the years as:

$$\hat{V}(\hat{\tau})=\hat{V}(N\bar{y})=N^2(\frac{s^2}{n})(\frac{N-n}{N})$$

$$s^2=\sum_{i=1}^{n}\frac{(y_i-y)^2}{n-1}$$

where s^2 was the sample variance (Scheaffer et al. 1986).

Bootstrap estimates were also used to determine the annual number of sharks caught by the fishery by multiplying the mean value by the total number of sets made by the fishery for each year (data courtesy of NMFS Beaufort Laboratory, unpublished vessel captains daily fishing report data).

Estimates of the proportion of sets with shark bycatch for 1994 and 1995 and their confidence intervals were also calculated (Scheaffer et al., 1986).

For our analysis examining the presence/absence of shark bycatch in menhaden sets and their relationship to fishing season, area and menhaden catch, we used a four-way loglinear model with the unit of effort (the fishing set) as the count. For this model, the variable shark bycatch (B) was a dichotomous variable where we classified each set sampled as presence or absence of sharks. The variable season (S) had five classes: 1) Jun-Aug 1994, 2) Sep-Oct 1994, 3) Apr-May 1995, 4) Jun-Aug 1995, and 5) Sep-Oct 1995. The variable area (A) consisted of three classes: 1) 11-13

corresponding to fishing grounds between 88^0 N. and up to 90^0 N, 2) 14-16 corresponding to fishing grounds between 90^0 N and up to 93^0 N., and 3) 17-18 corresponding to fishing grounds west of 93^0 N (Figure 2.1). Based on season-area groupings, the Kolmogorov-Smirnov two-sample test indicated that our sampling distribution was not significantly different to that of the overall effort by the fishery for 1994 and 1995, (1994-$|D|=0.063$, $P = 0.05$;1995-$|D|=0.077$, $P=0.05$). The variable catch (C) was a dichotomous variable where each set was classified as having either *above or less than or equal to the median catch of 52,500 standard menhaden* (approximately 16 t) observed over the two years. This four-way saturated loglinear model [BSAC] corresponded to the logit model with shark bycatch as the response variable and area, season, catch, all two-way interactions and the season-area-catch term as categorical explanatory variables. We used the backward selection procedure described by Agresti (1990) to find the simplest loglinear model with a logit form that had a fit as good as the saturated model (de Silva and Condrey, 1998). For the selection criteria of our final model we chose a p-value of at least 0.05 that the model had to meet.

Contrasts to examine differences in the log odds of observing a set with shark bycatch were constructed for the selected model. These contrasts were grouped into two basic groups:

1) Given a specific season, were the odds of observing a set with shark bycatch the same between 1994 and 1995. This hypothesis was tested for the June-August and September-October seasons.
2) Given a specific year, were the odds of observing a set with shark bycatch the same between any two seasons.

Because 13 contrasts were performed, an overall type I error level of 0.10 was adjusted by the number of contrasts, and only P-values less than 0.007 were considered significant. The estimated odds ratios for the conditions associated with the hypotheses were calculated from the parameter estimates derived from the model.

From a management perspective, we were interested in determining the spatial and temporal patterns of shark bycatch using a set of hypothetical criteria that the fishery might be subjected to. One of the proposals under Amendment 1 to the shark Fishery Management Plan (FMP) is that the permitted bycatch fishery be allowed to land a maximum of four sharks per day (NMFS 1996b). Though the menhaden fishery is not subjected to the shark FMP, we used those guidelines to examine the spatial and temporal patterns of the odds of observing more than four sharks/day.

We calculated the estimated number of sharks caught per fishing day per vessel sampled using the formula:

$$\hat{Sh}_{day/vessel} = \frac{\sum_{i=1}^{s} N_i}{T_s} \times T_d$$

where N_i = number of sharks caught in set i;

T_s = Total number of fishing sets sampled on vessel for day d; and

T_d = Total number of fishing sets made by vessel on day d.

We created a dichotomous variable limit (L) where we classified each fishing day per vessel sampled as "above", if $\hat{Sh}_{day/vessel}$ was greater than four, and "below" if $\hat{Sh}_{day/vessel}$ was less than or equal to four. Spatial and temporal patterns of the odds of observing more than four $\hat{Sh}_{day/vessel}$ were examined using a similar protocol to that

examining the odds of observing a set with shark bycatch. However, for this three-way loglinear model the variables used were L, S and A.

Results

Species composition and fate

During the two seasons we sampled 492 sets for releasable bycatch and observed a total of 726 sharks. For 1994 a total of 235 sets were sampled during which 324 sharks were observed. In 1995 a total of 257 sets were sampled during which 402 sharks were observed.

Ten species of large and small coastal sharks were identified as part of the releasable bycatch (Table 3.1). Sharks identified during field sampling were (by abundance for both years combined); blacktip shark, *C. limbatus*; dusky shark, *C. obscurus*; bull shark, *C. leucas;* spinner shark, *C. brevipinna*; silky shark, *C. falciformis*; sandbar shark, *C. plumbeus*; smalltail shark, *C. porosus*; finetooth shark, *C. isodon*; bonnethead shark, *Sphyrna tiburo* and; blacknose shark, *C. acronotus*.

Two hundred and forty eight sharks (34%) were not identified to species in the field (Table 3.1). Based on photographic records, the 146 unidentified sharks taken in one set were a mixture of blacktip/spinner sharks.

Figure 3.2 shows the species composition of sharks observed for the two years by percentage occurrence and number. For both years, blacktip sharks were the most common species encountered in terms of occurrence and number. In 1995 blacktips occurred in a greater percentage of sets sampled than in 1994. For both years, unidentified sharks were the second most common group in terms of numbers and occurrence. The importance of rare but numerically important events and their effect on species composition can be clearly seen (Figure 3.2). In 1994 the set comprising of

Table 3.1. Species composition of sharks encountered in the menhaden bycatch during 1994 and 1995.

Species/Group	Number	Number of Sets
blacktip shark	256	72
mixed group of blacktip and spinner sharks	146	1
unidentified requiem sharks	102	50
dusky shark	59	7
bull shark	58	23
spinner shark	40	19
silky shark	31	4
sandbar shark	13	9
smalltail shark	10	6
finetooth shark	6	2
bonnethead shark	4	4
blacknose sharks	1	1
Total	726	

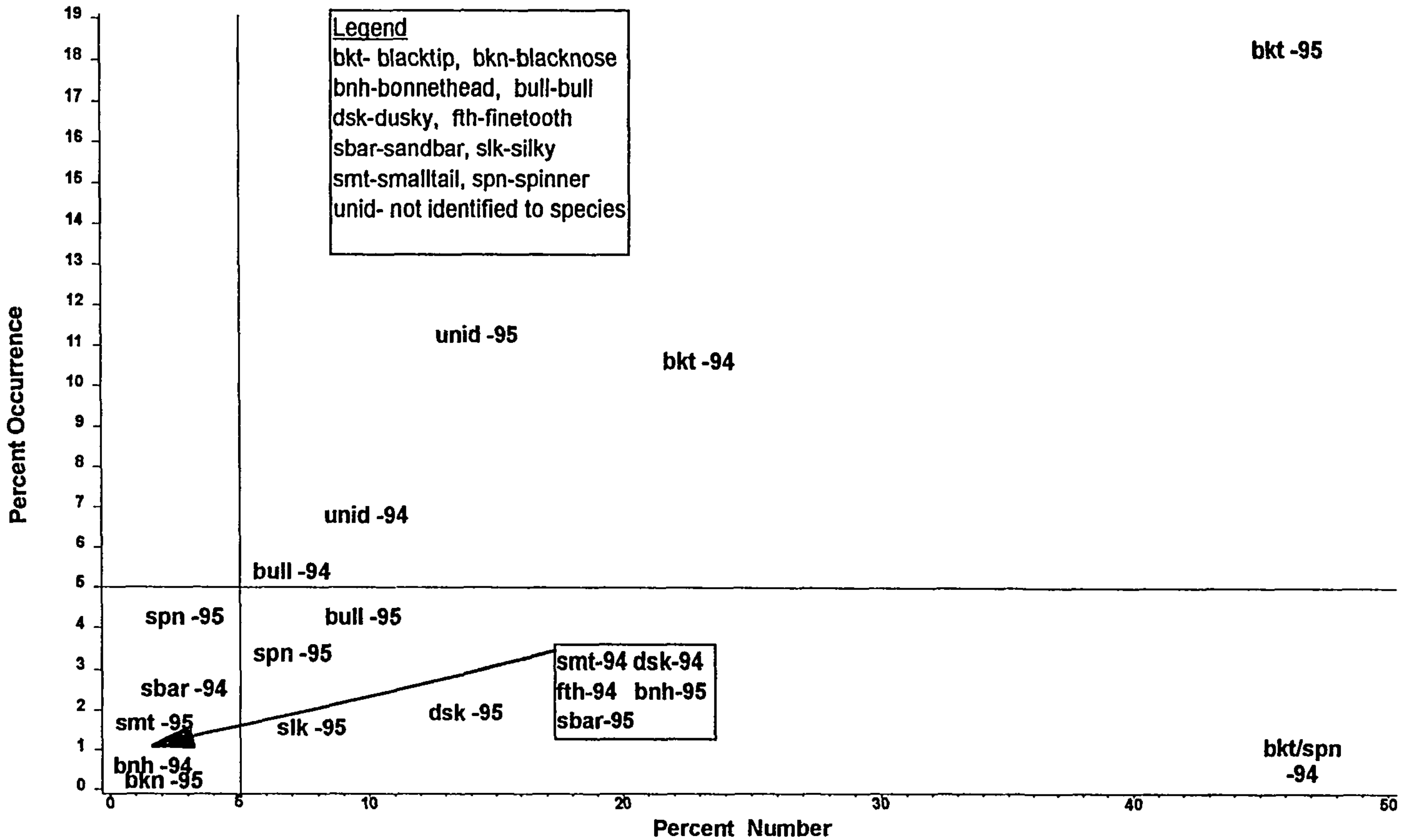

Figure 3.2. Species composition of sharks associated with the gulf menhaden fishery. Distributions for 1994 and 1995 are shown in terms of percentage occurrence (percent of total sets sampled for year) and percentage number (percent of sharks observed for year).The number of fishing sets sampled in 1994 and 1995 were 235 and 257 sets, respectively. In 1994 and 1995 the number of sharks observed were 324 and and 402, respectively.

blacktip/spinner sharks accounted 47% of the sharks observed for that year. Dusky and silky sharks, ranked 4 and 7 in overall numerical abundance, were primarily observed in 1995 and encountered in a small proportion of sets.

The estimated length distributions of the seven most numerically dominant species/groups indicated that for blacktip, dusky and silky sharks the 100 cm class accounted for the majority of these sharks caught (Figure 3.3). This size class interval also accounted for 14% of bull and 38% of spinner sharks caught. In addition, for the unidentified requiem sharks 47% were in the 50 cm class interval and 43% in the 100 cm class (Figure 3.3). For most other species, except bull sharks, the 50 cm class was the second most important class (Figure 3.3) accounting for between 20 % of the blacktip sharks and 33% of spinner sharks. Few bull sharks were caught in the 50 cm class. For bull sharks, the 150 cm class was the most important level (62%). For the other species, this size group ranked third in importance, accounting for between 3% of the silky sharks and 28% of the spinner sharks. Larger size groups > 200 cm were best represented in bull sharks, but the numbers encountered were low.

Of the 726 sharks observed during the two years, approximately 50% were released to sea dead, and 24% were collected dead off the deck and put into the hold. These two groups of sharks were usually gaffed out from the net to prevent the pump from being clogged. Twelve percent of the sharks observed were released disoriented - in a condition where their survival was questionable, and 8% released healthy. The released sharks were within the net and released after the menhaden were pumped onboard. The fate of 6% of the sharks observed could not be determined. These sharks were seen at least once during the pumping operation but not seen as the nets

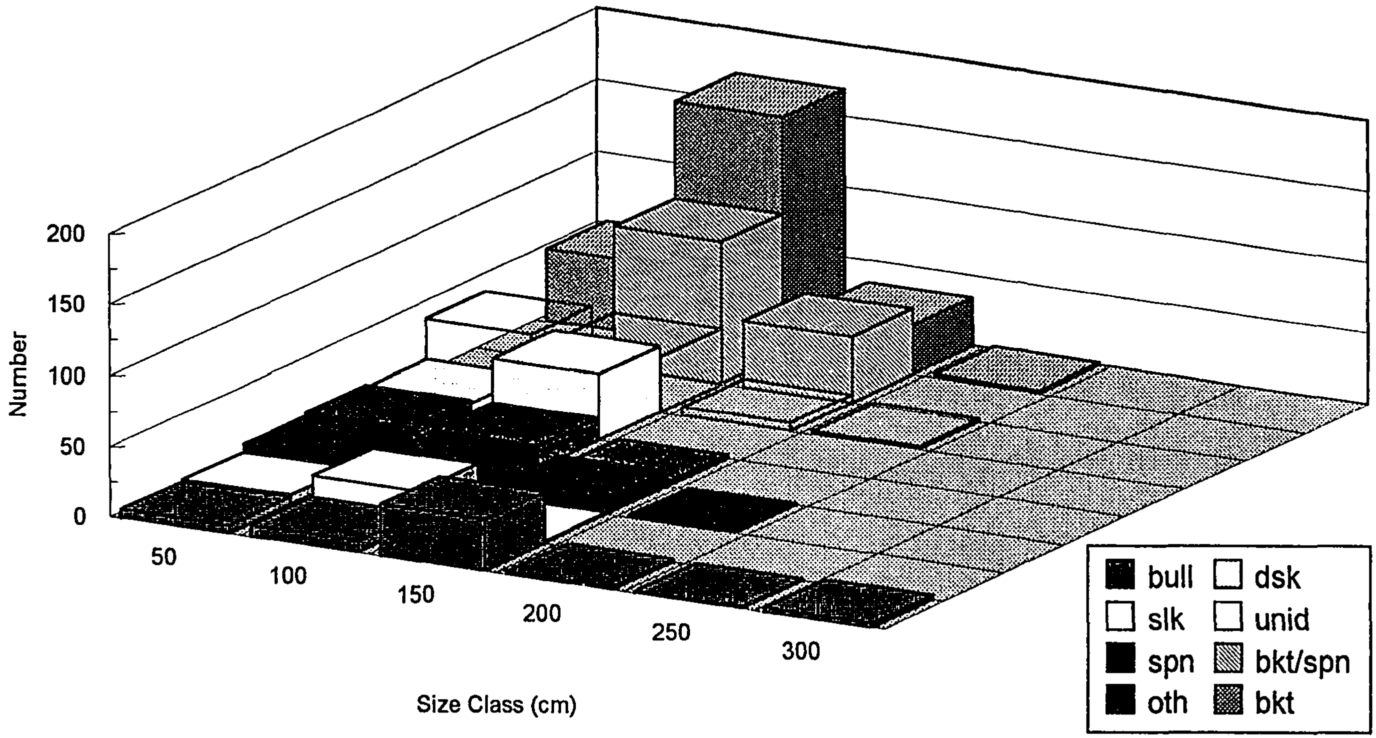

Figure 3.3. Size frequency distribution of sharks caught in the gulf menhaden fishery during the 1994 and 1995 fishing seasons. Class intervals are denoted by lower end of class. Key definitions: bkt =blacktip, bull=bull, dsk=dusky, spn=spinner, slk=silky, unid=sharks not identified to species.

were emptied. These sharks most likely entered the hold through the suction hose. A small percentage of the sharks, 0.3%, were kept by the crew for personal consumption.

Stomach analysis

A total of 62 shark stomachs from 8 species, were examined during the 1995 fishing season; 31% were empty.

A total of 32 blacktip sharks were examined ranging from 505 to 1140 mm FL and 2 to 22 kg in weight. Thirteen of the 32 stomachs examined were empty. The most common item present was gulf menhaden. Thirteen of the stomachs examined contained between one and five gulf menhaden. The size of those gulf menhaden whose length could be estimated ranged from 90 to 167 mm standard length (SL). Gulf menhaden accounted for the highest percentage of stomach contents in terms of weight, number and occurrence (Figure 3.4). Unidentified fish parts were the second most common item present (eight of the stomachs examined) ranging from 1 to 4 items and occurred in 38% of the stomachs with food (Figure 3.4).

