CHARACTERIZING MARINE MAMMAL STRANDING EVENTS ALONG THE TEXAS COAST

A Thesis

by

RUTH LOUISE MULLINS

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

MASTER OF SCIENCE

August 2008

Major Subject: Oceanography

CHARACTERIZING MARINE MAMMAL STRANDING EVENTS ALONG THE TEXAS COAST

A Thesis

by

RUTH LOUISE MULLINS

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

MASTER OF SCIENCE

Approved by:

Chair of Committee,	John Wormuth
Committee Members	Andrew Vastano
	Anthony Filippi
Head of Department	Piers Chapman

August 2008

Major Subject: Oceanography

ABSTRACT

Characterizing Marine Mammal Stranding Events Along the Texas Coast. (August 2008)

Ruth Louise Mullins, B.S., Texas A&M University

Chair of Advisory Committee: Dr. John Wormuth

The Texas Marine Mammal Stranding Network (TMMSN) is a valuable data resource for the marine mammal community. Limitations of funding and personnel severely impact the ability of the Network to maintain impeccable databases. This research constructed an application to address database complications and focused on investigating the species identification, temporal and spatial trends for stranding events along the Texas coast.

From 1980 to 2004, *Tursiops truncatus* accounted for approximately 80% of all stranding events. The remainder was 20 additional whale and dolphin species known to reside in the Gulf of Mexico. *Tursiops truncatus* strand along the entire coastline and are the only species stranding in the bays. All other species stranding are most dense along the southern coastline.

The temporal scales of events revealed no linear patterns from 1980 to 2004. A unique cyclic fluctuation occurred from 1992 to 1998, including the highest yearly counts and one isolated mortality event in Port Aransas. Attempts to forecast stranding events beyond 2004 were inconclusive due to multiple factors influencing a stranding event. A bimodal seasonal trend was evident, with events peaking in the spring and fall months. Density distributions by decade isolated three frequent stranding areas: Sabine-Galveston-Brazoria counties, Galveston Shipping Channel, and Corpus Christi Shipping Channel.

The final aspect analyzed spatial elaboration of events by creating six location values to describe the Texas coastline. Each event was assigned from the geographical location and the orientation of an event along the coastline. Analysis revealed the segregation of *Tursiops truncatus* in the bays and confirmed earlier results of density distributions. Examining the locations by time revealed a specific incident connected to a mortality event in 1992, accounting for 59% of the stranding events. Location categories were compared to the TMMSN stranding regions and the regions experienced different location frequencies.

This study demonstrated how to construct a stronger database and the necessity for database accuracy. Study conclusions demonstrated the need to better isolate and research factors responsible for event distributions in time and space along the Texas coast to forecast the magnitude and location of stranding events to better aid the TMMSN response efforts.

DEDICATION

To my parents, sister, and Houston

Your guidance, support, and love have made the person I am today.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to the Texas Marine Mammal Stranding for leaving their database in my possession and for the countless email conservations about the database. I am especially grateful to Dr. Daniel Cowan, Heidi Watts, and Brandon Bassett. If not for their help, this project would not have been completed. I hope they find the results useful and implement this new database into the TMMSN.

I would like to thank my committee members, Dr. John Wormuth and Dr. Drew Vastano, for their support of this project. I truly valued their input and suggestions with this process and appreciated the advice and conversations about future directions with this work and in other studies. I also thank my third committee member, Dr. Anthony Filippi, for serving on my committee and assisting with mapping analysis in this study. He is one of the best teachers I have ever had the pleasure of learning from and working with.

I must also take time to thank a few friends and colleagues that have been instrumental in my life and this project. The first person I want to thank is Xiaoqian Zhang. He is one of the most brilliant people I have had the pleasure to work with and would not have been able to finish this project or other work. He has always been available to help me solve a script problem and more than willing to take time from his work to teach and help with any problem. I will be forever thankful for his friendship and wish him all the best. The next person I would like to thank is Edwin Pinto. He is never afraid to provide criticism and is a true friend. I look forward to working with him on future projects. Finally, I would like to thank Sarah Landrum, Abby Schwab, Hartford Prewett, Kyle Kuskie, and Valeriya Kiselkova. It is very rare to find people in this world who are completely honest with you, support you through life, and will do anything possible to help you succeed. They are life-long friends and I cannot wait to see where life takes them. Finally, I want to thank Laura Rubiano-Gomez, Julia O'Hern, and Kelly Cole. Even though this project is completed, I am still looking forward to more great, late-night conservations about research and life. I look forward to working with them on our future research and hope to continue collaborating in the future, wherever the oceans may take us.

Finally, I dedicate all 225 pages to four people – Wayman, Louise, and Rachael Mullins and Houston Perry. These four people have been the motivation for finishing and I could not have done so without their love and support. They have pushed me through the hard times and cheered with me through the good times. There are not enough words and time to explain how much each one of them means to me and I love them with all my heart.