A total of eight smalltail sharks ranging from 620 to 800 mm FL and between 2.2 to 4.8 kg were examined during the study period. Two of these sharks had empty stomachs. The most common item present in the stomach was gulf menhaden. Three stomachs contained between 1 and 5 menhaden ranging from 120 to 162 mm SL. Though the percentage occurrence of menhaden in the stomachs was lower than for the other species sampled (Figure 3.4), gulf menhaden was the major food item in terms of occurrence, weight and numbers. Other items found in the stomachs of this

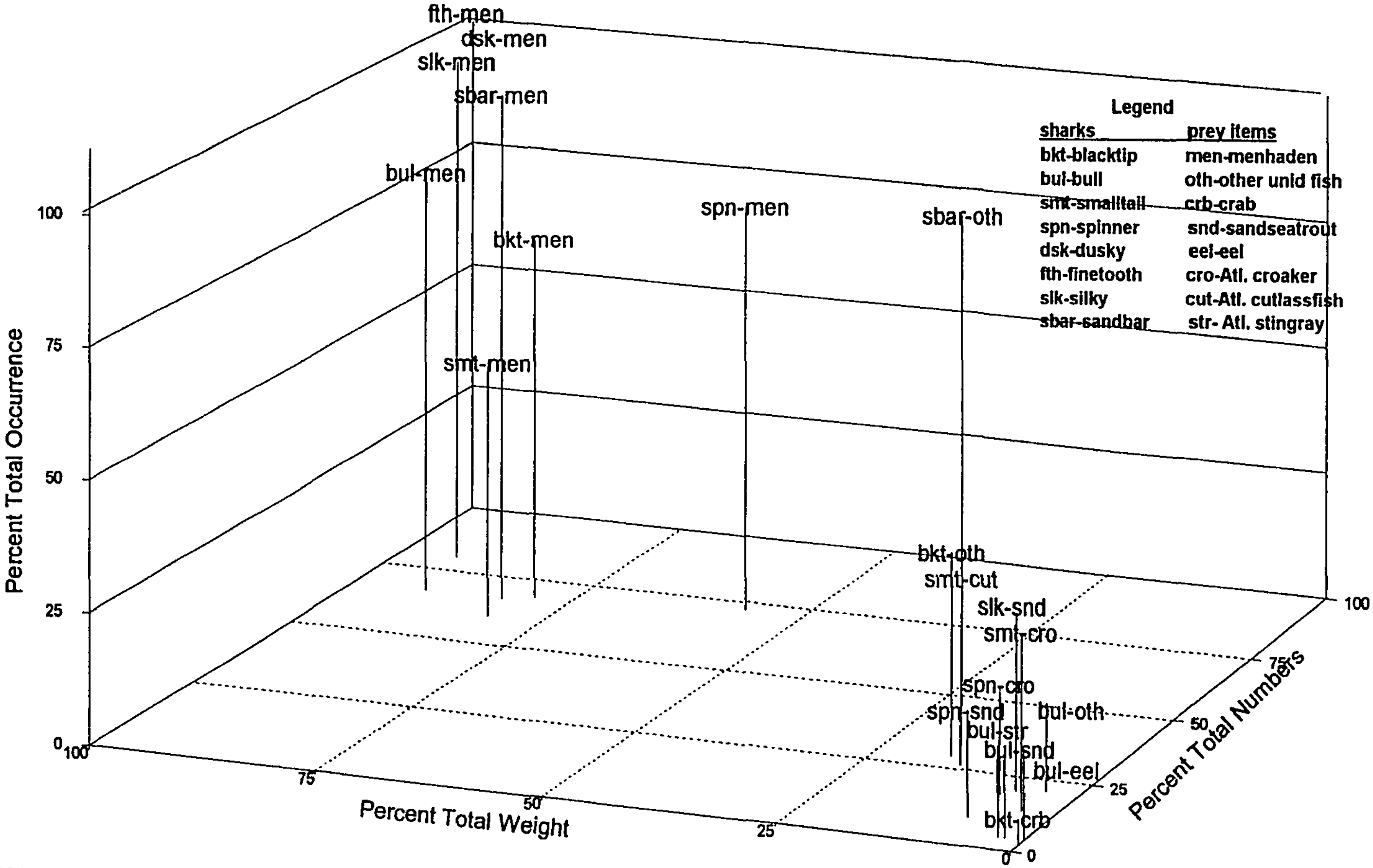

Figure 3.4. Graphical representation of stomach contents of sharks caught in the gulf menhaden fishery . Percent occurrence, Percent total number, and Percent weight calculated are based on stomachs containing food.

species were Atlantic croaker, *Micropogonias undulatus,* (two stomachs) and Atlantic cutlassfish, *Trichiurus lepturus*, (one stomach) but accounted for a small percentage in terms of weight or numbers (Figure 3.4).

A total of seven bull sharks, ranging from 785 to 1125 mm FL and weighing between 3.9 and 35 kg were examined. Only one of the stomachs was empty. The most common food item present was gulf menhaden. Five of the seven stomachs contained between one and nine menhaden ranging between 140 and 185 mm SL . Gulf menhaden accounted for the highest percentage of stomach contents in terms of weight, number and occurrence (Figure 3.4). Two stomachs contained unidentified items. An Atlantic stingray, *Dasyatis sabina*, a sand seatrout, *Cynoscion arenarius* and a partially digested eel were found in three of the stomachs that contained menhaden and accounted for a small percentage of the food items in terms of numbers and weight (Figure 3.4) .

A total of seven spinner sharks ranging from 580 to 1040 mm FL were examined. The weight of six of these sharks ranged between 3.2 and 5 kg. One shark was not weighed. Two of the stomachs examined were empty. The most common food item present was gulf menhaden. Four of the seven stomachs contained between one and three menhaden ranging between 135 to 170 mm SL for those which were intact. Gulf menhaden accounted for the highest percentage of stomach contents in terms of weight, number and occurrence (Figure 3.4). A sand seatrout (110 mm SL) was found in one stomach that also contained gulf menhaden. Two Atlantic croaker (90 mm SL) were also found in one stomach that contained gulf menhaden.

Three silky sharks, ranging from 750 to 795 mm FL and weighing between 3.3 to 4.1 kg, were found to have between one and three menhaden in their stomachs

(135 to 145 mm SL). Gulf menhaden accounted for the highest percentage of stomach contents in terms of weight, number and occurrence (Figure 3.4). The remnants of a sand seatrout were also observed in one of the stomachs.

Two finetooth sharks of 1040 and 1050 mm FL, weighing 16.25 and 15.75 kg respectively, were examined. One of these sharks had an empty stomach. The other had two menhaden (130 and 195 mm SL). Both sharks were females carrying four pups each.

Two dusky sharks of 750 and 800 mm FL, weighing 4 and 4.4 kg respectively were examined. The stomachs of these sharks contained one and four gulf menhaden, respectively, ranging between 136 and 140 mm SL. The stomach examined of a sandbar shark of 1200 mm TL was found to contain two menhaden (180 and 200 mm SL) and the remnants of an unidentifiable fish. For both these species gulf menhaden accounted for the highest percentage of stomach contents in terms of weight, number and occurrence (Figure 3.4).

Estimates of shark bycatch in the menhaden fishery

The number of sharks observed per set in 1994 ranged from 0 to 148 with a mean of 1.378 sharks per set (s= 9.854, n= 235). The bootstrap estimate of the mean number of sharks per set for 1994 was 1.375 (95% CI, 0.561 to 2.940).The estimated number of sharks caught by the fishery during the year were 35,989 (95% CI, 2,581 to 69,397). Bootstrap estimates provided similar estimates of sharks caught (35,987) with a 95 % confidence interval ranging from 14,662 to 76,754. The Shapiro Wilk test for normality indicated that the distribution of the bootstrap means were not normal (W= 0.9078, P<W= 0.0001), which suggests that the confidence intervals derived from the bootstrap estimates may be better.

The number of sharks observed per set for 1995 ranged from 0 to 24 with a mean of 1.562 sharks per set (s= 3.651, n= 257). The bootstrap estimate for the mean number of sharks per set for 1995 was 1.561 (95% CI, 1.140 to 2.019). The estimated number of sharks caught by the fishery during the year were 33,069 (95% CI, 23,497 to 64,241). Once again bootstrap estimates provided similar estimates (33,020) with a 95 % confidence interval ranging from 24,102 to 42,693. The Shapiro Wilk test for normality indicated that the distribution of the bootstrap means were normal (W= 0.9852, P<W= 0.2680).

For 1994, the proportion of menhaden sets that contained sharks was estimated at 0.263 (26.3%), with a 95% CI ranging from 0.207 to 0.320. For 1995, the proportion of menhaden sets that contained sharks was estimated at 0.369 (36.9%), with a 95% CI ranging from 0.309 to 0.429.

Spatial and temporal patterns of sets with shark bycatch

Using the backward model selection procedure on the set of loglinear/logit models (Table 3.2), we concluded that the logit model with size of menhaden catch, season, area, and the season-area interaction term provided a fit as good as the saturated model (G^2= 18.03, df= 14, P>χ^2= 0.2050). This model had significant season- area interaction (G^2= 21.43, df= 8, P > χ^2= 0.0061), catch (G^2= 16.95, df= 1, P > χ^2= 0.0001), and season (G^2= 51.67, df= 4, P > χ^2= 0.0001) terms. The area term was not significant (G^2= 1.00, df= 2, P > χ^2= 0.2102). However, the simpler logit model with catch, season and area was marginally outside our selection criteria (G^2= 39.47, df= 22, P>χ^2= 0.012). As such, we examined the standardized residuals of both these models to discern any grouping of areas or seasons for which the simpler model showed a lack of fit over the model with the interaction term. Though none of the

Table 3.2. Summary of stepwise selection of models examining the relationship between the log odds of shark bycatch to season, area and catch.

	Loglinear Form	Logit Form	df	G^2	$P > G^2$
	BASC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SA} + \beta^{AC} + \beta^{SC} + \beta^{SAC}$			
	BAS SAC BSC BAC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SA} + \beta^{AC} + \beta^{SC}$	8	7.45	0.4885
Best	BAS SAC BAC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SA} + \beta^{AC}$	12	8.25	0.7655
	BAS SAC BSC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SA} + \beta^{SC}$	10	17.79	0.0586
	BAC BSC SAC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{AC} + \beta^{SC}$	16	29.97	0.0182
Best	BAS SAC BC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SA}$	14	18.03	0.2052
	BSC SAC BA	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C} + \beta^{SC}$	18	38.21	0.0036
	SAC BA BS BC	$\text{logit}(B)= \beta^{A} + \beta^{S} + \beta^{C}$	22	39.47	0.0124

standardized residuals exhibited extreme values, the residuals for the conditionally independent model (without the interaction term) fitted the data well, except for the April-May 1995 season. For this period, it appeared that the residuals were larger (Figure 3.5) for the no interaction model. This was also confirmed by examining the model where we nested the area term by season (Stokes et al., 1995), which indicated that the nested term of the April-May 1995 season was significant. As such, we employed the technique suggested by Agresti (1990) of fitting a model which assumed conditional independence between season and area except for the April-May 1995 season. This model had a G^2= 30.99 with 20 df and P > χ^2= 0.0553, satisfying our selection criteria and is described as:

$$\log \frac{m_{ijkpresent}}{m_{ijkabsent}} = \alpha + \beta^{C}{}_{i} + \beta^{A}{}_{j} + \beta^{S}{}_{k} + \beta^{A[S=April\text{-}May95]}{}_{jk}$$

where $m_{ijkpresent}$ is the expected number of sets with sharks with catch i in area j and season k ;and

$m_{ijkabsent}$ is the expected number of sets without sharks with catch i in area j and season k.

This model had a significant season-area interaction explained by significant spatial differences in the odds of observing sharks during the April-May 1995 season that were not evident for the other seasons (G^2= 7.85, df= 2, P > χ^2= 0.0197). In addition, the catch (G^2= 15.96, df= 1, P > χ^2= 0.0001) and season (G^2 = 42.16, df= 4, P > χ^2= 0.0000) terms were also significant. The area term was not significant (G^2= 3.08, df= 2, P > χ^2= 0.2143).

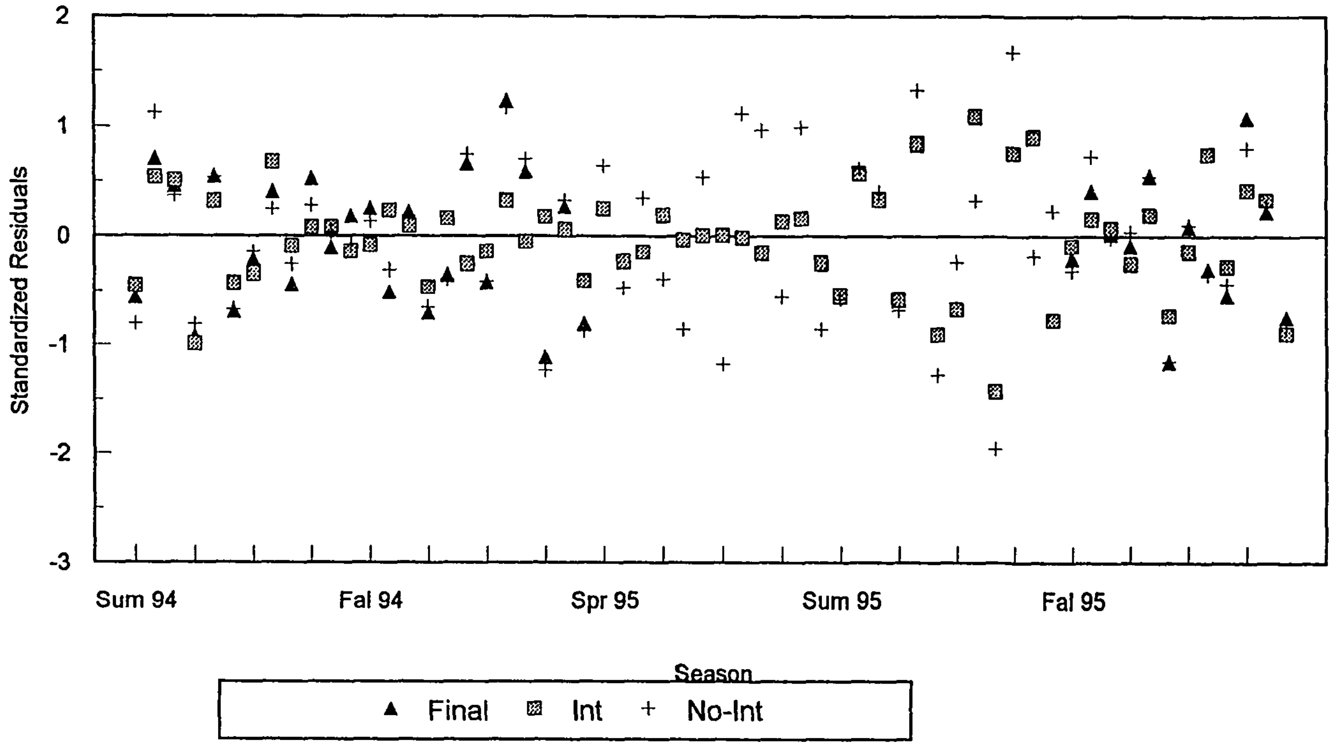

Figure 3.5. Standardized residual plot of logit model for the odds of observing a fishing set with shark bycatch. Final=residuals for final model. Int=residuals for model with season- area interaction term. Noint=residuals for no interaction model. Sum 94=Jun-Aug 94, Fal94=Sep-Oct 94, Spr=Apr-May 95, Sum 95=Jun-Aug 95, Fal 95=Sep-Oct 95.

This model indicated that the odds of observing a set with shark bycatch can be explained by two main components. The first component is the size of the menhaden catch. Here the odds of observing a set with shark bycatch and its association to menhaden catch are independent of season and area. The odds of observing a set with shark bycatch was approximately 2.3 times more likely for menhaden sets with a catch greater than the median of 52,500 std. menhaden than those for a set with a catch less or equal to the median.

The second component in this model relates to the relationship between the odds of observing a set with shark bycatch to season and area. There is a season-area interaction between the April-May 1995 season and the three zones. Here the odds of observing a set with shark bycatch differs significantly among the three zones for the April-May 1995 season. For all other seasons, the odds of observing a set with shark bycatch were conditionally independent of area.

For contrasts examining yearly differences by season, the odds of observing a set with shark bycatch between 1994 and 1995, indicated the null hypothesis (no difference) could not be rejected for both the June-August and September-October seasons (Table 3.3).

For 1994, inter-season differences between the odds of observing a set with shark bycatch for June-August and September-October were significant (Table 3.3). The odds of observing a set with shark bycatch was approximately two and a half times greater for June-August than the those odds for September-October. Since we had a dependence among zones and the April-May season for 1995 we modified our inter-season contrasts for 1995 by treating the April-May season as three subgroups: 1) April-May (Zone 11-13), 2) April-May (Zone 14-16), and 3) April-May (Zone 17-18).

Table 3.3. Summary of contrasts for logit analysis of the odds of observing shark bycatch in the menhaden fishery. Alpha level of ≤ 0.007 are considered significant and denoted by "sig".

	Comparison	df	Wald - X^2	G^2	Odds Ratio
Yearly Differences by Season					
	Jun-Aug 94 vs Jun-Aug 95	1	3.84	3.87	0.60
	Sep-Oct 94 vs Sep-Oct 95	1	0.17	0.17	1.22
Inter-Year Differences 1994					
	Sep-Oct vs Jun-Aug	1	6.89	7.49^{sig}	2.50
Inter-Year Differences 1995					
	Apr-May (Zone 14-16) vs Apr-May (Zone 17-18)	1	4.34	4.59	5.85
	Apr-May (Zone 11-13) vs Apr-May (Zone 17-18)	1	0.65	0.65	1.15
	Apr-May (Zone 11-13) vs Apr-May (Zone 14-16)	1	6.80	7.00	0.19
	Apr-May (Zone 11-13) vs Jun-Aug	1	0.34	0.33	1.37
	Apr-May (Zone 14-16) vs Jun-Aug	1	32.25^{sig}	13.61^{sig}	6.48
	Apr-May (Zone 17-18) vs Jun-Aug	1	0.29	0.29	0.68
	Jun-Aug vs Sep-Oct	1	21.31^{sig}	18.71^{sig}	5.06
	Apr-May (Zone 11-13) vs Sep-Oct	1	9.50^{sig}	9.35^{sig}	6.92
	Apr-May (Zone 14-16) vs Sep-Oct	1	28.36^{sig}	35.93^{sig}	32.83
	Apr-May (Zone 17-18) vs Sep-Oct	1	2.85	2.78	3.48

For 1995, inter-season differences between the odds of observing a set with shark bycatch were significant for four of the ten contrasts performed. The odds of observing a set with shark bycatch in June-August was approximately five times greater than those odds for September-October (Table 3.3).

In 1995, the odds of observing a set with shark bycatch for September-October were also significantly different from the odds for observing shark bycatch for both Zone 11-13 and Zone 14-16 during the April-May season. The odds of observing a set with shark bycatch was approximately seven times greater for Zone 11-13 in April-May than those odds for September-October. The odds of observing a set with shark bycatch for zone 14-16 in April-May was 33 times greater than those odds for September-October. Furthermore, the odds of observing a set with shark bycatch for zone 14-16 in April-May was approximately seven times greater than those odds for June-August (Table 3.3).

The odds of observing a fishing day with a catch of more than four sharks

When examining spatial and temporal patterns of the odds of observing a fishing day where more than four sharks were caught, our stepwise selection procedure indicated that the model with no season-area interaction term had a marginal fit (G^2= 19.25, df= 8, P > χ^2= 0.0136). Examination of the standardized residuals for this model indicated no extreme values. Furthermore, the residuals for the conditionally independent model (without the interaction term) fitted the data well except for the April-May 1995 season. For this period, the majority of the residuals were greater than one (Figure 3.6). Examining the model where we nested the area term by season (Stokes et al., 1995), also indicated that the nested term of the April-May 1995 season was significant. As such, we employed the technique suggested by

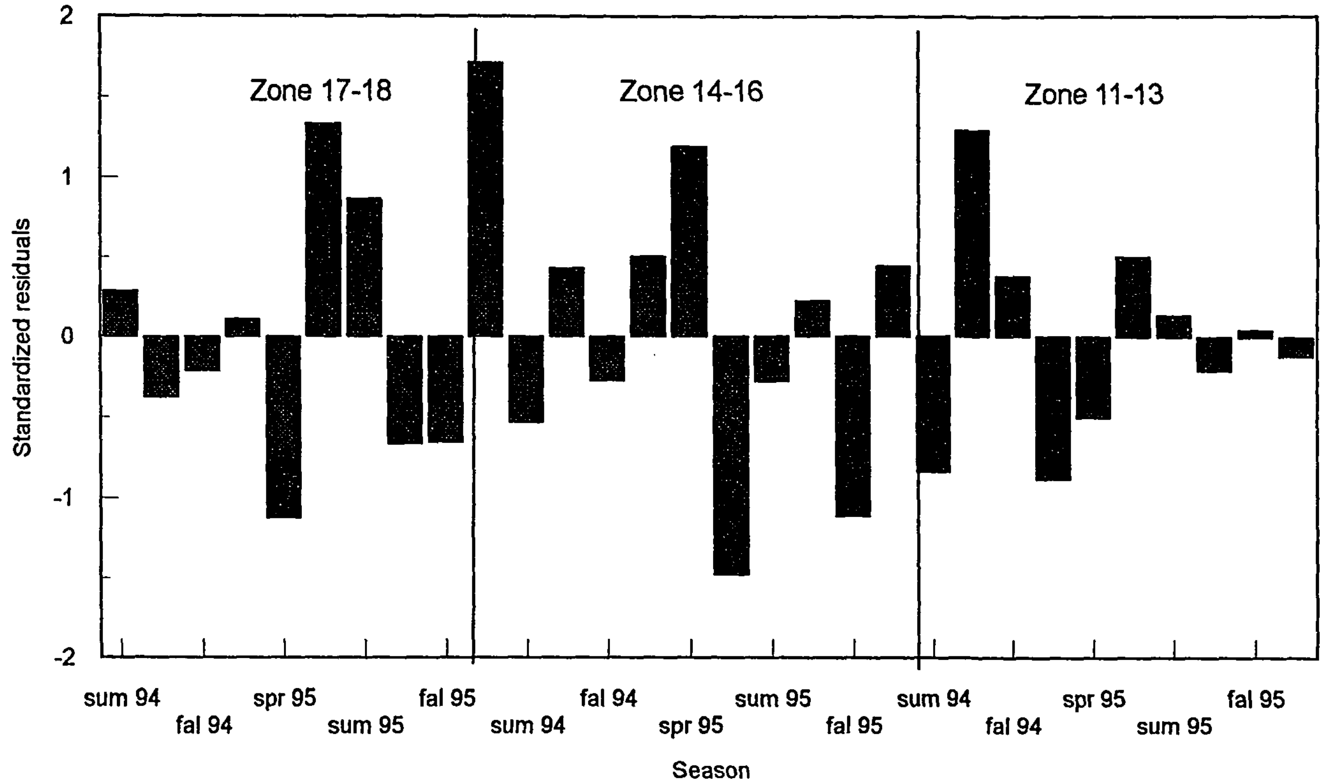

Figure 3.6. Standardized residual plot for logit model examining the odds of observing a fishing day with more than 4 sharks /day for model with no season-area interaction. Spr= April-May, Sum= June-August, Fal=Sep-Oct.

Agresti (1990) and fitted a model which assumed conditional independence between season area except for the April-May 1995 season. This model had a G^2= 9.92 with 6 df and P > χ^2= 0.1280 satisfying our selection criteria and is described as:

$$\log\frac{m_{ijabove}}{m_{ijbelow}}=\alpha+\beta^{A}{}_{i}+\beta^{S}{}_{j}+\beta^{A[S=April-May95]}{}_{ij}$$

where $m_{ijabove}$ is the expected number of fishing days with a catch of more than four sharks in area *i* and season *j*; and

$m_{ijbelow}$ is the expected number of fishing days with a catch of less than or equal to four sharks in area *i* and season *j*.

This model had a significant season-area interaction explained by significant spatial differences in the odds of observing more than four sharks/day during the April-May 1995 season that were not evident for the other seasons (G^2= 9.33, df= 2, P > χ^2= 0.009). The season term was also significant (G^2 = 10.47, df= 4, P > χ^2= 0.033). The area term was not significant (G^2= 1.12, df= 2, P > χ^2= 0.5712).

Since our model included conditional dependence between season and area for the April-May season, we modified our contrasts for inter-seasonal comparisons for 1995 by treating the April-May season as three subgroups of April-May (Zone 11-13), April-May (Zone 14-16) and April-May (Zone 17-18). Significant temporal or yearly differences in the odds of observing more that four sharks/day for the period June through September were not detected for the fishery. This is based on the yearly and seasonal contrasts we performed, where we failed to reject the null hypothesis (no differences) in; 1) the odds of observing a fishing day with more than four sharks between 1994 and 1995 for both the June-August, and September-October seasons

and; 2) the odds of observing a fishing day with more than four sharks between June-August and September-October for both 1994 and 1995 (Table 3.4).

Our model also takes into account that the odds of observing a fishing day with more than four sharks for each zone during the April-May season are different. This may be attributed to differences in the odds of observing more than four sharks per fishing day between Zone 14-16 and Zone 17-18 in April-May (Table 3.4). The odds of observing a fishing day with more than four sharks is approximately 32 times greater for Zone 14-16 in April-May than Zone 17-18 during the same period.

Other contrasts of significance were that the odds of observing a fishing day with more than four sharks being caught were significantly different between Zone 14-16 in April-May 1995 versus June-August and Zone 14-16 in April-May 1995 versus September-October (Table 3.4). The odds of observing a fishing day with more than four sharks was approximately 17 times greater for Zone 14-16 in April-May than for June-August, while the odds of observing this event was approximately 72 times greater for Zone 14-16 in April-May than in September-October.

Discussion

In this paper we describe the nature and extent of sharks associated with the fishery and a source of incidental shark mortality that has previously not been considered by management. While this objective was conservation motivated, this paper will also serves to illustrate our philosophy that flexible solutions developed in a non-confrontational manner have a better chance of gaining industry acceptance than rigid measures imposed through mandates. This philosophical approach is addressed in the second section of this discussion.

Table 3.4. Summary of contrasts for logit analysis of the odds of observing more than four sharks per fishing day in the menhaden fishery. Alpha level of $\leq$ 0.007 is considered significant and denoted by "sig".

	Comparison	df	Wald -χ^2	G^2	Odds Ratio
Yearly Differences by Season					
	Jun-Aug 95 vs Jun-Aug 94	1	0.01	0.01	0.96
	Sep-Oct 95 vs Sep-Oct 94	1	0.71	0.74	0.52
Inter-Year Differences 1994					
	Sep-Oct vs Jun-Aug	1	2.37	2.53	0.42
Inter-Year Differences 1995					
	Apr-May (Zone 14-16) vs Apr-May (Zone 17-18)	1	6.26	8.36^{sig}	32.0
	Apr-May (Zone 11-13) vs Apr-May (Zone 17-18)	1	1.04	1.12	2.4
	Apr-May (Zone 11-13) vs Apr-May (Zone 14-16)	1	3.63	4.46	0.07
	Jun-Aug vs Apr-May (Zone 11-13)	1	0.09	0.09	0.78
	Jun-Aug vs Apr-May (Zone 14-16)	1	11.48^{sig}	10.46^{sig}	0.06
	Jun-Aug vs Apr-May (Zone 17-18)	1	1.01	1.16	3.41
	Sep-Oct vs Jun-Aug	1	6.12	5.67	0.23
	Sep-Oct vs Apr-May (Zone 11-13)	1	3.00	2.95	0.18
	Sep-Oct vs Apr-May (Zone 14-16)	1	11.82^{sig}	19.56^{sig}	0.01
	Sep-Oct vs Apr-May (Zone 17-18)	1	0.03	0.03	0.79

the impact of the gulf menhaden fishery on food and game fishes, 63 sharks were observed in 59 sets sampled in Louisiana waters east of the Texas boundary in 1948 (Zones 17-18), with 202 sharks observed in 143 sets in 1949 in the same area (Miles and Simmons, 1950). Later, Christmas et al. (1960) noted that 25 % of 88 sets examined in areas east of the Mississippi River (Zones 11-13) included sharks. Condrey (1994) noted that sharks were observed in sets sampled over the entire range of the fishery in 1992. During his study, approximately 50 % of the 127 releasable bycatch sets sampled included sharks. In our study, approximately 30 % of the sets we sampled included sharks.

The mean number of sharks/set during of our study was 1.38 and 1.56 for 1994 and 1995, respectively. These values were similar to those determined from Condrey's (1994) study (1.58 sharks/set). Based on information contained in Miles and Simmons (1950), the mean number of sharks/set in 1948 and 1949 were 1.06 and 1.41 sharks/set, values similar to those observed in our study.

We believe that our study of the bycatch underestimated a portion of sharks associated with the fishery. Small slender sharks, defined as less than 1 m (TL), were less likely to be detected during our releasable bycatch sampling as they were easily suctioned through the pumping system with the menhaden becoming part of the automatically retained bycatch. Our sampling of the automatically retained bycatch was inefficient at collecting small sharks. Furthermore, small sharks were also less likely to be identified. Approximately 47% of the unidentified sharks were less than a meter. For sharks less than 1m, classification as unidentified sharks was the most frequent choice (based on occurrence). We believe that the species composition of these sharks would be a mixture of small coastal sharks and young large coastal

Sharks have been documented in the bycatch of the gulf menhaden fishery as early as 1948 (e.g., Knapp, 1949). During these early studies, conducted to examine sharks. For example, photographs taken of small sharks removed from the hold suggested the presence of small blacktip/spinner and Atlantic sharpnose sharks, *Rhizoprionodon terraenovae,* (Figure 3.7). Since most of these small sharks would enter the hold, dockside sampling would provide an estimate of the magnitude and species composition of the retained bycatch of these small sharks. However, dockside sampling has two drawbacks. First, it combines automatically retained shark bycatch and releasable shark bycatch which has been retained. Second, information on frequency of encounter per set and information on location of catch is diminished.

From the ratio of bycatch to menhaden in dockside samples collected during the 1980-81 fishing seasons, Guillory and Hutton (1982) back calculated an average annual landed bycatch of 14.6 million Kg for the period 1970-75. Since 2% of this landed bycatch were sharks, this equated to 290 mt (total weight) of sharks landed as bycatch for 1970-75. Based on Guillory and Hutton's (1982) estimates of bycatch ratios, we updated their estimates to reflect the years they sampled. The landed bycatch of sharks for 1981 and 1982 using this method was 225 and 343 mt (total weight), respectively.

While we field identified 10 species of sharks in our study, we believe that this is not a complete list of species associated with the fishery. While most previous menhaden bycatch studies classed sharks as a generic group, three (Miles and Simmons 1950; Christmas et al. 1960; and Condrey 1994) did contain some information on the species identified. Miles and Simmons (1950) noted that for the 1949 study conducted by Breuer (1950) 80 % of the 202 sharks observed were

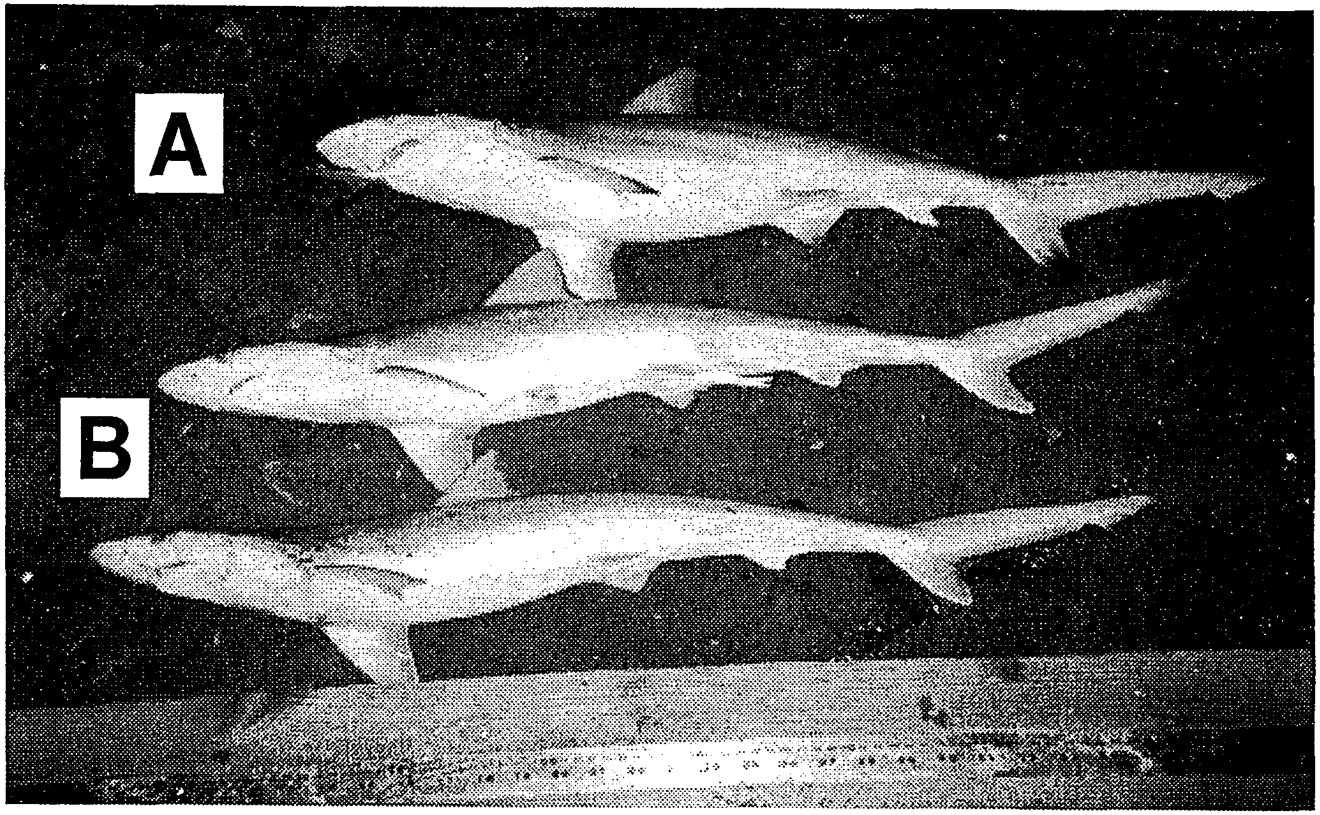

Figure 3.7. An example of small sharks (~ 75 cm TL) taken from the fish hold. A = small blacktip/spinner. B=Atlantic sharpnose.

identified as sand shark, *Carcharias littororalis*, a synonymy (Compagno, 1984a) for sand tiger shark, *Odontaspis taurus*, with the rest classified as bonnethead and hammerhead sharks (*Sphyrna spp.*). Christmas et al. (1960) observed bull, blacktip, Atlantic sharpnose, bonnethead and hammerhead sharks. Examination of the original data sheets of Christmas et al. (1960) indicated that species with the highest abundances which also occurred in more than 5% of sets sampled included the unidentified sharks, blacktip, bonnethead and scalloped hammerhead. A re-examination of Condrey's (1994) data indicated that 70% of the sharks observed were blacktip sharks, 11 % dusky sharks, and 7.5 % bull sharks. Approximately 9 % were not identified to species.

Examination of the species composition of sharks observed in the menhaden bycatch over the last 50 years suggest changes may have occurred over this time and/or the species distribution of sharks in the bycatch is patchily distributed. A review of Breuer's (1950) bycatch report, described in Miles and Simmons (1950), indicated that sand tiger sharks were the most numerically abundant. We did not observe sand tiger sharks in our study, nor did Condrey (1994). The species most commonly found in our study and that of Condrey (1994) was the blacktip shark, a species not recorded in those early studies. Furthermore, the proportion of hammerhead sharks encountered in those early studies was higher than in this and that of Condrey (1994). Both Simmons (1948) and Breuer's (1950) studies indicated that hammerhead sharks accounted for 18 and 19 % of the shark bycatch. Based on the original data sheets of Christmas et al. (1960), it appears that hammerhead sharks occurred in 14% of the sets sampled and accounted for 20% of the shark bycatch. In our study bonnethead

sharks accounted for less than 1% of the sharks, while Condrey (1994) did not encounter any.