NOMENCLATURE

GIS	ESRI ArcGIS 9.2
GOM	Gulf of Mexico
MMPA	Marine Mammal Protection Act of 1972
NOAA	National Oceanographic and Atmospheric Administration
TMMSN	Texas Marine Mammal Stranding Network
TGIC	Texas Geographic Information Council
TPWD	Texas Parks and Wildlife Department

TABLE OF CONTENTS

1. INTRODUCTION

Stranded cetaceans provide valuable information about habitat characteristics, such as feeding and breeding grounds, and overall cetacean population status. Stranding rates indicate changes in the marine environment, either on intermittent or long time scales. The information collected during the initial stranding response and from necropsies performed on stranded cetaceans can be applied to studying population responses to environmental factors and the effects of marine environment changes on localized cetacean habitats. Necropsies reveal evidence for reproductive and physiological stress on individual cetaceans, yet only minimal information is learned about the marine environment. To investigate marine environmental factors influencing cetacean habitat, scientists utilize both data collected during the initial response efforts, meaning when personnel first find and process a stranded cetacean, and from the necropsy reports. According to Davis et al., many factors affect the geographical distribution of cetacean habitat (1998). Distribution factors affecting habitat and stranding rates are commonly classified as environmental, biological, or anthropogenic and are often a combination of three major factors (Borcard et al. 1992). Stranding events are also attributed to one or more of these factors. Studying stranding events provides an alternative method for understanding cetacean population distributions without relying on expensive ocean surveying efforts to track such populations. However, compared to the available surveying research, stranding event investigations are severely under-utilized and rarely applied to population studies. In order to study

This thesis follows the style of Marine Mammal Science.

stranding events, it is necessary to understand the logistics of a stranding, responses and monitoring of events, and causes for a stranding. Stranding events enhance knowledge about the status of cetacean habitats and population structures. This research will introduce the possibility of stranding events as tools to monitor Texas cetacean populations.

1.1 Addressing the Use of 'Stranding' in Cetacean Research

There are various interpretations for terminology addressing stranding events in cetacean studies. To understand the aspects of a stranding, it is necessary to address the variations in meanings and definitions for a stranded cetacean. The term 'stranding' is often used interchangeably and refers to different conditions of a stranded marine mammal. The definition of *stranded* or *stranding* would imply the process of running aground by various means and refers to a ship, person, or animal stranding in a helpless or uncontrolled manner (Geraci and Lounsbury 1993). When referring to a marine mammal *stranding*, the action is not necessarily helpless or uncontrolled in all situations. As defined by the United States federal government, a *stranding* confers "a marine mammal is dead and is (i) on a beach or shore of the United States… or (B) a marine mammal is alive and is (i) on a beach or shore of the United States and is unable to return to the water; (ii.) on a beach or shore of the United States and, although able to return to the water, is in need of apparent of medical attention;.. (16 United States Code [U.S.C.] 1421h). Despite the legal definition, these terms are not consistently utilized in international literature. International scientific literature terminology depends on the publishing country and often includes the terms *stranding, stranded event, marine* *mammal stranding*, yet there is less consistency between these interpretations and the meaning typically depends on the researcher(s) and the research purpose and less about the stranding event.

The major complication with the terminology is describing the health status of the stranded cetacean. Many terms referenced assume the animal is alive or barely alive and does not consider animals deceased prior to stranding ashore. To address this discrepancy, the term ‘beaching’ is often used and refers to marine mammals floated ashore deceased (Geraci 1993). ‘Beaching’ is less common in scientific publications, but is commonly in mass media publications, such as local newspapers or television news channels. This term and the previous do not address all incidents and focus primarily on an alive animal stranded.

Despite the obvious explanations of a stranding occurring directly in only the surf zone, events can occur in deeper waters. Larger cetaceans may strand closer inshore, but still be in water deeper than the body girth and maintaining a floating or slightly swimming position rather than partially or completely exposed to air in the coastal swash zone. Pelagic cetaceans rarely frequent coastal waters, and can be considered stranded if on the continental shelf (Southall et al. 2006). Examples in these locations have been documented from deep ocean oil platforms, ocean vessels in transit, or on volcanic islands located on tectonically active trench boundaries. The earlier terminology discussions demonstrate the impracticality that a stranding is only limited to a cetacean exposed on a shoreline rather than encompassing all possible stranding situations to include stranding events transpiring in deeper waters beyond the coastal zones. To address such discrepancies, the term 'marine mammal stranding event' has reemerged in the scientific literature. A *stranding event* refers to a cetacean accidentally or intentionally stranding or beaching on the shore or sustaining serious injury or death from an unnatural environmental interaction, such as by-catch in a fishing net. This description appears in many literature sources (Atlantic Fleet 2008) (Geraci and Lounsbury 1993) (Geraci 1978) and specifically refers to the vague interpretations with the prior terms. Considering the incident as an event implies a cetacean stranding alive in any location or the cetacean is deceased before floating ashore. Referring to the incident as an *event* also explains a *beaching* as well, in which the animal is forced ashore and is unable to move back into the surf (Geraci 1978). This term addresses all possible situations and is escalating in popularity among cetacean stranding event researchers. For this study, the term 'marine mammal stranding event' will be used when referring to the TMMSN cetacean data since no previous knowledge is known for any of the events analyzed.