While these differences may reflect changes in species composition over time, they also are likely to reflect the patchy distribution of sharks. Examination of our own data and the raw data of Christmas et al. (1960) indicates that the occurrence of a species can be clumped in space and time. For example, during 1994 the single set in which 148 blacktip/spinners were encountered accounted for 47% of all sharks encountered that year. This patchy distribution also extends to species, and within-species distribution. In our study all silky sharks encountered were taken on two consecutive days in the same location by one vessel. During 1995, the occurrence of dusky sharks also exhibited a similar patchy trend. Furthermore, during 1994 approximately 50% of the blacktip sharks encountered were observed in 4 sets made during June. For 1995, 50% of the blacktip sharks encountered were caught in 9 sets, the majority of which were sampled in May and June.

A similar pattern was observed for the Christmas et al. (1960) data set. For example, all bull sharks encountered occurred on the same day, in consecutive sets while fishing in the same area. Other examples of this clumping were noted for bonnethead sharks which appeared to be taken over a two-day period in August by the same vessel, and Atlantic sharpnose which were encountered in two sets with 23 of 25 being taken in one set. As the original data sheets of Breuer (1950) and Simmons (1948) apparently no longer exist, we could not determine if the patchy occurrences of shark species in menhaden bycatch could help explain the species composition they observed.

Sharks are generally considered to be opportunistic feeders with the ability to use a wide variety of prey in different habitats and may feed most heavily upon the most abundant prey (Wetherbee et al., 1990). Because of their great abundance and schooling behavior, gulf and Atlantic menhaden are prey for many piscivorous fish and birds (Leard et al., 1995). Compagno (1984b) noted that blacktip and spinner sharks commonly feed on schooling fishes in inshore areas. The relationship between feeding sharks to menhaden and anchovy schools has been noted for bull and blacknose sharks, respectively (Branstetter, 1981). Stomach analyses on bull sharks (Branstetter, 1981; Snelson et al., 1984) and blacktip sharks (Castro, 1996) have indicated the presence of menhaden in their diet. Our examination of stomach contents from sharks taken incidentally in the gulf menhaden fishery, found gulf menhaden to be the most important item in terms of percent occurrence, number, and weight for all species examined (Figure 3.4). Castro (1996) noted that for blacktip sharks on the east coast of the United States, the frequency of menhaden in the stomach was 14% and considered this to be a conservative estimate since much of the unidentified stomach contents could have been well digested menhaden.

Based on our stomach analyses, we believe that menhaden schools are a forage base for sharks in the region, and the incidence of shark captures as bycatch in the menhaden fishery is tied to this predator-prey (trophic) relationship. Our analyses indicate that gulf menhaden are the predominant food items of sharks associated with these schools. Based on the varying digestive state of menhaden in the stomach, we hypothesize that these sharks had encountered the school prior to the fishing operation, and were feeding on the school at the time of capture. However, our

estimates of menhaden in the stomach contents of sharks may be influenced by net predation, the co-occurrence of menhaden and sharks appears to reflect a predator-prey relationship.

Parrish (1992) noted that prey schools, may act as predator-aggregating devices. This may well be the case for gulf menhaden schools and sharks. Trent et al. (1997) noted that spotter pilots searching for sharks in the drift gillnet fishery off Georgia and east Florida look for concentrations of bait fish and in particular menhaden.

Approximately 30% of the releasable bycatch sets we sampled included sharks. If we assume gulf menhaden schools are an important food source for sharks in the nearshore Gulf of Mexico and accept Pitcher's (1980) idea that once a predator finds a school they will maintain contact (travel) with the school, our incidence of co-occurrence reflects the success rate of sharks locating schools of menhaden and/or their ability to avoid being captured during the retrieval of the purse seine. Since our analysis indicates that the odds of observing a set with sharks are significantly greater for larger menhaden schools (> 16 t), this may be indicative of the ability of sharks to better locate large prey schools.

Parrish (1993) noted that for four piscivorous predators on flatiron herring, *Harengula thrissina*, schools, the time spent cruising with the school was much higher than that spent attacking it. Parrish (1993) observed that one of the water column positions predators took when associated with the school was stalking along the edge. Gunter (1963) noted that sharks were observed around the edges of menhaden schools and generally avoided the nets, which suggests that sharks associated with a menhaden school may exhibit a stalking position. More detailed information on the

behavior of sharks in relation to menhaden schools may provide valuable information to help refine menhaden harvesting strategies to reduce their take.

This paper was a result of an overall study of the bycatch in the menhaden fishery. As such, we did not collect detailed biological information on those sharks caught. However, based on our size distributions coupled with age and maturity information in the literature, we can make inferences on the age and maturity of those sharks caught in the fishery. The sharks caught in the menhaden fishery ranged in sizes from those expected for young of the year to mature adults. However, this distribution does vary by species. For blacktip sharks, using Branstetter's (1987) age and growth estimates for this species in the northwestern Gulf of Mexico, approximately 19 % were probably recently born pups. Approximately 66% of blacktip sharks were between 100 and 125 cm (TL) and would be considered immature. Branstetter (1987) noted that male blacktip sharks mature at approximately 130 cm, while females mature at 150-155 cm. Approximately 13% of blacktip's corresponded to a size considered to be mature. Branstetter and Stiles (1987) age estimates for bull sharks in the northern Gulf of Mexico suggest a size range for maturity is between 210 and 225 cm (TL) for both sexes. Based on our size distribution and Branstetter and Stiles (1987) age estimates, approximately 12% of bull sharks we encountered could possibly be classified as mature with the majority of the sharks being immature ranging from newborn to about age 7+. Seventy percent of the spinner sharks caught in the menhaden bycatch were 1.5 m (TL) or smaller and based on Branstetter's (1987) estimates were immature. Branstetter (1987) noted that male spinner sharks were estimated to mature at seven years of age at 170 cm (TL), and females at seven to eight years of age at 180 cm (TL). A proportion of this group may have been young of

the year sharks. Castro (1983) noted that the size at birth for dusky sharks ranges from 85-100 cm. All dusky sharks encountered in the menhaden bycatch were 1 m (TL) or less and were probably at most one year of age (Natenson et al., 1994). While performing stomach analyses we encountered two female finetooth sharks, each with four embryos. Both these specimens were obtained in the same set.

Castro (1993) defines shark nursery areas as "geographically discrete parts of the species range where gravid females deliver their young or deposit their eggs, and where the young spend their first weeks, months or years". The presence of gravid females, neonates and small juveniles are factors to be considered in detecting such areas (Castro, 1993). Our study was not designed to define such areas, as this was part of an overall study on bycatch in the fishery. However, based on the size distribution of sharks observed and the literature concerning age and maturity of some of the species we observed, it appears that the fishery may be impacting a portion of the shark nurseries in the Gulf of Mexico. Examination of the raw data from Christmas et al. (1960) and their report (Christmas et al., 1959) indicated that "all blacktip sharks taken in Breton Sound in May 1959 were pregnant females. The young of those opened were apparently fully developed". In addition, Breuer (1950) also noted the presence of pregnant female sharks.

Shark bycatch in the gulf menhaden fishery may be an important source of incidental mortality impacting some of the summer nursery grounds and possibly the pupping grounds for some species of sharks in the northcentral Gulf of Mexico. Branstetter (1990) has suggested that nursery areas provide young sharks with protection from predation as well as a good source of prey. However, the amount of protection from predation that nursery areas will provide would vary by species

(Branstetter, 1990; Springer, 1967). Branstetter (1990) goes on to suggest that the young of slow growing species utilize protected nursery areas, where there would be low predation reducing juvenile mortality. He also suggested that fast growing species or those with large young, could utilize areas that would afford little protection from predation (Branstetter, 1990). For blacktip and spinner sharks, both species with relatively fast growth rates, Branstetter (1990) noted that pups increase at > 20 cm in the first six months and apparently continue to grow through the first winter after they move offshore. These sharks return the following spring when they are between 90 - 100 cm (depending on the species) and remain until they attain a size that may deter predators, and actively avoid predation.

Bass (1978) has defined nursery areas into two types; primary and secondary nurseries. Primary nurseries are those areas where partution occurs and where the young live for a short time. Secondary nurseries are those in which the juveniles occur after leaving the primary nursery and before reaching maturity. It is probable that the region in which the menhaden fishery operates includes both primary and secondary nursery grounds for sharks. However, more detailed studies would be required to evaluate this hypothesis.

Most shark nurseries are located in high productivity areas such as coastal marshes, estuaries or sea grass and mangrove ecosystems (Castro 1993). The nearshore area of the northcentral Gulf of Mexico where the menhaden fishery operates is classified as such an area (Deegan and Thompson, 1985). Description of the physical settings of the shark nursery in Bulls Bay, South Carolina by Castro (1993) characterize the area as 1 to 4.5 km from the beach in waters 2 to 4 m in depth. It appears the majority of sets sampled in our study were in physical conditions

similar to those described by Castro (1993). The majority of sets sampled were at depths less than 5.3 m. Furthermore, for the 1992 and 1993 menhaden fishing seasons, Leard et al. (1995) noted that 60% of the fishing effort was in waters 3 miles (4.8 km) or less from the shore.

Springer (1967) speculated that within these nursery areas the predation on young sharks is minimal, since the major predator of young sharks are larger sharks that usually do not inhabit these shallower areas. Based on the size range of sharks observed in this study, with the exception of bull sharks, there may be some evidence for the lack of larger sharks in these coastal areas. During this study Atlantic bottlenose dolphins, *Tursiops truncatus,* and crevalle jack, *Caranx hippos,* were the other common large predators associated with menhaden schools. While bottlenose dolphins were observed chasing the schools, they were almost never caught within the purse seine, but our visual observations suggest they were targeting the menhaden. Stomach analyses of crevalle jacks indicated they were primarily feeding on gulf menhaden. If one assumes there are few large predators within this habitat that could feed on juvenile sharks, it is possible that the recreational and commercial fishers may be an important source of mortality on juvenile sharks while they are in these nursery and pupping grounds.

Estimates of annual bycatch for the entire fishery during 1994 and 1995 were 35,989 and 33,069 sharks, respectively. The patchy distribution of sharks affects the range in the confidence intervals for our estimates, particularly those for 1994. As such, we also used the bootstrap method which may be a more appropriate technique for such data. Based on our description of the fate of sharks in the menhaden fishery, approximately 33,006 and 30,328 sharks would have died or been released in poor

condition during 1994 and 1995. Of these sharks, identified large coastal sharks would have equaled 27,953 in 1994 and 25,685 in 1995. Demographic models for large coastal sharks have highlighted the importance of juvenile mortality on stock production (NMFS, 1996a). The 1996 SEW noted the need to consider juvenile shark mortality from all sources, not just the directed fishery, and the importance of increasing juvenile survival. For blacktip sharks, the major species encountered in this study, the fishery in the Gulf of Mexico is juvenile-based (NMFS, 1998). There is concern that the nature of the blacktip shark fishery, together with the lack of knowledge on the fishery dynamics of this species, could result in future population declines (NMFS,1998). Using commercial landings as a benchmark to assess the magnitude of the shark bycatch, the serious injury/mortality of large coastal sharks for the menhaden fishery would have been equivalent to 14.7% of the commercial landings of large coastal sharks (NMFS, 1996a) in 1994 and 16.0 % in 1995. However, to readily enable standardized comparisons of bycatch mortality, we believe there is a need for guidelines to be set (e.g., within the framework of a management plan). A parameter, conceptually similar to the potential biological removal rate, as used in marine mammal stock assessments (e.g., Waring et al., 1997), could be a useful tool for such comparisons.

Given the current Federal management measures for both large and small coastal sharks and the current 1998 semiannual quotas of 642 t dressed weight (approximately 32,300 sharks) for large coastal sharks (NMFS, 1997a) and 880 t dressed weight for small coastal sharks (NMFS, 1997a), the incidental mortality of sharks in the menhaden fishery requires further study, in particular with respect to describing the biology of those sharks impacted.

Due to the strong positively skewed distribution of shark bycatch we used the loglinear/logit models to discern patterns in their distribution (de Silva and Condrey, 1998). Our analysis indicates temporal patterns to the shark bycatch. Between June and August, the odds of observing sharks in the menhaden catch were significantly higher than towards the end of the fishing season (September-October). Furthermore, for the early part of the 1995 fishing season (April-May), the odds of observing a fishing set with sharks was also greater than at the end of the season for fishing areas east of 93^0 West. This may be particularly important as this includes the pupping period for blacktip and spinner sharks which is from April to June (Compagno, 1984b). The importance of these events are also heightened by the distribution of fishing effort. In 1995, 88% of the sets sampled were associated with active fishing by other menhaden boats in the general area (3 to 40 % of the fleet).

While assessments and management associated with the Secretarial Plan for Sharks does not address bycatch of sharks in the gulf menhaden fishery, we were interested in using the currently proposed regulations, such as the permitted bycatch fishery being allowed to land a maximum of four sharks per day (NMFS, 1996b), to evaluate areas-seasons where the odds of observing such an event would be higher than normal. Overall, approximately one third of the fishing days we sampled had a total shark bycatch that exceeded four sharks/day. Our contrasts indicated that we could not discern inter-year differences in the odds of observing more than four sharks/day for June-August and September-October. During the 1995 fishing season, the odds of observing a fishing day with more than four sharks was significantly higher for zone 14-16 in April-May than all other zones during the rest of the fishing seasons and could be described as a hot spot.

Since these results suggest that an arbitrary imposition of a landing of four sharks/day limit might have a general and negative impact on the menhaden fishery, we were interested in the possible impact of this and other hypothetical actions to reduce the take of sharks in the fishery, which are in keeping with our philosophy of searching for potential solutions described earlier. In examining these hypothetical management goals a 50% reduction in shark bycatch mortality, consistent with that of NMFS (1996a), was taken as a benchmark.

As such, we recalculated our estimates of shark bycatch for the 1995 fishing season under 12 actions representing three policies (Table 3.5). While these calculations are theoretical, they provide insight on the effectiveness of different ways to reducing shark bycatch. The first policy approach was based on the results of our logit analyses. Here we consider policies that concentrate on reducing bycatch in season-areas with high statistically significant odds of observing a fishing set with sharks. These were areas where the odds of capturing sharks with the menhaden school were aggregated in space and/or time (actions 1 through 6, Table 3.5). We also evaluated the impact of the size of the menhaden catch, a significant factor in our model, by considering two scenarios (actions 7 and 8, Table 3.5) taking into account a reduction in shark bycatch for fishing sets greater than 52,500 std. menhaden. An example of a practical solution to using such information could be implementation of a reduction device, such as a modified hose cage (Rester, 1996), for those specific area-seasons or fishing sets.

The second policy approach was based on minimizing the take of sharks when more than four per set were encountered (actions 9 and 10, Table 3.5). These infrequent events accounted for approximately 10% of the sets we sampled, and at

Table 3.5. Hypothetical examples of the potential reduction in the take of sharks for twelve approaches based on the number of sharks caught during the 1995 gulf menhaden season.

	Total	% Reduction
Shark Bycatch	33,069	
Baseline - 50% reduction of sharks over entire fishery	16,534	50.00
1) 50% reduction of Sharks > 1m in July-August	26,987	18.39
2) 50% reduction of all Sharks in July-August	23,362	29.35
3) 50% reduction of sharks > 1m. in April-May for Areas 11 to 16	29,367	11.19
4) 50% reduction of all sharks in April-May for Areas 11 to 16	27,269	17.54
5) 50% reduction of sharks > 1m. in July-August and April-May for Areas 11 to 16	23,285	29.59
6) 50% reduction of all sharks in July-August and April-May for Areas 11 to 16	17,563	46.89
7) A maximum take of 4 sharks for all sets where the menhaden catch exceeds 52,000 std. menhaden	23,527	28.85
8) A maximum take of 1 shark for all sets where the menhaden catch exceeds 52,000 std. menhaden	19,578	40.80
9) A maximum take of 1 shark for all sets which encounter more than 4 sharks.	11,928	63.93
10) A maximum take of 4 sharks for all sets which encounter more than 4 sharks	18,344	44.53
11)A maximum take of 4 sharks for all sets with more than 4 sharks for July-August	24,431	26.12
12)A maximum take of 4 sharks for all sets with more than 4 sharks for April-May in Areas 11 to 16	24,925	24.63

the level of the individual fishermen were probably considered insignificant. However, they do make a significant contribution to the bycatch mortality of sharks. The implementation of a program to reduce bycatch using such criteria could be based on avoidance techniques instigated by the fishermen, or by taking extra care to release sharks alive during these infrequent encounters. For example, many of the sharks encountered tend to be gaffed out of the net during the pumping operation and thrown overboard at the end of the set. Developing a technique to increase the number for sharks released live during these infrequent but abundant occurrences may be a feasible solution. Alternatively, determining if the occurrence of such incidences can be reduced by minor changes in fishing practices or be accounted for by specific fishing conditions may also prove to be effective.

The third policy approach was to consider a mixture the two previous approaches of reducing the take of sharks when more than 4 sharks/set occurred for area-seasons and in which the odds of observing shark bycatch was high (actions 11 and 12, Table 3.5).

Our recalculations revealed that reaching a 50% reduction in mortality could theoretically be approached by at least three of the twelve scenarios. Our policy approach based on minimizing the mortality of sharks when more than four per set were encountered was the most effective in approaching our goal. Here both actions tried were promising. Action 9 (Table 3.5), minimizing the take to 1 shark/set when more than 4 sharks/set were encountered, was the most effective with a 64% mortality reduction. Action 10 (Table 3.5), minimizing the take to 4 sharks/set when more than 4 sharks/set were encountered, was less effective with a mortality reduction of 45%.

Of the actions based on the results of the logit analysis, action 6 (Table 3.5), with a 47% mortality reduction, would also near our goal of a 50% reduction in shark bycatch. Though this is a fairly broad area-season, encompassing Zones 11 to 16 from April to August, it leaves the western region of the fishery unaffected throughout the whole fishing season.