1.2 Causes for Cetacean Stranding Events

After understanding the stranding vocabulary, it is now possible to investigate the individual components of a stranding event. Historically, cetacean stranding events have been influenced by various biological, environmental and anthropogenic sources (Colbert et al. 1999) (Davis et al. 1998) (Atlantic Fleet 2008) (Finneran et al. 2000) (Fire et al. 2007) (Geraci et al 1999) (Geraci and Lounsbury 1993) (Constantine et al. 2004). The more recent sources summarized from the literature and the public media outlets include:

a. *Hearing distortions and damage by human-induced sound disturbances*

This event source is extremely popular with conservation organizations and public media. Organizations rely on stranding events as attack mechanisms against naval fleets performing sonar testing in the world's oceans. Recent scientific publications concentrate on testing the validity of anthropogenic sound in affecting cetacean orientation and comfort (Balcomb and Claridge 2001) (Finneran et al., 2000). Noise originates from a variety of sources, including coastal transportation vehicles, dredging, ocean construction and drilling, geophysical surveying, both commercial and industrial boating, and exploration efforts. With these other sources, it is not possible to attribute sonar testing as the only source of ocean noise. Scientists concluded a single responsible sound-producing source is impossible to determine, but generally concluded the ambient noise levels in the ocean have increased over the last 50 years (McDonald et al. 2006) (Jasny et al. 2005) and the increase affects cetacean physiology.

Laboratory investigations and field recordings have supplemented the above findings by demonstrating the affects of sound in producing short-term behavioral responses (Finneran et al. 2000) (Atlantic Fleet 2008). The investigation and recordings confirm sound sources do not cause permanent damage, but slightly alter normal behavioral reactions. Examples of altered responses include decreased feeding rates, resting periods, and social interactions (Atlantic Fleet 2008). Another behavioral implication for sound disturbances is the disruption in communication among cetaceans (Jasney 2005). To date, research on this aspect is recent and will entail more comprehensive field investigations to be categorized a permanent stranding source.

b. *Echolocation disruptions*

The second source is documented in the literature as temporary disruptions due to changing bathymetry in coastal features or agitation resulting from storm or short-lived weather events. Few scientists feel distortion of the echolocation is a breakdown in the pulse sending and returning from the cetacean and occurs when a cetacean maneuvers along gently sloping coastlines (Geraci 1978). Disturbances by atmospheric events alter the coastal floors by suspending large amounts of sediment to create new bathymetric contours, altering the customary inshore habitat for coastal cetacean species (Geraci 1978). These incidences are often quick acting and may force isolated and small-numbered marine mammal stranding events (Geraci and Lounsbury 1993).

Past studies have dismissed this source and believe gently sloping shorelines or particle suspension cannot impair echolocation signaling (Geraci 1978). Mass stranding events repeatedly occur on gently sloping beaches, but no evidence attributes these events to echolocation disruption (Geraci 1978) (Geraci and Lounsbury 1993). With the width and shape of the Texas shelf, echolocation disruption does not seem practical explanation for the stranding events investigated in this study.

Dynamic atmospheric-ocean coupling within Gulf of Mexico can influence stranding event rates. Hurricanes and severe weather fronts can force cetaceans inward on the continental shelf or coastal features for protection, but at the same time trigger spatial awareness distortion from the immediate constraint in an unknown location Geraci (1978, 1993).

c. *Cyclic and magnetic interruptions and/or variations*

Research for this stranding source concentrates specifically on lunar cycles, solar activity, and geomagnetic topographical variability. Lunar cycles and solar activity influencing stranding rates have been investigated in the northwestern Atlantic Ocean. These few and localized studies indicate a weak relationship between solar flares and sun cycles to the stranding increases of sperm whales around the North Sea (Vanselow and Ricklefs 2005). The idea behind the effect is solar radiation temporarily interferes with the earth's magnetic field by changing the geomagnetic structure during extreme solar flares. Cetaceans relying on the magnetic field for navigation and migration can experience temporary distortion during these solar activities leading to stranding events (Vanselow and Ricklefs 2005).

Lunar cycles are another recent investigation as a source of stranding events. According to Andrew Wright (2005), lunar cycles have not previously been considered a stranding source. His investigation compared full moon cycles to the stranding records in the North Atlantic (2005). The results introduced statistical comparisons between sperm whales and lunar cycles, basing the stranding events on the diurnal feeding, tidal motion, and prey habit disruptions by lunar cycles (Wright 2005). Since this publication, no other investigations have been conducted comparing other cetaceans with lunar cycle variability.

In 1985, Klinowska attributed live stranding events to “mistakes made by animals attempting to use geomagnetic topography for orientation”. He based his findings on the United Kingdom’s stranding database and created geomagnetic topography maps to accentuate distortions in the geological magnetic fields. The analysis confirmed live events occurred in relatively low geomagnetic anomalies, but applied to only single animal stranding events. Results also demonstrated geomagnetic anomalies were not statistically relevant to events composed of three or more cetaceans. Though a thorough investigation, this conclusion was not applied to any additional geographic locations other than the North Sea area.

d. *Illness and injury (mental, physiological, human interactions)*

This category is one of the more common source explanations and covers a multitude of specific incidences. General effects in this discussion include internal and external infections (disease), naturally-occurring toxins, predation, fisheries interaction, point and nonpoint pollution, vessel strikes, and tourism. Disease and parasitism are two of the principal sources in the scientific community, including 100 plus articles specifically focusing on toxicity levels of heavy metals, inorganic, and organic compounds in cetacean blubber and vital organs. Disease bioaccumulation is also studied, including a recent focus on brevetoxin exposure along the coasts of Texas and Florida (Fire et al. 2007).

Similar to other mammals, cetaceans experience a high susceptibility to numerous viral, bacterial, and fungal pathogens. Along with heavy metal toxicity, this is a large component of stranding source studies, because samples are relatively simple to acquire during standard necropsies of the cetaceans. Geraci (1993 and 1999) wrote that microparasites are common in most marine habitats, but pose little threat to healthy marine mammals. Macroparasites, such as trematodes, are also internally common to marine mammal species, but an increase in these internal communities can lead to severe mental impairment. Generally, when a population is ill, injured, or experiencing a decrease in prey or starvation, infections increase and can spread rapidly through the community, similarly to human infectious diseases (Geraci et al. 1999) (Ridgeway and Dailey 1972) (Morimitsu et al. 1987).

Coastal anthropogenic pollution has also been a consistently studied topic in biological oceanography and has experienced resurgence in the marine mammal community, due to the effects of various pollution sources on cetacean prey. Point and non-point source pollution rates in the Gulf of Mexico are constantly monitored, but toxic levels and bioaccumulation rates affecting cetaceans along the Texas coastline is unknown. Another pollution aspect is the dumping of large trash items in the ocean by coastal residents or from boats and ships. Certain cetacean species will commonly investigate foreign objects, including plastics and other garbage, and often ingest these objects causing stranding and/or death.

The increase in coastal populations is another direct source on marine mammal stranding rates. Many cetacean species are highly sociable and often investigate boat/fishing traffic, shipping routes, rivers, or coastal channels. These curiosities can often result in fatal injuries and are difficult to prevent (Geraci 1978) (Atlantic Fleet 2008). Strong prevention efforts have been made with coastal fishing industries, but at the same time are difficult to regulate. Coastal development and population increase, however, cannot be strictly regulated and will continue to be a threat in the future. Yet, governmental regulations are in place, as a result of the MMPA of 1972, to regulate trafficking in important habitat reserves and within inshore waterways to reduce the impact to marine mammals.

e. *Behavioral responses (social structure, psychological)*

Finally, the last major source for stranding events is cetacean behavior. Stranding events can simply be a result from a choice decided by the marine mammal. Marine mammals age and may strand due to fatigue or reaching the end of life. The theory of suicide can be implied; however is a difficult measure to actually test (Geraci 1978). Most of the general research with stranding events attributes stranding events to animal choice (Geraci 1978). A more simple idea to comprehend is stranding events are simply an unfortunate mistake of healthy cetaceans, typically as shown with other mammal experiments (Lusseau et al. 2006). Mistakes can simply be a misjudgment with an action or a fault of learning. Since cetaceans are considered to have abilities of higher-level cognitive processes, learning new techniques can result in a fatal mistake. Examples of behavioral causes involve bottlenose dolphin feeding or social strategies, from using induced bow waves to hydroplaning along the shallow coastal waters as pursuit methods for prey. (Sargaent et al. 2005) (Duff-Echevarria et al. 2008) Social strategies include behavior alterations due to the presence of human activity, such as dolphins interacting with tour-watching boats(Constantine 2004). A slight miscalculation in techniques such as these can cause an accidental stranding. Behavioral actions can vary from animal to animal or group to group, and are often the most difficult source to scientifically test.

To conduct these stranding causal studies, researchers rely on entire specimens or particular samples collected by various responders, either volunteers or trained personnel, at a stranding event. To understand how stranding events are responded to and documented for research and particularly this investigation, it is necessary to learn about the agencies responsible for responding to an event and how the information and samples are collected.

1.3 Formation of Stranding Networks in the United States

Stranding event data for source studies is collected, processed, and documented by multiple volunteer and governmental agencies. The common response units in the United States are categorized as stranding networks. The creation of stranding networks originated from the formation and implementation of the Marine Mammal Protection Act of 1972 (MMPA) (Geraci and Lounsbury 1993). The major goal of the MMPA is to protect marine mammal populations in the United States under the jurisdiction of the federal government. The United States Marine Mammal Commission and the National Stranding Alert Networks were formed for monitoring protection efforts (www.nmfs.noaa.gov/pr/laws/mmpa). Thus, stranding networks arose as a result of the protection efforts implemented by the federal government and are currently managed under the National Marine Fisheries Service (NMFS).

To effectively manage and protect marine mammal populations, the NMFS divided the United States into five federal jurisdictions loosely based on the NMFS zoogeographic regions (Figure 1.1). However, the regions are not restricted to the only one stranding network, and often manage numerous response centers. For example, the Gulf of Mexico is considered as the Southeastern Region, but each state has a state stranding network and/or multiple volunteer organizations to also assist with stranding events. The Texas Marine Mammal Stranding Network (TMMSN) is an example of a state network that reports to the NMFS Southeastern jurisdiction. States as California and Florida have many conservation groups federally authorized for stranding event response and cetacean rehabilitation. Although California does not have a dedicated state network, the state government financially supports these response foundations, such as The Marine Mammal Center (www.mmc.org) and the Northcoast Marine Mammal Center (www.nmmc.org). The number of foundations or designated state agency depends on the sources and amount of funding available from the state.