Our simulations, while not all encompassing, do highlight the potential benefit in considering the importance of the unusual event in developing conservation guidelines. Restrictions which apply only when the affected bycatch is abundant may well serve the dual role of conservation and industry acceptance as long as they do not imbalance the complex shark species interactions with the fishery.

Hoenig and Gruber (1990) noted that the relationship between stock and recruitment in elasmobranchs is direct because of their reproductive strategy of low fecundity combined with a few but well formed offspring. The 1996 shark evaluation workshop (NMFS, 1996a) noted that recovery of the shark stocks is more likely to occur with a 50% reduction in effective fishing mortality. The workshop suggested that in addition to the basic quota stock recovery could be achieved through other strategies such as the implementation of minimum sizes, differentially reducing fishing mortality on females, and season closures to protect reproductive females and young of the year. Given the current status of shark stocks in the Atlantic and Gulf of Mexico coupled with the life history characteristics of these species, the incidental mortality on juvenile and young of the year sharks in these nursery areas by fishers, may play a major role in the future health of shark stocks in the region. While we have highlighted the relationship of the gulf menhaden fishery to sharks in the region, information on the interaction of other shark resource users in the region is scarce. Such information

needs to be collected, together with studies to determine the importance of the nearshore habitat of the northcentral Gulf of Mexico as a shark nursery ground.

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CHAPTER 4

BOTTLENOSE DOLPHIN-BROWN PELICAN-MENHADEN FISHERY INTERACTIONS WITH AN ASSESSMENT OF THE INCIDENTAL MORTALITY OF BOTTLENOSE DOLPHINS BY THE FISHERY

Introduction

The nature and extent of non-lethal species interactions with commercial fisheries

There is an increasing awareness of the necessity to understand that fisheries are an important, integral part of the ecosystems in which they operate (e.g Condrey and de Silva, in press; Hutchinson, 1996). Their impacts are broader than the direct impacts on their target species, bycatch species, and environments which come in contact with their gear.

Two potentially important roles often occur with fisheries on schooling species. In one, fishers use the presence of nonhuman predators to locate schools of fish (e.g., Allen, 1985; de Silva and Boniface, 1991). In the other, nonhuman predators have learned to use the fishery to locate and capture live fish (Leatherwood, 1975). When both of these occur in the same fishery, the potential exists for the fishery and the nonhuman predators to develop an almost symbiotic relationship. This potential is especially present when the nonhuman predators are birds or mammals, because of their greater ability to learn.

The importance of such nonhuman interactions have been incorporated into the management policies governing the Southern Ocean (Beverton, 1985) and in the management of tuna in the eastern Pacific Ocean (Allen,1985). For example, the 1981 Convention on the Conservation of Antarctic Marine Living Resources, requires the Southern Ocean to be managed on an ecosystem basis (Beverton, 1985). Beverton

(1985) noted that in practice such a policy meant "taking into account of whatever significant interaction exists between the main components of the ecosystem - whales, seals, birds, squid, fish and krill".

Marine mammal-fishery interactions are categorized into operational and biological (ecological) interactions (Beverton, 1985; Earle, 1996). Operational interactions are when marine mammals become involved in fishing operations to the detriment of fishers and/or the mammal. Biological or ecological interactions are those interactions that arise mainly as a result of the marine mammal being a predator on fish or invertebrate marine organisms which are also exploited commercially, or which are the food of other commercially important species (Beverton, 1985).

We have been studying bycatch in the gulf menhaden, *Brevoortia patronus*, fishery (de Silva and Condrey, 1997). This is a large volume reduction fishery operating in the northcentral Gulf of Mexico which primarily searches for and harvests large schools of gulf menhaden. It is a healthy fishery, currently operating at about a 50% spawning stock biomass (Vaughan et al., 1996).

During our first year of sampling bycatch in this fishery (1994), it became apparent that, while the incidental capture of bottlenose dolphins encircled by the pursed menhaden seine was exceedingly rare (operational interaction), dolphins were frequently observed in the immediate vicinity of where a set was being made (biological interaction). During the same period, it also became apparent that while the primary criteria for identifying menhaden schools were "color" or "whip" (Leard et al., 1985), some vessel captains also looked for signs of diving brown pelicans, *Pelecanus occidentalis,* as an indicator of menhaden.

While the relationship between birds, dolphins and fish schools has been documented (e.g., Gallc-Reynoso, 1991) information on seabird-dolphin-fishery interactions in the Gulf of Mexico and the gulf menhaden fishery in particular have not been documented. However, interactions between fisheries and seabirds (e.g., Nettleship et al., 1984) and between dolphins and fisheries have been documented in certain regions (e.g., Au and Pitman, 1986; de Silva and Boniface, 1991; Simmonds and Hutchinson, 1996),

The previous work of this author has resulted in the use of fisheries sampling programs to collect information on fishery-dolphin interactions and describe the incidental marine mammal mortality in Sri Lanka's drift gillnet fishery (de Silva and Boniface, 1991; Dayaratne and de Silva, 1991). As such, for the second year of sampling, we were interested in collecting information on the presence/absence of dolphins and pelicans and describing their association with the fishery.

As a primary objective, we examine the bottlenose dolphin-brown pelican-gulf menhaden fishery associations over the eastern and central range of the fishery and comment on other fishery-seabird associations.

Prey capture associations between seabirds, marine mammals and fish

Prey capture associations between seabirds and marine mammals are considered to benefit both groups in searching for food and is considered to be a form of commensalism with the appearance of being opportunistic (Gallo-Reynoso, 1991). Associations between dolphins and seabirds feeding on shoals of fish have been noted in the Gulf of California for the common dolphin, *Delphius delphius*, and bottlenose dolphin (Gallo-Reynoso, 1991; Ballance, 1992). Brown and Nettleship (1984) noted that capelin, *Mallotus villosus*, are a important component in the food

web of seabirds, marine mammals and fish in Newfoundland. Concentrations of seabirds in the area consume about 7200 t of capelin during the breeding season, June to August. Annual consumption rates of capelin by seabirds in Newfoundland is of the same order of magnitude as that by seals and whales and one-tenth that of Atlantic cod, *Gadus morhua,* (Brown and Nettleship, 1984).

In other marine ecosystems studies have shown that seabirds can consume between 20-30% of the estimated annual fish production (Weins and Scott, 1975; Furness, 1978; Furness and Cooper, 1982). With the increasing utilization of marine resources, changes to the marine ecosystem can influence non-target species through the alteration in availability, quantity or quality of their food supply (Furness, 1984). For example, while the location of breeding sites strongly influence feeding distribution patterns, fisheries have been also have an impact on these patterns on a smaller scale (Garthe and Hüppop, 1994).

The incidental capture of bottlenose dolphins in the gulf menhaden fishery

A secondary objective of this paper is to determine the nature of the relationship between the rare incidental capture of dolphins and the occurrence of dolphins in the immediate vicinity of a set while it was being made. Our hypothesis is that areas or seasons with above average occurrences of dolphins in the immediate vicinity would be associated with a greater likelihood of incidental capture. The purpose of testing this hypothesis was if true, it could be used as an indicator of areas or seasons where extra caution should be taken by the fishery.

Read (1996) noted that a systematic review on the impact of mortality in purse seines on populations of small cetaceans is lacking. Currently such work has only been carried out for drift gillnet fisheries (Northridge, 1991). Read (1996) also

suggested that purse seines used to capture small fishes, which are important prey items for many marine mammals, could potentially result in the high incidental capture of small cetaceans such as dolphins.

Bottlenose dolphin groupings in relationship to the area covered by the gulf menhaden fishery

The gulf menhaden fishery operates within a region covered by three bottlenose dolphin groupings as they have been defined for management purposes. These are: 1) the western Gulf of Mexico coastal stock, 2) the northern Gulf of Mexico stock and 3) the Gulf of Mexico bay, sound and estuarine stocks (Waring et al., 1997).

The western Gulf of Mexico coastal bottlenose dolphin stock extends from the Texas-Mexico border to the mouth of the Mississippi River and from the shoreline barrier islands or bay boundaries of this region to 9.3 km seaward of the 18.3 m isobath (Waring et al., 1997). Bottlenose dolphin abundance for this stock has been estimated at 3,499 dolphins (Waring et al., 1997).

The northern Gulf of Mexico coastal stock extends from the mouth of the Mississippi River eastward to approximately 84^0 W longitude and from the shoreline, barrier islands or bay boundaries to 9.3 km seaward of the 18.3 m isobath (Waring et al., 1997). Bottlenose dolphin abundance for this population has been estimated at 4,191 dolphins (Waring et al., 1997). In comparison to these two stock groupings, the range of the gulf menhaden fishery extends from Alabama to eastern Texas.

Bottlenose dolphins inhabiting bays, sounds and adjacent estuaries are treated as discrete stocks in the U.S. Gulf of Mexico (Waring et al., 1997). There are five Gulf of Mexico bay, sound and estuarine stocks included within the geographic region of the menhaden fishery. These are: 1) Vermilion Bay-West Cote Blanche Bay-Atchafalaya Bay, 2) Terrebonne Bay-Timbalier Bay, 3) Barataria Bay, 4) Mississippi

River delta, and 5) Bay Boudreau-Mississippi Sound. Within these stocks, the Bay Boudreau-Mississippi Sound and the Mississippi River delta stocks are associated with the geographic region where most of the bay/sound/estuary menhaden fishing effort is conducted. The population for the Bay Boudreau-Mississippi Sound area has been estimated at 1,401 dolphins. There are no population estimates for the Mississippi River delta stock. A small portion of the menhaden fishing effort takes place within the area covered by the other three bay/sound/estuarine bottlenose dolphin stocks, for which the combined population is estimated at 319 dolphins (Waring et al., 1997).

Under the Marine Mammal Protection Act of 1972, the gulf menhaden fishery is considered a Category III fishery (NMFS, 1998). "A Category III commercial fishery is one that has a remote likelihood of causing incidental mortality and serious injury of marine mammals and which collectively with other fisheries is responsible for the annual removal of 10 % or less of any marine mammal stock's potential biological removal level (PBR) or more than 10% of any marine mammal stock's PBR, yet the fishery itself is responsible for the annual removal of 1 % or less of that stock's PBR" (50 CFR Part 229.2). The potential biological removal level is defined as the maximum number of animals that may be removed from a marine mammal stock by human activities, and still allows the stock to reach or maintain its optimum sustainable population (50 CFR Part 229.2).

Brown pelican populations in Louisiana

The eastern brown pelican suffered a catastrophic population decline in the 1960's and was extirpated from Louisiana by 1963 (Mc Nease et al., 1984). Direct toxicity of endrin was identified as a probable cause for extirpation of the species in Louisiana (Blus et al., 1979) Since 1968, brown pelicans have been reintroduced into

Louisiana to reestablish the species to its historic nesting grounds that extend from North Island in the Chandeleur chain to Isle Dernieres (Figure 4.1; Wilkinson et al., 1994). Since this reintroduction, the Louisiana population has recovered dramatically and the nesting range of this species has expanded considerably (Visser and Peterson, 1994). However, brown pelicans are listed under Endangered and Threatened Wildlife and Plants for all regions, except the U.S. Atlantic coast, Florida and Alabama (50CFR Part17). Wilkinson et al. (1994) estimated a total of 1,443 brown pelican nests in five colonies for Louisiana in 1990. Recent estimates indicate the presence of 10,250 breeding brown pelicans in Louisiana in 6 colonies (Visser and Peterson, in preparation).

Materials and Methods

Sampling protocol

As we have previously reported, we conducted routine onboard sampling of bycatch in the U.S. Gulf of Mexico menhaden fishery during the 1994 and 1995 fishing seasons by alternatively using two methods to measure the automatically retained bycatch and the releasable bycatch (de Silva and Condrey, 1998). During both these sampling periods, the initial incidental capture and ultimate fate of dolphins encountered were recorded.

In 1994 twenty-four, week-long trips aboard commercial menhaden vessels were made June through October. During this period a total of 455 fishing sets were sampled, equivalent to 1.74 % of the total fishing effort for the fishery. During 1995 twenty-seven, week-long sampling trips were made April through October. A total of 450 fishing sets were sampled, equivalent to 2.12 % of the total fishing effort of the fishery. During both years the entire geographical range of the fishery was sampled

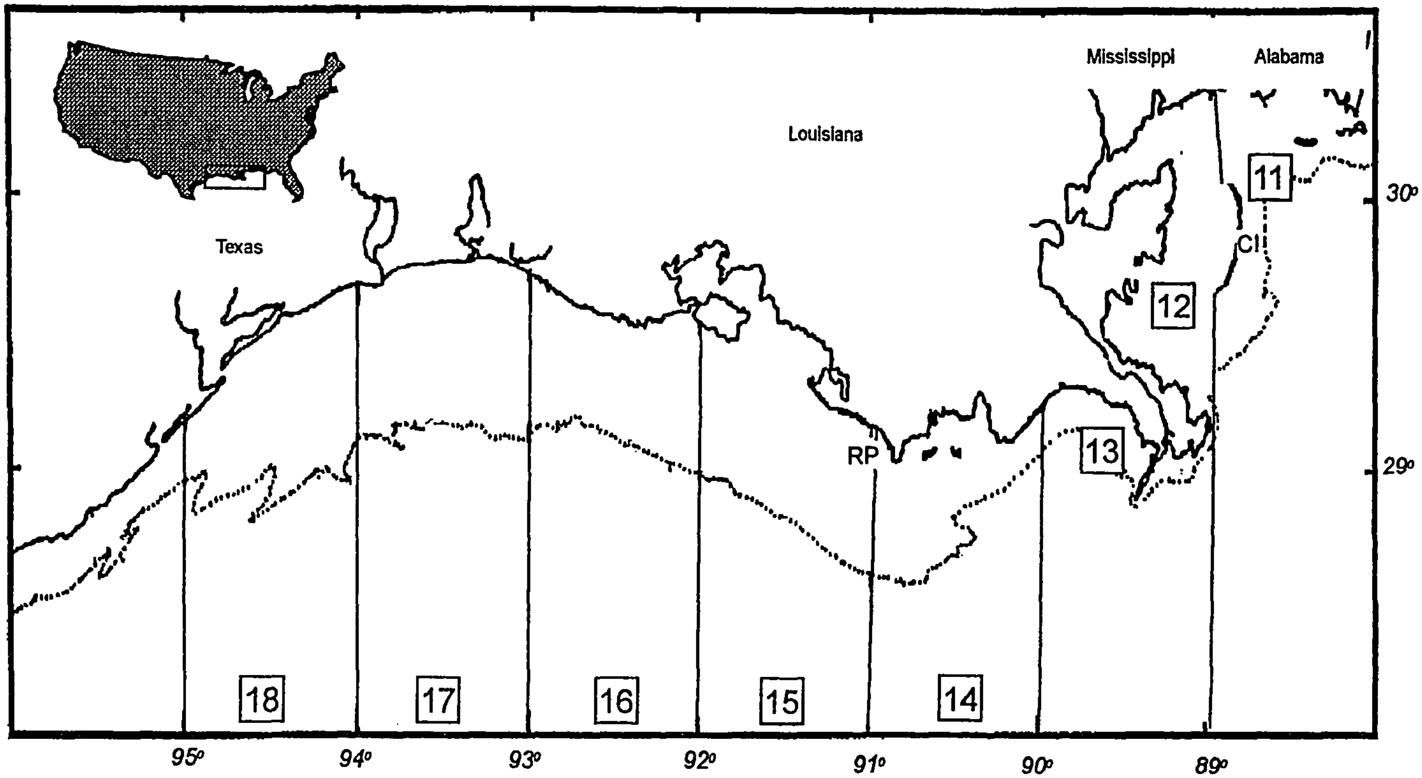

Figure 4.1. Map encompassing the extent of the U.S. gulf menhaden fishery along the Texas to Alabama coasts and the range of brown pelican breeding sites. RP= Racoon Point. CI=Chandeleur Island.

every other week by boarding vessels from ports in the western, central and eastern regions to the maximum extent possible. The fishery primarily operates in the coastal waters from Dauphin Island, Alabama to eastern Texas. For all fishing sets, the location in latitude and longitude was recorded from the vessel's Loran system or determined by using navigation charts and observations made by the vessel's captain.

In 1995 we instituted a new procedure for recording those bottlenose dolphins and brown pelicans which were in the "*immediate area of the set*" (*Figure 4.2*). We defined the immediate area of the set as the line of vision of an observer on the carrier ship whose eyes were trained on the direction the purse boats took from the moment they proceeded toward the area where a set was to be made until the setting of the seine was completed. Within this area and time, the number of dolphins observed were recorded. The presence of pelicans diving or circling in the area prior to the set being made were also recorded. Our definition of "immediate area of set" was chosen so as to be most representative of events where the fishery interacted with bottlenose dolphins and brown pelicans. Observations on other bird species-associations in the area of fishing activity were also recorded during some trips. While we do not use these observations in the statistical analysis, we discuss them as preliminary findings in our discussion.

Using the location of the fishing set and navigational charts, we classified each set into one of three depth stratums: $\leq$ 5.48 m; > 5.48 m and $\leq$ 9.14 m; and > 9.14 m, which correspond to the 3, 5 and 10 fathom depth contours.

<u>Statistical analysis</u>

Estimates of the proportion of sets ($\hat{p}$) (Scheaffer et al., 1986) in which: 1) dolphins were caught in the menhaden fishery (1994 and 1995 combined), 2)

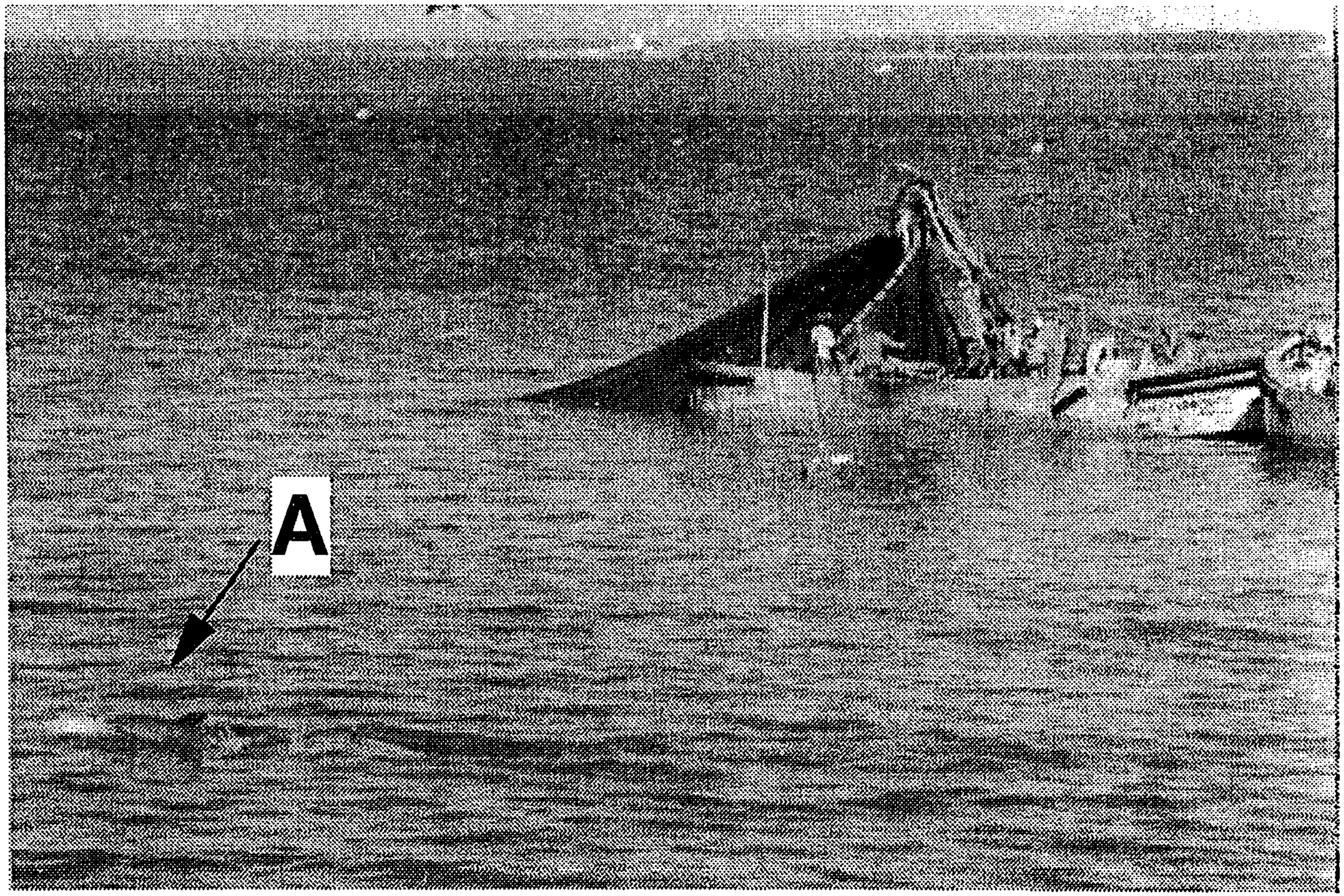

Figure 4.2. An example of a bottlenose dolphin observed outside the net in the immediate vicinity of the fishing operation (A). In this instance the dolphin was observed during the entire fishing operation.

dolphins were sighted in the immediate vicinity of the set (1995) and 3) pelicans were encountered prior to the set being made (1995) were calculated using:

$$\hat{p}=\frac{\sum_{i=1}^{n} y_i}{n}$$

where y_i= occurrence of the event in set i; and

n= number of sets sampled.

The estimated variance $\hat{V}(\hat{p})$ of ($\hat{p}$) was calculated as:

$$\hat{V}(\hat{p})=\frac{\hat{p}\hat{q}}{n-1}\left[\frac{N-n}{N}\right]$$

where ($\hat{q}$) = 1-($\hat{p}$); and

N= the total number of fishing sets made by the fishery.

The total number of fishing sets (N) was provided to us by the National Marine Fisheries Service Beaufort Laboratory (personal communication Joseph Smith, unpublished captains daily fishing report data, 1997).

The flexibility of loglinear/logit models in exploring categorical information has been highlighted in earlier chapters. In this study the loglinear form was used as there was no defined response variable of interest. Loglinear models were used to examine the association of dolphins in the immediate vicinity of sets, diving or circling brown pelicans prior to the fishing set being made, and their relationship to fishing season and area. During our study, diving or circling brown pelicans were not observed on fishing grounds west of 93^0 N (Figure 4.1). As such, our dolphin-pelican-fishery

analysis is limited to fishing zones east of 93^0 N. For these models, we used the unit of effort (the fishing set) as the count. For the analysis, dolphins (D) was a dichotomous variable where we classified each set sampled as presence or absence of dolphins. The variable season (S) had three classes; April-May 1995 (spring); June-August 1995 (summer); September-October 1995 (fall). The variable area (A) consisted of two classes; Area 11-12 corresponding to fishing grounds between 88^0 N and 89^0 N (east of the Mississippi River); and Area 13-16 corresponding to fishing grounds between 89^0 N and 93^0 N (west of the Mississippi River). Based on season-area groupings, the Kolmogorov-Smirnov two-sample test indicated that our sampling distribution was not significantly different to that of the overall effort by the fishery, ($|D|=0.072$, $P = 0.05$). Pelicans (P) was a dichotomous variable where we classified each set sampled as presence/absence of diving or circling pelicans prior to the set being made. Prior to conducting the analysis, a constant 1×10^{-9} was added to cells with zero counts (Agresti, 1990). For this analysis, only the cell representing the spring season for the area east of the Mississippi River, associated with the presence of dolphins and absence of brown pelicans in the vicinity had a zero count.

Beginning with the four-way saturated loglinear model [DSAP] we used the backward selection procedure described by Agresti (1990) to find the simplest loglinear model that had a fit as good as the saturated model. For the selection criteria of our final model, we chose a p-value of at least 0.05 that the model had to meet. The highest significant interactions ($p \leq 0.05$) in the model are described using the estimated odds (ratio of probabilities of observing two mutually exclusive events) and odds ratios, calculated from the parameter estimates derived from the model.

The relationship between menhaden catch in standard menhaden (1000 standard menhaden ~ 305 kg), dolphins and pelicans was examined using a two-way ANOVA. For this model the response variable was log (menhaden catch) with dolphins (presence or absence), pelicans (presence or absence), and their two-way interaction as explanatory variables.

Results

Atlantic bottlenose dolphins and brown pelicans associated with the gulf menhaden fishery

During 1995 a total of 450 sets were observed for the presence of dolphins in the immediate vicinity of a set. We estimated the proportion of sets during which dolphins were observed as 0.1933 (19.33%) with a 95% confidence interval ranging from 0.1512 to 0.2354. For those sets where dolphin were observed in the immediate vicinity of the set, their numbers per set ranged from 1 to 20 (mean= 5.78, s^2= 18.77, n= 87).

Of the total instances when dolphins were observed in the immediate vicinity of a set, 78 % were in depths $\leq$ 5.48 m and 21 % were in depths > 5.48 m and $\leq$ 9.14 m. For sets made in the deeper waters >9.14 m, the number of total sets observed was low (n=21, 4.6 % of all sets sampled) and only one set was observed with dolphins in the immediate vicinity. The depth distribution of sets with dolphins in the immediate vicinity were not different to those sets in which dolphins were not observed (df= 2, G^2= 4.637, $P > \chi^2$= 0.098).

For 1995, the proportion of sets during which pelicans were seen diving or circling prior to the set being made was 0.233 (23.3%) with a 95% confidence interval ranging from 0.1912 to 0.2754. Eighty-six percent of the sets in which diving or circling pelicans were observed were at depths $\leq$ 5.48 m, 12 % were at depths > 5.48 m and

$\leq$ 9.14 m, and 2% at depths > 9.14 m. Sixty-eight percent of sets with no pelicans were sampled in water $\leq$ 5.48 m in depth, 26% of those sets were in depths greater than 5.48 m and $\leq$ 9.14 m, and 6% at depths > 9.14 m. The depth distribution of sets where pelicans were sighted were different from sets where no pelicans were observed (df= 2, G^2= 13.853, P > χ^2= 0.001).

Dolphin-pelican associations with fishing areas and seasons

Using the backward selection procedure (Table 4.1), we concluded that the loglinear model with pelican-season-dolphin, dolphin-season-area, and pelican-season-area terms [DPS DSA PSA] was the simplest model that provided a fit as good as the saturated model (G^2= 1.28, df= 3, P>χ^2= 0.7349). Since each of the three-way interactions represents heterogeneity of association between two variables across the third, we used the nested procedure described by Stokes et al. (1995) to interpret the association patterns. As the season term was common to all three-factor terms, we nested each three-factor term by season (Table 4.2). Using this procedure a simpler model with selected three factor terms met our selection criteria (G^2= 13.46, df= 8, P>χ^2= 0.0968; Table 4.3). This model can be described as:

$$\log m_{ijkl}=\mu+\lambda^{P}{}_{i}+\lambda^{A}{}_{j}+\lambda^{S}{}_{k}+\lambda^{D}{}_{l}+\lambda^{PS}{}_{ik}+\lambda^{AS}{}_{jk}+\lambda^{SD}{}_{kl}+\lambda^{DP(S=spring)}{}_{lik}+\lambda^{DA(S=fall)}{}_{jlk}+\lambda^{PA(S=spring)}{}_{ijk}+\lambda^{PA(S=fall)}{}_{ijk}$$

Where m_{ijkl} = the expected number of sets observed with pelicans i in area j and season k and dolphins l;

i = presence or absence of brown pelicans;

j = zone 11-13, zone 14-16 or zone 17-18;

Table 4.1. Summary of stepwise selection procedure of suitable loglinear models examining the relationship among observing bottlenose dolphins (D) and brown pelicans (P) in the immediate vicinity of fishing set with fishing season (S) and area (A).

	Level	Description of Models	Loglinear Form	df	G^2	$P > G^2$
	1	Saturated Model	DPSA			
	2	All 3-way interactions	DPA PSA DSA DPS	2	1.27	0.5228
	3	With selected 3-way interactions removed	DPA DSA PSA	4	10.19	0.0374
			DPS DPA PSA	4	36.91	0.0000
Best			DPS DSA PSA	3	1.28	0.7349
			DPS DPA DSA	4	15.45	0.0039
	4	With selected 3-way and 2-way interactions	DPS PSA DA	5	38.48	0.0000
			DPS DSA PA	5	15.57	0.0082
			DSA PSA DP	5	11.88	0.0364

Table 4.2. Maximum likelihood analysis of variance table for loglinear model [DPS DSA PSA] with three-way interactions in nested form (G^2= 1.28, df= 3, $P>\chi^2$= 0.7349). Superscripts on source table denote nested terms within each three-way term: a) nested terms within DPS; b) nested terms within PSA and; 3) nested terms within DSA

Source	df	Wald χ^2	Prob > χ^2
Dolphins (D)	1	52.98	0.0000
Pelicans (P)	1	1.89	0.1697
Area (A)	1	9.48	0.0021
Season (S)	2	41.31	0.0000
Season x Area	2	9.05	0.0108
Dolphins x Season	2	0.37	0.8303
Pelicans x Season	2	15.22	0.0005
Dolphins x Pelicans(Season=spring)[a]	1	9.38	0.0022
Dolphins x Pelicans(Season=summer)[a]	1	5.90	0.0151
Dolphins x Pelicans(Season=fall)[a]	1	1.51	0.2191
Pelicans x Area(Season=spring)[b]	1	17.84	0.0000
Pelicans x Area(Season=summer)[b]	1	2.07	0.1500
Pelicans x Area(Season=fall)[b]	1	7.28	0.0070
Dolphins x Area(Season=spring)[c]	1	2.81	0.0937
Dolphins x Area(Season=summer)[c]	1	0.23	0.6305
Dolphins x Area(Season=fall)[c]	1	25.81	0.0000

Table 4.3. Maximum likelihood analysis of variance table for the simplest loglinear model describing dolphin-pelican-menhaden fishery associations (G^2= 13.46, df= 8, P>χ^2= 0.0968).

Source	df	Wald χ^2	Prob > χ^2
Dolphins (D)	1	58.83	0.0000
Pelicans (P)	1	5.50	0.0190
Area (A)	1	10.38	0.0013
Season (S)	2	36.65	0.0000
Season x Area	2	6.43	0.0402
Dolphins x Season	2	2.62	0.2699
Pelicans x Season	2	21.35	0.0000
Dolphins x Pelicans (Season=spring)	1	6.88	0.0087
Pelicans x Area (Season=spring)	1	16.28	0.0001
Pelicans x Area (Season=fall)	1	6.97	0.0083
Dolphins x Area (Season=fall)	1	27.47	0.0000

k = spring, summer or fall; and

l = presence or absence of dolphins .

The three highest order associations of the loglinear model represent two levels of biological association. The first level of association, represented by the dolphin-season-area and pelican-season-area terms, describe the spatial and temporal pattens in the association of bottlenose dolphins and brown pelicans with the fishery. The second level of association, which is biologically more complex, describes the association among pelicans, bottlenose dolphins and the fishery and is represented by the dolphin-pelican-season term. The nested factors included in the final model (Table 4.3) can be interpreted are those factors where significant differences among the variables of interest (dolphins, pelicans and areas) are observed within each season.

The significant dolphin-season-area interaction reflects differences in the odds of observing a set with dolphins in the immediate vicinity among areas for each season (Figure 4.3). During the spring and summer, the odds of observing dolphins in the immediate vicinity of a fishing set were not significantly different between areas east and west of the Mississippi River. However during the fall, it appears that the odds of observing dolphins in the immediate vicinity of a fishing set was 29 times greater for fishing grounds east of the Mississippi River than for fishing grounds west of the river and up to a longitude of 93^0 West.

The significant pelican-season-area term reflects differences in the odds of observing pelicans among areas for each season (Figure 4.4). During the spring, the odds of observing pelicans diving in the immediate vicinity of a set is 17 times greater for fishing grounds east of the Mississippi River than those odds for fishing grounds

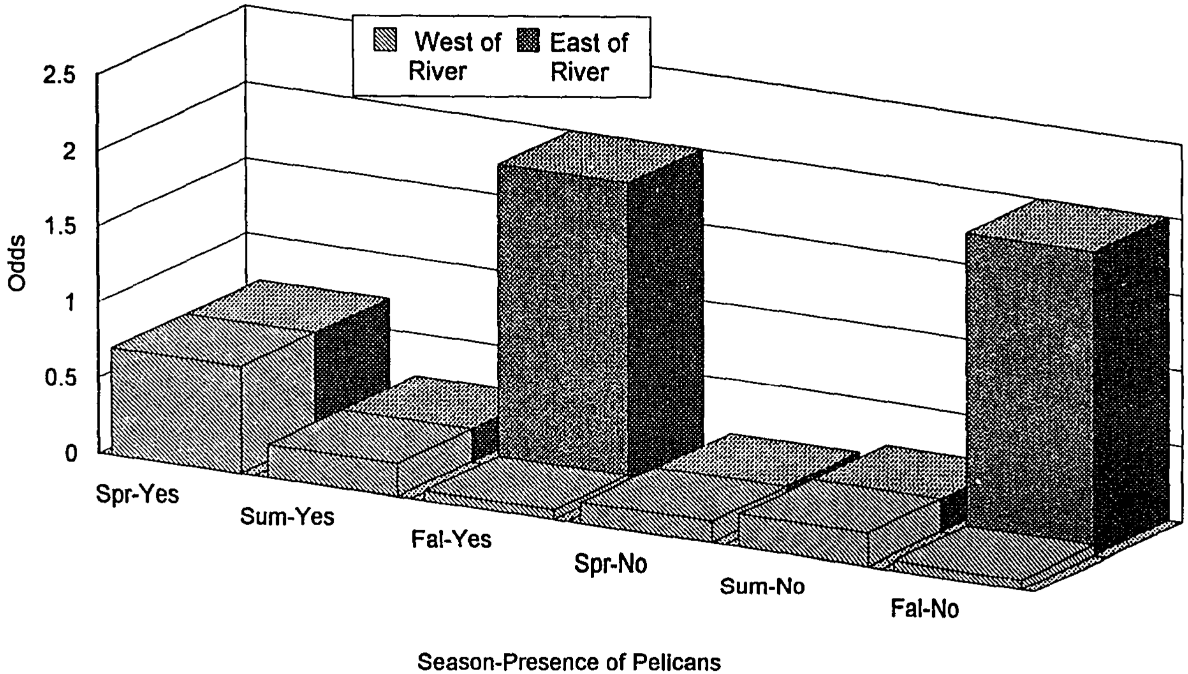

Figure 4.3. Estimated odds of observing a fishing set with bottlenose dolphins in the immediate vicinity of a fishing set by season,area and presence of diving or circling pelicans in the vicinity of the fishing set. Keydefintions: Spr=spring, Sum=summer, Fal=fall, Yes=presence of pelicans in the immediate vicinity, No= absence of pelicans in the immediate vicinity. See Materials and Methods section for definition of immediate vicnity.