As with any governmental agency, stranding networks adhere to federally stated objectives. According to the National Marine Fishery Services, national objectives are defined for any stranding facilities, as well as regulations and guidelines in the network infrastructure (www.nmfs.noaa.gov). The objectives stated as published by Geraci and Lounsbury (1993) are:

1. To provide rapid and effective action that will best serve the well-being of the stranded animal(s)
2. To protect the public while acting on an agency's concern
3. To gain maximum scientific information

The basic elements of a network's structure revolve around the first and last goal. The federal government under the stipulation of the Marine Mammal Protection Act believes a network should include responses teams, support and equipment for animal response and rehabilitation, and a science entity for data collection, analysis, and storage. The science entity often includes a scientist or affiliation to an academic institution. Network composition and resource levels depend on secured funding from federal, state, or institutional grants or private donations. The response teams are typically composed of trained personnel and volunteers that can provide the necessary response and medical aid to a stranded cetacean. A veterinarian is also an integral part of the unit and members can be employees of the network or volunteers. Support and equipment for animal response can vary depending on financial resources. Equipment covers tools to run an operation center for people to call in a stranding, logistic supports for the response teams and animals, rehabilitation facilities if the network is not involved with external entities, collection supplies necessary for processing the event, and basic processing equipment for data storage and processing. Rehabilitation facilities are typically partnerships with an academic institution, as between the TMMSN and the University of Texas, or through a partnership with location aquariums or public marine mammal facilities, such as SeaWorld. Despite a common purpose, stranding networks' differ in structure and response capability, which can affect the stranding data availability for researchers. The data for this research was borrowed from Texas Marine Mammal Stranding Network, which is a unique organization compared to other states.

1.3.1 The Texas Marine Mammal Stranding Network Organization

In Texas, the TMMSN is the only response network and is supported entirely by institutional grants and private donations. The state of Texas does not allocate any state funding towards the operations and sustainability of the Network. The TMMSN, with the collaboration of the University of Texas Marine Science Institute, covers response and rehabilitation of stranding events along the entire coast of Texas and in Louisiana east to Morgan City, LA (www.tmmsn.org). This Network was formed in 1980 with the goals of a 'further understanding and conservation of marine mammals through rescue and rehabilitation, research and education' (www.tmmsn.org). With almost 400 statute miles of coastline to cover, the TMMSN is divided into seven response regions according to state county lines: Sabine Pass, Galveston, Port O' Connor, Port Aransas, Corpus Christi, and South Padre Island (Figure 1.2). The seventh region, Louisiana, was added in the past couple of years allowing jurisdiction for the TMMSN to respond to events along Texas coast to Cameron County, Louisiana (www.tmmsn.org).

1.3.2 Data Collected by TMMSN

With only one state network, data maintenance and publication is impaired and generally only contains yearly counts and descriptive accounts of unusual events, such as a mass stranding. The collaboration of the TMMSN with the University of Texas Medical School provides publications specifically focused on marine mammal disease and pathology. The lack of government and financial support creates a substantial weakness for the TMMSN compared to other state networks. The extent of data publication from the TMMSN is limited to yearly reports published in publically released summary reports or online, not in scientific literature, because most of the financial support available is dedicated to response and rehabilitation efforts. This project examines the entire database provided by the TMMSN to characterize marine mammal stranding events by species, temporally, and geographically.

1.4 Study Questions

In an attempt to assist the TMMSN with data analyses, this research will address four general questions. By performing a basic descriptive analysis of the TMMSN database, I hope to show how stranding events provide invaluable information about marine mammal communities, how the TMMSN can benefit from this analysis, and how the results can aid in forecasting stranding events. The four questions addressed in the remainder of the document are:

1. *How are the TMMSN Stranding Events Documented and/or Researched in the Literature?*
2. *How Many and What Types of Marine Mammals Strand Along the Texas Coastline?*
3. *How are the Stranding Events Distributed in Time Along the Texas Coastline?*
4. *How are the Stranding Events Distributed in Space Along the Texas Coastline?*

This research focuses specifically on a descriptive analysis of the data. The efforts of this research will show the deficiency in statistical analysis with marine mammal stranding events in the scientific literature and how preliminary analyses need to be conducted and related to the vitality of the cetacean populations. The outcome of the analyses will also show the importance and necessity of maintaining databases for accuracy and precision in data recording. Finally, the results of the analyses will relate the aforementioned ideas and demonstrate the need for continuing investigative research efforts into real-time modeling of environmentally suitable areas for stranding events. The ability to create models can assist and improve the TMMSN ability to respond more quickly to events. Models can also reveal coastal areas susceptible to stranding events based on the earlier factors mentioned and assist in educating conservation and public organizations. Using the Texas coastline as a baseline may be useful for developing models for other United States coastlines and thus, minimize the time, money, and labor intensities for additional stranding networks. This research will also reveal the importance for investigating stranding events over longer time series and how such analyses are important indicators of cetacean population sustainability.

2. MATERIALS AND METHODS FOR THE TMMSN DATA ANALYSIS

This section outlines the original TMMSN database form, database reconstruction, and exporting steps for analysis programs used. The information in this section only describes steps taken to prepare data for analysis in answering each of the four questions. For each individual section addressing a specific question, there is a short methods section describing unique procedural applications not included in this general explanation section. This section is divided into three main sections: Description of the TMMSN database, graphical preparations for the TMMSN stranding event analyses, and mapping preparations of the TMMSN stranding events.