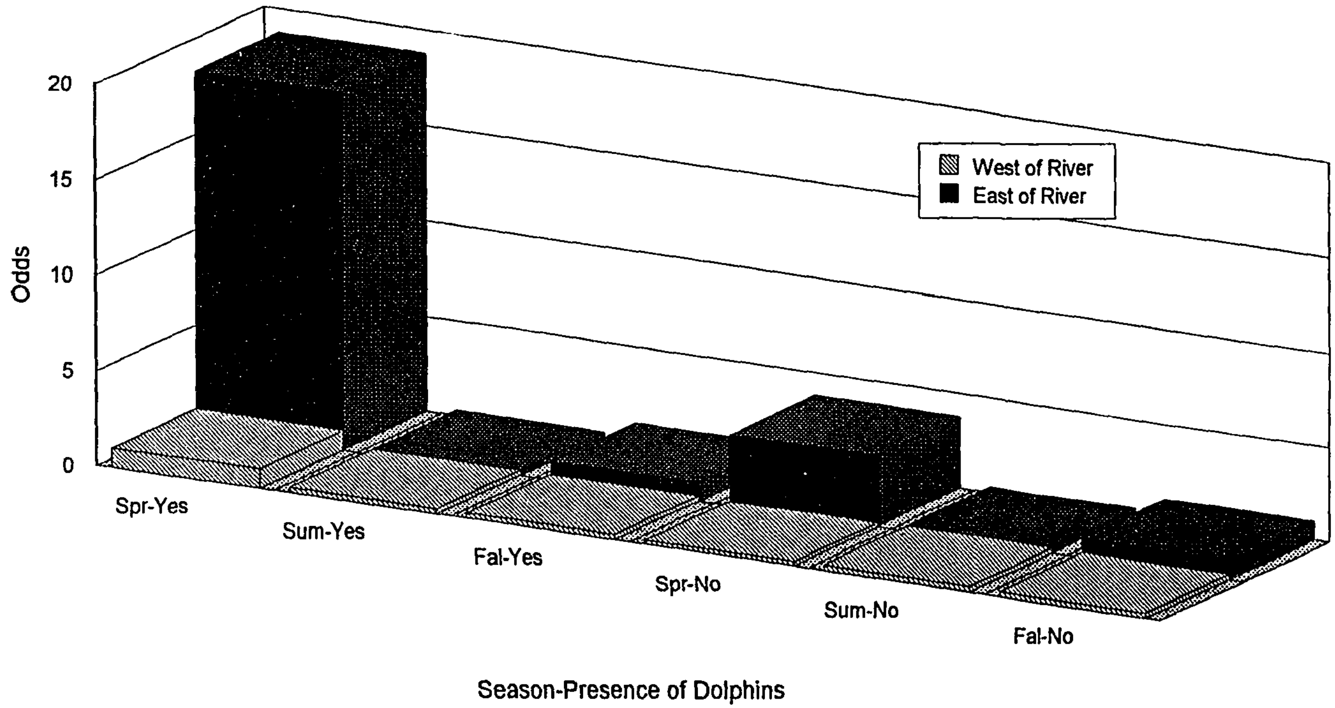

Figure 4.4. Estimated odds of observing brown pelicans in sets where dolphins were present /absent in the vicinity of a fishing set by season and area. Key definitions: Spr=spring, Sum=summer, Fal=fall, Yes=presence of dolphins in the vicinity of the fishing operation, No=absence of dolphins in the immediate vicinity of the fishing operation. See Materials and Methods section for defintion of immediate vicinity.

west of the river. During the summer, the odds of observing pelicans diving in the immediate vicinity of a set are similar on all fishing grounds. During the fall, the odds of observing pelicans diving in the immediate vicinity of a set is 3.5 times greater for fishing grounds east of the Mississippi River than those odds for fishing grounds west of the river.

The significant pelican-dolphin-season term reflects an association between pelicans and dolphins that differs among seasons. During the spring, the odds of observing pelicans in a set where dolphins were also observed was five times greater than for those sets in which dolphins were not observed. During the summer and fall, the odds of observing a set with pelicans, for sets where dolphins were also observed were similar to those sets where dolphins were not observed in the vicinity.

The ANOVA model examining the relationship of log menhaden catch to dolphins, pelicans and the dolphin-pelican interaction term were not significant (Table 4.4). The model also had a very low R-square of 0.016.

Incidental capture of bottlenose dolphins

During the two fishing seasons, we observed a total of 905 sets. In three of these sets, four Atlantic bottlenose dolphins were captured within the pursed net. The low percentage of sets with dolphins captured highlights the extremely rare occurrence of such events. Of those sets in which dolphins were captured, one occurred in 1994 and two occurred in 1995. Three of the four dolphins captured were released alive and one dolphin drowned in the net. We estimated the proportion of sets in which dolphins were captured as 0.0033 (0.33 %) with a 95% confidence interval ranging from -0.0346 to 0.0412.

Table 4.4. Analysis of variance table for log menhaden catch with dolphins, pelicans and dolphins x pelicans terms.

Source	df	Sum of Squares	Mean Square	F value	P > F
Model	3	5.787	1.929	2.55	0.055
Error	446	337.957	0.757		
Corrected Total	449	343.745			
		Type III SS			
Dolphins	1	2.525	2.525	3.33	0.068
Pelicans	1	1.952	1.953	2.58	0.109
Dolphins x Pelicans	1	0.705	0.705	0.93	0.335

Discussion

Based on our analysis of dolphin-pelican-menhaden fishery associations, a complex relationship exists among the three groups. Although the occurrence of dolphins and pelicans with the fishery is patchy in space and time, it is large in terms of the total number of interactions. Dolphins were observed in the immediate vicinity of the set in approximately 19% of the fishing sets sampled, equivalent to an estimated encounter rate of 4,086 sets for the fishery in 1995. Similarly, pelicans diving and circling prior to the set were encountered in 23% of sets sampled, equivalent to an estimated encounter rate of 4,925 sets for the fishery in 1995.

This relationship can be classified into two levels of ecological interaction: 1) those between all three components and 2) those between dolphins and the fishery and pelicans and the fishery. The three highest order interaction terms in our final model were the dolphin-season-area, pelican-season-area and the pelican-dolphin-season terms. These can be used to explain the level of ecological association and are discussed sequentially below.

While the relationship between dolphins and other commercial fisheries has been documented (e.g., Shane et al.,1986; Read,1996), little is known on the magnitude of these interactions or their relationship to the fisheries in terms of area and time. Based on the results of the loglinear analysis, it appears that spatial and temporal patterns in the presence/absence of bottlenose dolphins in the immediate vicinity of active menhaden fishing can be discerned. For both the spring and summer, spatial differences in the odds of observing dolphins were not evident. However, the odds of observing dolphins in the immediate vicinity of a menhaden set in the summer were higher than for those odds for the spring. During the fall, the odds of observing

dolphins in the immediate vicinity of a menhaden set were higher for menhaden fishing grounds east of the Mississippi River (which approximately corresponds to the range of the Bay Boudreau-Mississippi Sound bottlenose dolphin stock) than those odds for fishing grounds west of the river (which is part of the western Gulf of Mexico coastal bottlenose dolphin stock).

The season-area differences in our sightings of dolphins associated with menhaden sets may not be related to seasonal changes in dolphin abundance. Scott et al. (1989) noted that seasonal abundance estimates of dolphins in the region were not significantly different, based on 80% confidence intervals. These estimates were for the area which corresponds to the Bay Boudreau-Mississippi Sound stock and coastal Louisiana (Zones 13 to 18). However, Scott et al. (1989) had no estimates for the Bay Boudreau-Mississippi Sound stock for the spring.

It is possible that those spatial and temporal patterns we observed are influenced by both the feeding behavior of bottlenose dolphins, and seasonal abundance of the forage base of these species. Bottlenose dolphin feeding behavior is diverse and they appear to be able to take advantage of any readily available food resource, adapting their feeding methods according to food type and local conditions (Shane et al., 1986). Among the food resources dolphins are known to target are schooling clupeids. Gallo-Reynoso (1991), examining the group behavior of common dolphins during prey capture, noted that schools of Monterey sardines ,*Sardinops sagaxcaerulea*, thread herring, *Opisthonema* spp., round herring, *Etrumeus teres*, and anchoveta, *Centengraulis mysticetus,* were among the prey schools observed. Coordinated feeding behavior by Atlantic spotted dolphins, *Stenella frontalis,* on menhaden, *Brevoortia* spp., in the Gulf of Mexico has been documented by Fertl and

Wursig (1995). Leatherwood (1975) noted similar coordinated feeding strategies for bottlenose dolphins in the Gulf of Mexico feeding on schools of small baitfish thought to be menhaden. Rogers et al. (1994) noted that bottlenose dolphins were regularly seen following their trawls feeding on what appeared to be bycatch escaping from reduction devices being tested in Lake Borgne, and Lake Barre, Louisiana. Dolphin-fishery associations have been described as feeding related (Leatherwood, 1975; Shane et al.,1986). Leatherwood (1975) noted three feeding associated behaviors of bottlenose dolphins to shrimp boats and suggested that dolphins have learned the advantages of fishing-related activity in harnessing food resources. Strategies such as mud bank feeding and following shrimp boats by dolphins are characteristics that are learned by succeeding generations (Shane et al., 1986). Similar relationships between bottlenose dolphin feeding and fishing activity were noted behind a commercial beach seine in Caminada Bay, Louisiana Leatherwood (1975).

Given the opportunistic nature of dolphin feeding habits and their following shrimp boats in search of food (Shane et al., 1986), it is probable that dolphins also target menhaden vessels in a similar fashion. Shane (1990) noted that feeding bottlenose dolphins concentrated close to shore where estuaries, mud banks and mangroves provide higher prey densities and an opportunity to " corral" prey. On a few occasions, while our samplers were observing a menhaden set they noted that a dolphin was within the seine during setting, but that by the completion of the operation the dolphin had escaped.

We hypothesize that the relationship between dolphins seen in the immediate vicinity of a set and the menhaden fishery is forage based. In addition to feeding upon schools of menhaden in the vicinity, dolphins could be taking advantage of the

"corralling" of the menhaden by the fishery to opportunistically feed upon the targeted catch. The majority of fishing sets sampled were in waters less than 5.48 m in depth, which was also the depth range in which the majority of dolphin occurrences were observed.

Diving and circling brown pelicans were never observed in zone 17-18 (West of 93^0 W) . This western area of the menhaden fishery is outside the brown pelican's breeding area in Louisiana. For example, Visser and Peterson (1994) noted that brown pelicans in Louisiana appear to have recolonized historically important colony sites such as Racoon Point (latitude 29^0 04.50', longitude 90^0 59') which marks the western boundary for such areas within Louisiana (Wilkinson et al., 1994). As such, the absence of brown pelican associations with the fishery in zone 17-18 probably reflects the geographical distribution of the species. Within those areas east of zone 17-18 spatial and temporal patterns in the odds of observing diving or circling pelicans were discerned. During both the spring and fall, odds of observing pelicans were significantly higher for fishing grounds east of the Mississippi River. This is also the region where vessel captains traditionally use diving pelicans as an indicator of menhaden schools.

In our study most of the occurrences of pelicans diving or circling around sets were in waters less than 5.48 m in depth. Eastern brown pelicans primarily forage in shallow estuarine waters and in marine waters within 32 km of shore (Hingtgen et al., 1985). The brown pelican is a plunge diver capturing prey using its bill and pouch (Lowery, 1974). Food habits of the brown pelican vary within its range. In South Carolina, brown pelicans feed almost exclusively on young Atlantic menhaden, *B. tyrannus,* and in Louisiana and Texas 90-95% of the diet consists of a combination of

gulf menhaden, mullet (*Mugil* spp.) and other species not considered sportfish (Hingtgen et al., 1985). Anderson et al. (1982) noted that for brown pelicans in the Southern California Bight, the location of traditional breeding colonies most likely represents environmental conditions where nesting substrate and attainable food supplies consistently occur together.

Examination of the pelican-dolphin-season interaction indicated that the odds of observing pelicans was greater for sets also associated with dolphins than those with no dolphins in the spring. During the summer and fall, pelican-dolphin associations were not significant. For approximately 40% of the sets in which dolphins were observed in the immediate vicinity of a set, pelicans were also observed. This value is comparable to that of Au and Pitman (1986), who noted that 42.7% of delphinid schools observed in yellowfin tuna fishing grounds in the eastern Pacific were associated with bird flocks (where a flock was defined as ≥ 10 birds/flock). Ballance (1992) noted that seabirds were frequently present with feeding groups of dolphins in the Gulf of California and she suggested that circling and diving seabirds were one of the most reliable methods for locating feeding dolphins. Au and Pitman (1986) noted specific associations between dolphin and bird species, and that the size of the flock was related to the numbers of dolphins in the school.

While our statistical analyses were conducted on diving or circling pelicans, three other fishery-seabird associations were also observed. The first association involved pelicans and gulls. For many of the sets in which diving or circling pelicans were observed, gulls were also present in the area. Schnell et al. (1983) noted that laughing gulls, *Larus atricilla*, were frequently attracted to brown pelican feeding dives often behaving aggressively toward them in attempts to obtain food from them,

exhibiting a kleptoparasitic relationship. Based on our observations, a similar relationship between brown pelicans and gulls may occur while they are associated with the menhaden fishery.

The second association occurred in the interval after a set was made and before the net was completely hardened. During this time brown pelicans would be attracted to the net to feed upon the menhaden (Figure 4.5). While detailed records of all such sets were not kept, in 22 sets where such observations were noted, between 2 and 400 pelicans (mean= 27) were seen feeding on menhaden at the corkline of the seine. A detailed examination of this relationship by Rester (1996) indicated that most of those pelicans associated with these types of observations were juveniles. Rester (1996) hypothesized that this feeding behavior was advantageous to juvenile brown pelicans by helping them reap the energetic benefits of a concentrated food source during a critical period when they are still not proficient at prey capture. During our study we did not record if the diving or circling pelicans observed were juveniles or adults. As such, we cannot make any inferences on the portion of the population predominantly associated with our observations.

The third association involved gulls and terns scavenging from the nets or scraps in the pump water (Figure 4.6). While species identification of these birds were not made on all sets, the laughing gull, herring gull, *Larus argentatus,* Caspian tern, *Hydroprogne caspia* , gull-billed tern, *Gelochelidon nilotica*, royal tern, *Sterna maxima*, sandwich tern, *Sterna sandvicensis,* and frigate bird, *Frigata manificens* , were among those species identified.

Of the sets in which records of gulls/terns associated with the fishery were kept (345 sets), gulls occurred in 38 % of sets sampled in zone 17-18, 28 % of sets

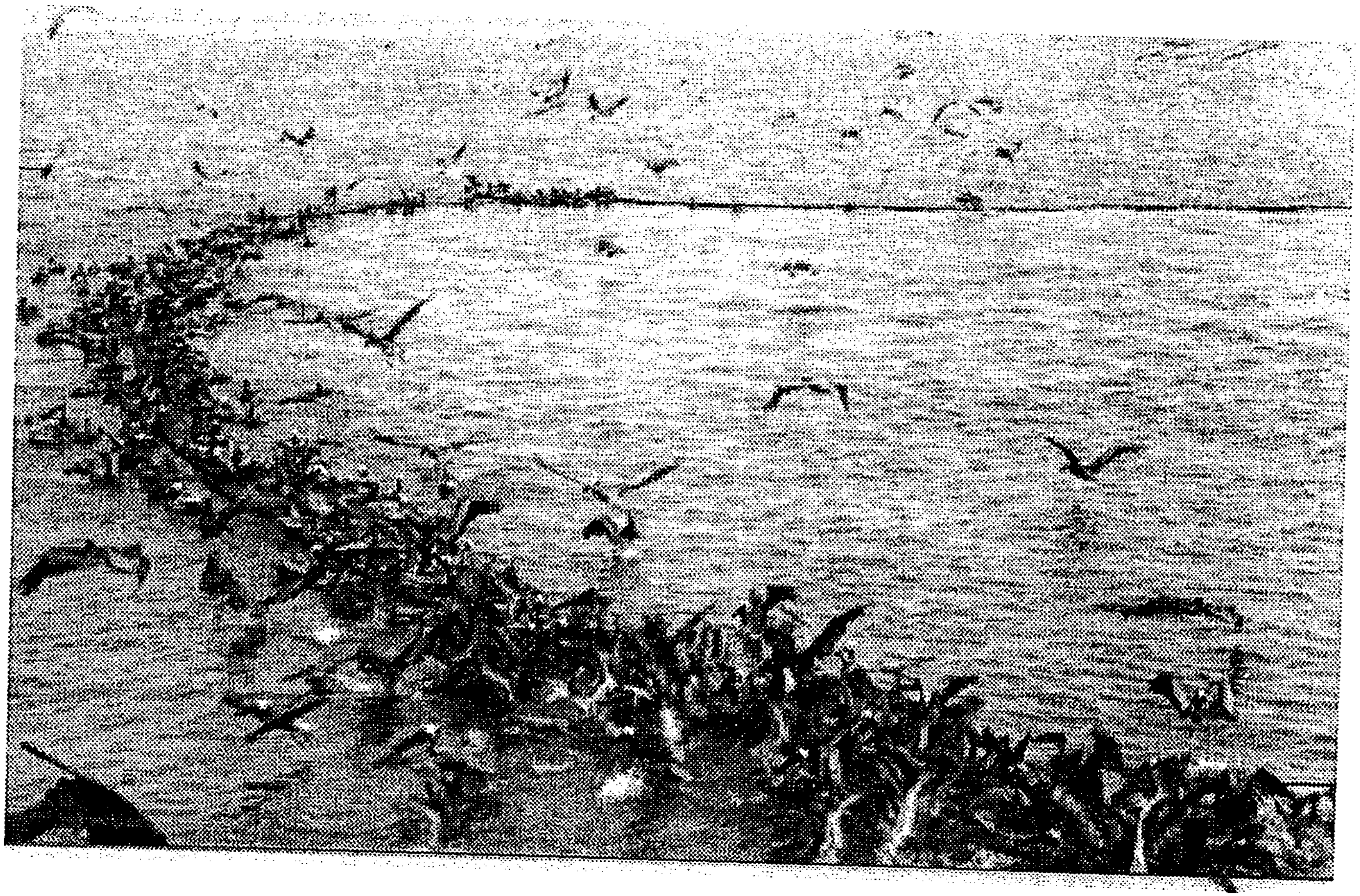

Figure 4.5. Brown pelicans attracted to the purse seine to feed upon menhaden.

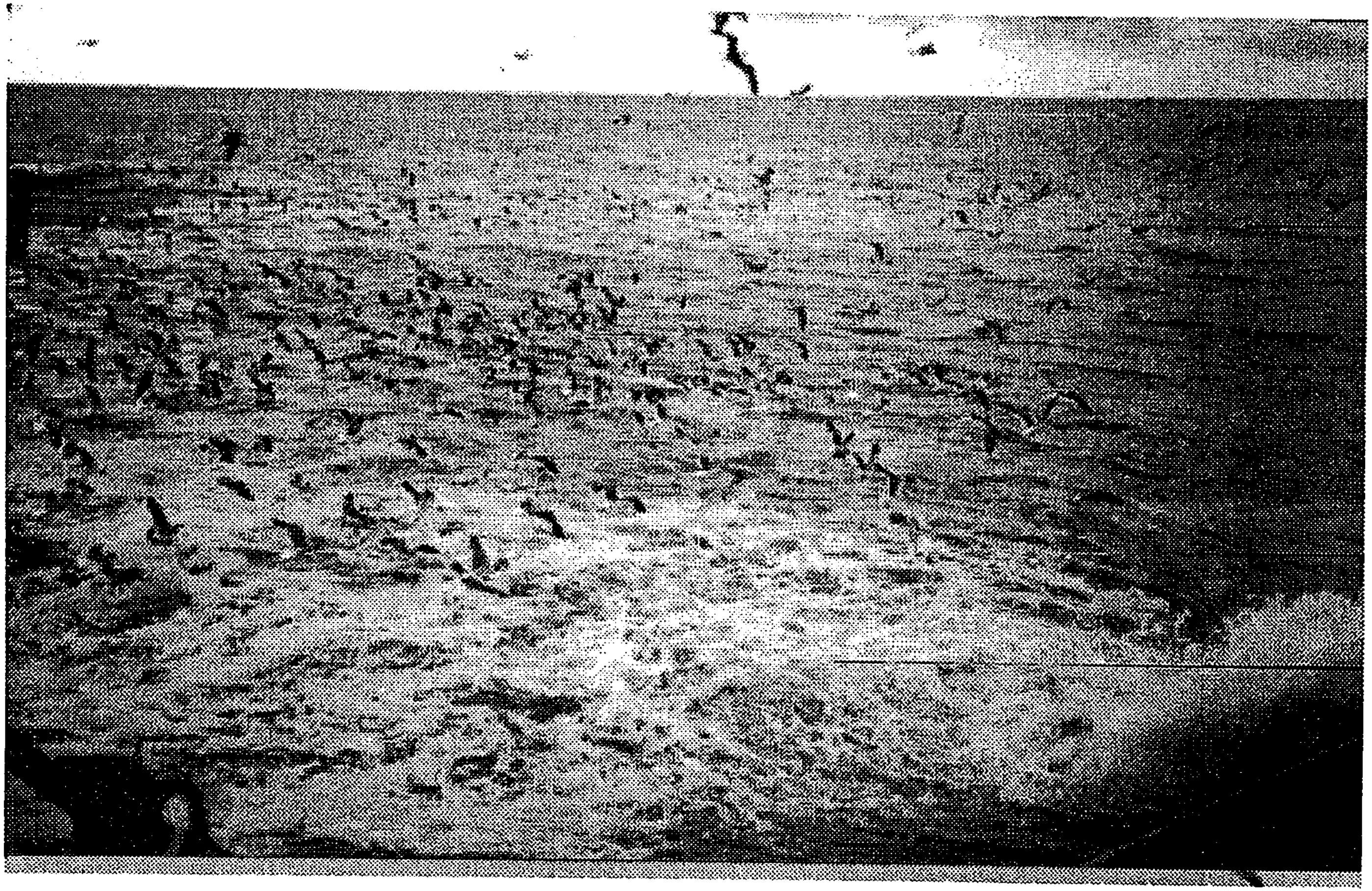

Figure 4.6. Gulls and terns feeding upon fish scraps in the water discharged during pumping of menhaden into the fish hold.

sampled in zone 14-16, and 4 % of sets sampled in zone 11-13. These preliminary observations suggest a possible gull-fishery association that is strongest at the western edge of the fishery and decreases eastward, the opposite trend for pelicans.

Determining which of the pelican-fishery-dolphin components attracted the others to the area is difficult to ascertain. While the common denominator is the menhaden school, it is likely that these associations are a mixture of attraction and opportunism. The associations could have been triggered by fishing activity in the vicinity prior to the specific set we were observing.

Records kept by samplers indicated that for 88% of the sets sampled, active fishing by other menhaden vessels in the general area of the set were observed. The number of other actively fishing menhaden boats observed ranged from 1 to 21 with a mean of 4.24 boats and a standard deviation of 3.25.

In addition, for 62% of the sets sampled, shrimp boats were observed either moored or fishing in the area. As such, the presence of fishing effort in the area prior to sampling may have set the observed association in motion. Gruber (1981) noted seasonal dolphin concentrations in association with shrimping in Matagorda Bay, Texas but she could not determine if shrimping was responsible for these concentrations.

While the overall proportion of sets during which dolphins were captured, for both years combined, was 0.33 % with a 95 % confidence interval ranging from -3.6 % to 4.1%, the proportion of sets during 1995 where dolphins were observed in the immediate vicinity was much higher (19.33% of sets with a 95% CI ranging from 15.12% to 23.54%). This suggests that even though the occurrence of dolphins around sets is high, they appear to effectively avoid being captured during the fishing

operation. Based on our sampling and the distribution of effort by the fishery, it appears that the western Gulf of Mexico coastal stock, the Bay Boudreau-Mississippi Sound stock and Mississippi delta stock of dolphins are those most likely to interact with the menhaden fishery.

During 905 fishing sets sampled in 1994 and 1995 we encountered four captured dolphins in three sets. Three of these four dolphins were released alive and one drowned in the net. All three occurrences were for dolphins from the western Gulf of Mexico coastal stock. It is believed that some of this stock may co-occur with the associated resident bay, sound and estuarine stocks (Waring et al., 1997). No seasonal pattern in these occurrences of dolphin capture were apparent. The three incidents occurred in different months (August 1994, June and July 1995). However, all three incidents did occur at depths less than 5.48 m, with two occurring close to shore. At shallow depths the length and depth of the purse seine, which is approximately 366 m in length and greater than 19.3 m in depth (Leard et al., 1995), could play a role in reducing escape routes for dolphins that are within it.

Comparison of the two occurrences of incidental capture in 1995 to spatial and temporal patterns in the occurrence of dolphins in the immediate vicinity of a menhaden set, showed no trend. During the first incident, one dolphin was encountered during June 1995 (spring season) in zone 14-16. This was the season during which the proportion of sets with dolphins in the immediate vicinity was highest for this area (34% of sets). However, the second incident for 1995 occurred for the season-area group (summer, zone 17-18) with the lowest incidence of dolphins in the immediate vicinity (3 % of sets) and was also the lowest of all season-area groups. In

fact, this incidental capture also represented the only instance when dolphins were seen in the immediate vicinity of that set for this season-area grouping.

During our observations, most of the dolphins accidentally caught were released alive (3 of 4 dolphins captured). However, given the extremely low PBR levels for these stocks, the one mortality in 1995 for the western Gulf of Mexico stock (PBR= 29) is equivalent to 3.45 % of the PBR. This may be particularly important for this stock, since the total fishery-related mortality and serious injury levels are not less than 10% of the calculated PBR levels and are not insignificant (Waring et al., 1997). Estimates of dolphin mortalities associated with the fishery between 1982 and 1988 ranged between 0 and 4 dolphins annually (Waring et al., 1997). Other bycatch studies on gulf menhaden have also observed the incidental capture of dolphins, some of which resulted in mortality (Christmas et al., 1960; Condrey, 1994).

Given the extremely rare occurrence of incidental dolphin mortality during our sampling of the fishery (one event in 1995) and the small proportion of menhaden fishing effort we sampled (approximately 2% per year), we did not extrapolate our rates of observed mortality to obtain total dolphin mortality rates for the entire fishery. However, based on the proportion of sets during which we observed dolphins encircled, and the amount of total 1995 fishing effort conducted west of 90^0 W (which approximates the range of the western Gulf of Mexico coastal stock of bottlenose dolphins the fishery could potentially impact) the fishery could have had an estimated 46 encounters during that year. Since encountering a dolphin in the set does not necessarily result in mortality, an assumption that 90 % of encounters would result in no mortality or serious injury suggests that the hypothetical four mortalities/serious injuries for the stock would be equivalent to 14% of the PBR. As such, a resource

conservative view towards the stock suggests that it is possible that the fishery exerts a very small, but biologically-significant source of mortality to the western Gulf of Mexico coastal stock of bottlenose dolphins.

One of the purposes of the regulations on commercial fisheries under the Marine Mammal Protection Act is "to reduce the incidental mortality or serious injury of marine mammals occurring in the course of commercial fishing operations to insignificant levels approaching a zero mortality and serious injury rate by the statutory deadline of April 30, 2001" (50 CFR Part 229.1). We believe an evaluation of the release methods used by the fishery, together with a better understanding of how to prevent the rare incidents of drowning can result in this fishery attaining a zero mortality rate.

In concluding, we have highlighted some of the positive and negative associations the fishery has with the ecosystem it operates in. While our analyses did not include food consumption estimates of pelicans, gulls and dolphins, it appears that the fishery may help to positively influence the foraging success of these species.

Small pelagic species such as sardines, pilchards and menhaden are important prey species for marine mammals, and many of those fish stocks are fully exploited (Earle, 1996). Lavigne (1996) noted that many of the perceived conflicts between marine mammals and fisheries tend to surface most often when commercial fishing stocks are in a state of decline. According to Vaughan et al. (1996), the gulf menhaden fishery is currently operating at about a 50% spawning stock biomass. The complex associations among pelicans, gulls, dolphins and the fishery highlight the importance of maintaining the gulf menhaden fishery in its current healthy state, as it

would benefit both the fishing community and those members of the aquatic community that utilize the fishery to improve their foraging success.

Given the current status of brown pelicans and the small stock size of bottlenose dolphins in the region, the associations we describe highlight some of the positive benefits the fishery has on the ecosystem it operates in. These types of associations strengthen the argument that fisheries should be evaluated using an ecological approach, which considers both positive and negative influences they may have on the ecosystem.

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CHAPTER 5

SUMMARY

A categorical approach to exploring patchy data was used on the releasable bycatch in the U.S. Gulf of Mexico gulf menhaden, *Brevoortia patronus*, fishery. With no previous statistical studies on the releasable bycatch (bycatch), this dissertation serves as an analysis of patchy data with categorical techniques and as a quantitative description of a biologically important-portion of the gulf menhaden bycatch. In particular, this study examines the significance of the rare event in terms of its biological importance. The philosophical approach of this study is in keeping with precautionary principles being applied to fisheries management in recent years.

In Chapter 2, by means of exploratory analyses with loglinear and logit models, spatial and temporal patterns in bycatch of the menhaden fishery were discerned. Contrasts revealed that at fishing grounds east of the Mississippi River, the probability of observing fishing sets with high bycatch rates in spring and summer were greater than in the fall. Furthermore, spring bycatch rates were higher in fishing areas east of 89 ^{0} W than in fishing areas west of 93 ^{0} W.

Correspondence analysis indicated that the fate of the releasable bycatch could be classified into three major groupings. The first group, species associated with being gilled, was composed primarily of Atlantic croaker, *Micropogonias undulatus*, Atlantic cutlassfish, *Trichiurus lepturus*, Atlantic bumper, *Chloroscombrus chrysurus,* and sand seatrout*, Cynoscion arenarius.* The second group consisted of species associated with being released dead or disoriented; it included the requiem sharks, crevalle jack, *Caranx hippos* and red drum, *Sciaenops ocellatus.* The third group included those fish that were associated with being put into the hold, kept by the crew,

or those whose fate was unknown. These included hardhead catfish, *Arius felis*, gafftopsail catfish, *Bagre marinus* and Spanish mackerel, *Scomberomorus maculatus*.

Seasonal and spatial associations of bycatch species were also examined with correspondence analysis. From April through August, two distinct bycatch species assemblages were observed, that separated the fishery at a longitude of 91^0 W. From September through October, a shift in the species assemblage indicated that the western region of the fishery (west of 93^0 W) appeared to have a assemblage distinct from the rest of the fishery.

In Chapter 3 shark bycatch in the U.S. Gulf of Mexico gulf menhaden fishery, their fates, distribution, and estimates of the number of sharks caught by the fishery were examined in detail. Eleven species of sharks were identified, with blacktip sharks, *Carcharhinus limbatus*, accounting for 36% of those identified. Approximately 75% of the sharks encountered died, 12% were released disoriented, and 8% were released healthy. Stomach analyses of sharks indicated that the menhaden schools were functioning as a foraging base for those sharks captured. While detailed age and maturity information were not collected, comparison of the size distribution of sharks encountered to the size at age distributions in the literature suggests that the fishery may be impacting the summer nursery grounds of sharks in the northcentral Gulf of Mexico.

Using loglinear and logit models spatial and temporal patterns to the shark bycatch were determined. Contrasts revealed the odds of observing a fishing set with shark bycatch was significantly greater in June-August than September-October. For areas east of 93^0 W the odds of observing shark bycatch during April-May was also significantly different from September-October. For the 1994 and 1995 fishing

seasons, annual shark bycatch was estimated at approximately 30,000 sharks. The biological importance of this source of incidental mortality is significant in light of the current population status of sharks in the Atlantic and Gulf of Mexico and their life history features of slow growth, late maturity and low fecundity. The value of loglinear/logit models as a tool in evaluating bycatch patterns based on management criteria was also shown. This was highlighted in the analysis based on the odds of observing more than four sharks/day. While these loglinear/logit analyses used a dichotomous response variable, an extension of such techniques using a multinomial response could provide a more refined analysis. However, a strong positively skewed distribution, as in the case for sharks, may not enable classification of a response into more than two levels, without affecting the validity of the test statistics.

In Chapter 4 spatial and temporal patterns of bottlenose dolphin, *Tursiops truncatus,* and Brown pelican, *Pelecanus occidentalis,* associations with the gulf menhaden fishery were described. The incidental capture of bottlenose dolphins by the fishery was also examined.

Dolphins were observed in the immediate vicinity of fishing sets for 19% of sets sampled and diving and circling pelicans were observed in 23% of sets sampled. Research results suggest a complex relationship exists between dolphins, pelicans and the schools of menhaden the fishery targets. Spatial and temporal patterns in the level of association among pelicans, dolphins and the fishery are evident, and can be described by a loglinear model with the pelican-season-dolphin, dolphin-season-area, pelican-season-area term and all lower order interactions.

While the incidental capture of dolphins in the fishery is extremely low, they are far more frequently associated with the fishery than previously known. This suggests

that dolphins have learned to avoid being captured, while taking advantage of the "corralling" of the menhaden by the fishery to opportunistically feed upon the targeted catch. However, the low rates of incidental capture may be biologically important given the low population estimates for the stock.

APPENDIX

LETTER OF PERMISSION

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1026

Fishery Bulletin

July 9, 1998

Ms. Janaka de Silva
CCEER Coastal Fisheries Institute
Wetland Resources Building
Louisiana State University
Baton Rouge LA 70803-7503

Dear Ms. de Silva,

In response to your letter dated July 6, 1998, requesting permission to reproduce your article "Disceming patterns in patchy data: a categorical approach using gulf menhaden *Brevoortia patronus* bycatch" as part of your Ph.D. dissertation: there is no problem whatsoever with your using this material.

Copyright law does not cover government publications; they fall within the public domain. If an author reproduces any part of a government publication in his or her work, reference to source is considered correct form.

Sincerely,

John B. Pearce
Scientific Editor

Tel: 508 495-2261 E-Mail: Jack.Pearce@noaa.gov Fax: 508 495-2258

VITA

Janaka Anthony de Silva was born in Colombo, Sri Lanka, on December 11, 1962. He graduated from the Royal Wolverhampton School, England in 1981. In 1984 he graduated from Plymouth Polytechnic, England, with a bachelor of science. (Honours) degree in Fishery Science. From 1985 to 1990 he worked as a Research Officer for the National Aquatic Resources Agency, Sri Lanka. In 1993 he received his master of science in Fisheries from the School of Forestry, Wildlife, and Fisheries, Louisiana State University. He began his graduate studies at the Department of Oceanography and Coastal Sciences in January 1994 and is presently a doctoral candidate which will be awarded in December 1998.

He is married to Yasanti Seniviratne and has a daughter, Annissa.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Janaka Anthony de Silva

Major Field: Oceanography and Coastal Sciences

Title of Dissertation: The Nature and Extent of Species Interactions with the U.S. Gulf Menhaden Fishery

Approved:

Richard Condrey
Major Professor and Chairman

John M. Larkin
Dean of the Graduate School

EXAMINING COMMITTEE:

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Bruce A. Thompson

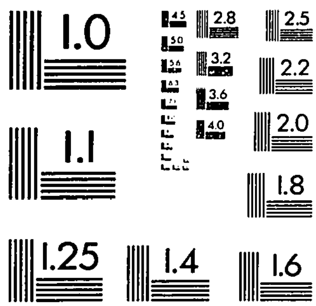
William H. Herke

[illegible]

Date of Examination:

August 21, 1998

IMAGE EVALUATION TEST TARGET (QA-3)



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