2.1 Description of the TMMSN Database

The initial import of the database from TMMSN showed 2258 available records. With the initial test of importing in Microsoft Access, 3301 records were visible. Examining this in the original dataset, 1043 records were hidden in the Excel sheet. Opening these columns revealed a total of 3302 rows, with the first row as the column headers. The final stranding count in the original TMMSN database is 3301 events. Each row describes one single event for one cetacean. Each event's descriptors start from column A and extending to AS, accounting for 45 different descriptors for each stranding events. Columns AR and AS were additional columns created and will be described later in this section. The original data was collected on the stranding event site generally by paper record and with a global position satellite unit device. Each data recording was then entered into a Microsoft Excel worksheet and the paper record stored in a file. There are no row or column data format designations and the cell formatting is determined internally by Microsoft Excel, often revealing multiple entry formats in the original dataset. The event is designated by a generalized code in the database and all corresponding paper records from the rehabilitation or necropsy are entered corresponding to the event. Typically, one or two people are responsible for the entering the records into the database and performing any quality control but, being a volunteer organization, the primary database controllers continually alternate positions. This lack of reliability and transfer of data to and from paper records accounts for the majority of errors in the database. According to the TMMSN personnel, the paper records are compiled and entered into the database in the middle (June to August) of the year and at the end of the year (December) when stranding rates are low (Brandon Bassett and Heidi Watts, personal communication) . However, this timeline is extremely flexible and can often move into the following year, accounting for the slow acquisition of yearly additions to the main database. This time consumption with data recording is why the interval analyzed in this project ranges only from years 1980 to 2004.

The list below details the 43 columns and formats of each in the TMMSN database. The descriptors are described below with X representing a letter and # representing a number in the column formats.

Column A: *Region#*

This first column is a text string format following the shape of XX####. The XX is a two letter abbreviation of Column B. There are seven combinations of two letter codes followed by sequential order of numeric from 0000 to 0XXX depending on the number of records per two letter code. There are no missing entries in this column. This column is also considered the identity code for each stranding event.

Column B: *Region*

The second column corresponds to the *Region#* and is a text string. There are seven region locations (*Corpus Christi, Galveston, Louisiana, Port Aransas, South Padre, Port O'Connor, and Sabine Pass*) that are designated areas predetermined by the TMMSN and represent response regions to a stranding event. There is one missing entry in this column corresponding to *Corpus Christi* region. Figure 1.2 details the spatial boundaries of the six Texas region locations.

Column C: *TMMSN#*

This column is a special designation created by the TMMSN and the reasoning for this column is not known. Like *Region#*, this column is also a text string, but is formatted as X#### and ranges sequentially according to *Region*. The only fields filled match to *Corpus Christi* region, however there are two records that do not correspond to the correct *Region.* There are 2168 blank records.

Column D: *Species*

The fourth column is the scientific name of the stranded animal. The list of species will be discussed in the next section. There are 23 designations, with 22 identifiable species and 1 to represent unknowns, or animals that could not be identified). There are 19 records blank in this column.

Column E: *Sex*

The *Sex* column is the gender determination for each of the events. This is a text field of one character (M, F, and U). The designations are M for male, F for female, and U for unknown. Not all entries in this column follow the single numeric code and 19 fields are blank.

Column F: *Length*

This column is the length measured for each animal in the event. The column entries are numeric and represent centimeters. This is not stated in the description, but was confirmed by TMMSN. The validity of the entries is not known and is questionable. Four records fall under 10 centimeters and two records reach 1000 centimeters. There are also 391 records that are blank.

Column G: *Age*

Column G is an age determinant for each event. According to the TMMSN, this estimate was determined from necropsy data or from the length of the animal. The numbers are stored as a text entry and not as a numeric value. Also the values are not whole numbers, which can or cannot alter the validity. The values of the *Age* range from 0.0 to 38. Also, 3020 records are blank.

Column H: *Sexual Maturity*

This column has no initial descriptor and was explained by the TMMSN to be derived from the necropsy report, *Length*, or *Age* columns. The data is entered as text string and has multiple entries. The two main designations are Mature, Neonate, Immature, and Adult. There are 3240 blank fields. The validity of this column was an issue in the data analysis and not included in any final analysis.

Column I: *Girth*

The *Girth* is another measurement taken in addition to the animal length. This number is entered as a numeric and represents the largest part of the body width on an animal, typically behind the pectoral fins. As with *Length*, the values are in centimeters ranging from 3 to 400. There are 312 completed fields and 2290 blank records.

Column J: *Weight*

Column J is another characteristic variable measured in a necropsy. If the animal is alive, the weight is also taken depending on where the animal is transported and held. These records also vary substantially similar to the length and girth. The data is entered in numerically in units of pounds ranging from 7.1 to 1000 pounds. On initial comparisons to *Sexual Maturity*, not all weights correspond to the matching record in Column H, also 3072 records are blank.

Column K: *Condition Code*

This next column is a text field containing values of 1 to 6, with letter designations of E, L, M, and U. The low end of the scale refers to a live animal and ranges to magnitudes of decomposition. Few of the records are also ranges of the values, such as 2-3 still stored as a text. Correspondence with the TMMSN indicated that each person filling in the records had a slightly different explanation for the code letters. The general consensus was that E, L, and M relate to status of the condition: early, late, or middle respectively. The last code, U, means the condition is unknown. There are also no additional descriptors attached to the file for this column. Five records do not follow the pattern of the rest of the column and 81 records are blank.

Column L: *Condition Comment*

Column L is a text string column with comments corresponding to the *Condition Code* and to the necropsy files. There is not a defined structure to the comments and some range from a few words to longer sentences. The records also range from percentages of the carcass remaining to behaviors of live animals during rehabilitation efforts. Not all records with a *Condition Code* have a *Condition Comment*. There are 377 blank records.

Column M: *Date Reported*

The format of this column is a date string appearing as MM/DD/YYYY, where M = month, D = day, and Y = year. This is a common form of entering date values and in this database the events start from November 13, 1980 (11/13/1980) and end at December 18, 2004 (12/18/2004). This is the amount of data acquired in complete from the TMMSN in 2006. The process of entering individual records is a slow process, due to the time requirements for necropsies, pathological, and toxicity analyses. Depending on the staff and laboratory space available, TMMSN may take over a year to enter the previous year’s data in the main database. Files also may or may not be completed by the same person, accounting for the variability in this column and others. There are 162 missing data records.

Column N: *Time Reported*

This column marks the time of the call for the stranding event. The format of the column is a time string entered as HH:MM:SS, with H = hour, M = minute and S = second. There is also a second format for the time, as ####. The time switches between Central Standard Time and zone and military time. There are no additional descriptors attached to the file to delineate between standard and military time. Four of the records do not have an associated time, but have text entered and 1142 records are empty.

Column O: *Reported By*

The next two columns describe the responder to the event and this one is entered as a text string. The values range from a general description of an entity (ex. Port Aransas Police Department, tourist) to a specific person (ex. A. Amos). However, 678 records do not have any data.

Column P: *Reported Phone*

Along with the column above, this is descriptor of the responder to the event. Unlike Column O, this column is a numeric string in the format ###-###-#### representing an associated telephone number. Few of the columns do have telephone numbers and no reported information in Column O. Six of the records do not follow the numeric format and 1268 records are blank.

Column Q: *Recovery Date*

Recovery Date is the date that the TMMSN responded to the stranding event, which can slightly vary from the report date depending on the distance from a TMMSN region location to the animal(s). Also, this column is also formatted differently as ##### to represent Julian calendar day. There is no explanation for the change in format from the TMMSN. Records are not available for every matching *Date Reported* field and 1287 fields are blank.

Column R: *Recovery Time*

This column corresponds to *Recovery Date* in a similar manner to *Date Reported* and *Time Reported*. There are no additional format styles to the standard and military time reporting. As with the other time column, there are missing blanks to the values in Column Q. Also, 1667 fields are blank in this column.

Column S: *Recovery By*

Like the past columns, this one is similar to *Reported By*. The difference is the text string is one or two names of responders directly affiliated to the TMMSN. There are fewer entities or people than in the *Reported By* column. There are still 1380 empty records.

Column T: *Recovery Phone*

Recovery Phone is in the exact same format as *Reported Phone*, but now corresponds to the column above. There are 1433 blank fields.

Column U: *Date Collected*

Column U is formatted in Julian day time string. There is one field not following the format and 280 records are empty.

Column V: *Time of Exam*

The *Time of Exam* is a field associated with medical examination on live animals or the start of the necropsy. As with the other time columns, the format shifts between central standard and military time. There is not start time or date of exam time, but most correspond with the *Date Collected* field. There are 958 empty fields and 1 field with a general description that is a text string and not a time value.

Column W: *Collected By*

This column is structured the same as *Recovery By*, but is even more refined to persons conducting the necropsies of the stranding events. There are discrepancies in this column, such as fields with no specific name (ex. same), abbreviations, or do not have proper full names. Only 397 records are blank.

Column X: *Collect Phone*

The phone numbers in this column match the format of previous numeric telephone columns and are the phone number directly related to the field in Column W. There are 441 empty fields in this column.

Column Y: *State*

The *State* column designates the state in which the stranding event occurred. The format is a text string and is either the proper state name or two-letter postal abbreviation. There are three options in this column: Texas, TX, or Louisiana.

Column Z: *County*

This column records the Texas or Louisiana county that stranding event occurred in. The data is entered as a text string and can be one of following: Aransas, Brazoria, Calcasieu, Calhoun, Cameron, Chambers, Galveston, Harris, Jackson, Jefferson, Kennedy, Kleberg, Matagorda, Nueces, Refugio, San Patricio, Vermilion, and Willacy. There is one unidentified field labeled '*Offshore*' and 51 columns are not filled.

Column AA: *Specific Location*

Specific Location is a text string description of where the event happened and includes references to geographic features, structures, and commonplace items. Mileage to and from these references is also included in the majority of the events. There are some fields that do include only a distance or only a feature reference. The remaining amount of fields includes both distance and a feature reference, but 107 fields are empty.

Column AB: *Latitude Degree*

The next columns are the geographic location of each stranding event. These data are recorded with a standard hand-held GPS unit and no specific coordinate plane is identified. The format is separate columns with degree and minutes.

This first column is latitude and ranges from 21 to 30 degrees. There are two columns with abnormally large degrees, '96' and '97', which do not fit into the range of the Texas or Louisiana coastlines. Also, 174 fields do not have a latitude recording.

Column AC: *Latitude Minute*

This column corresponds to the one adjacent and is the remainder of the geographic location in the numeric format of ##.#### and range from 0 to 60. However, there are 9 fields above 60 and reach as high as 4302. There are 180 empty records.

Column AD: *Longitude Degree*

Column AD is the complementary geographic location to the *Latitude* columns. The numeric values in this column start at 27 and reach 98. There is one column with a data up to '976.5'. The lower end of the scale is not correct longitude values for either Texas or Louisiana. There are 175 blank data fields.

Column AE: *Longitude Minute*

This column structure is identical to *Latitude Minute*, but there are only 6 fields above 60 extending to 80. There are also 182 empty fields in this column.

Column AF: *NMFS Stat. Zone*

The formation of this column and data entered is not known. This is currently being followed up with the TMMSN. There are only four values (18, 19, 20, and 21) largely repeated, but one value (53) in the column. This is also one of the least filled columns with 2738 empty fields.

The next series of columns are information determined from the individual event necropsies. The reasoning and descriptions for the data are dependent on the party responsible for conducting the necropsy. The pathology data (*Toxicity* columns) units are not known and not necessary for the questions addressed in this project. These last series of columns are the most incomplete in the dataset.

The remaining columns are formatted as text strings, despite the numeric values ranging from 0 to 4. The columns are defined as text by the Y or N in the columns, which means the column topic, was measured or not. According to the peronsal communication with the TMMSN, not all necropsy data for the events will be conducted or recorded if previously conducted.

The last columns are numerically formatted and represent data recovered in addition to the stranding event site, depending on the condition of the animal. The *Teeth Count* columns represent the number of teeth and respectively are in order as upper right (*UR*), upper left (*UL*), lower right (*LR*), and lower left (*LL*).

Column AG: *Vouchers*

There are 494 blank records for this column.

Column AH: *Toxicity Blubber*

There are 2198 blank records for this column.

Column AI: *Toxicity Muscle*

There are 2202 blank records for this column.

Column AJ: *Toxicity Kidney*

There are 2218 blank records for this column.

Column AK: *Toxicity Left Liver*

There are 2223 blank records for this column.

Column AL: *Toxicity Right Liver*

There are 3046 blank records for this column.

Column AM: *Toxicity Bone*

There are 2162 blank records for this column.

Column AN: *Teeth Count UR*

There are 2202 blank records for this column.

Column AO: *Teeth Count UL*

There are 2167 blank records for this column.

Column AP: *Teeth Count LR*

There are 2193 blank records for this column.

Column AQ: *Teeth Count LL*

There are 2119 blank records for this column.

2.2 Deciding the Supporting Program for the Database

The original data arrived from the Texas Marine Mammal Stranding Network in a Microsoft Excel file containing 3302 entries. Upon opening the original file, only 2258 were visible, with the remaining 1043 rows hidden within the Excel worksheet. The file condition was weakly structured with no limitations on types of data stored in the rows and columns. The deficiency in organization could be attributed to multiple users entering data and the rate of turnover in database monitors at the Stranding Network. The database originated as a requirement of the NMFS protocol and has primarily served to only to store paper record entries, but was not designed to be accessible for extraction and analysis into other systems. This is evident in the variations between numeric and text fields and the multiple option choices for each column. The original status of the file also does not include descriptors for data entry to maintain continuity among the fields and does not impose restrictions for quality control during data entry, such as limiting date stamps to only a single format.

To utilize the data in other applications, such as GIS, it was necessary to rebuild the database. However, rebuilding efforts should be done with application similar to the current application used by the TMMSN. The focus in this study is to enhance the current storage system to increase the accuracy and the reliability of data entered and transferred from the original application. The other major focus is to choose an application to serve all user levels working with the data entry and processing in the future. When choosing a new application, I considered four main points. The points considered were:

- *The original purpose is to store data and report event rates to NMFS*

  The application of choice must have adequate storage capacity and be able to extract specific datasets from the entire table without affecting the integrity of the entire database. Any additions and redesigning should have this point as the primary focus.

- *The application must be accessible to multiple users and levels of user-computing capabilities.*

  Since no one person is responsible for data entry or collection, the application must account for all possible user-levels from users with minimal computer skills to higher-level users familiar with application coding and scripting. With the multiple user-levels, the new application should be similar to the application currently used and provide the most benefit to the TMMSN.

- *The application must have restrictive monitoring capabilities for data entry.*

  Unlike the original database, the rebuilt system must restrict cell entries by allowing the user to designate strict entry formats for each column and row. By enforcing specific cell formatting to the row and column, rather to the individual data cell, the user can prevent multiple formats in one descriptor, such as the *Date* or *Time*, and can validate the range of entries within a particular column, such as the geographical extent for *Latitude Degree* and *Latitude Minute*.

- *The application must be accessible for data entry, importing and exporting data, and adding or altering specific data entries.*

  Along with the previously mentioned requirements, this application must be simple enough for the user to isolate smaller sets from the database to export into other applications and/or to create individual reports as necessary for the user. The application must also restrict access among various users to the entire dataset and allow event information importing and exporting on smaller datasets, rather than requiring the user to maneuver through the entire dataset. An example of such use would be having the veterinarian performing the necropsy to enter in necropsy results for a particular event in a smaller subset table adjoined to the entire database. This would eliminate the veterinarian having to sift through the all information collected at the stranding site or during rehabilitation efforts, when he/she only needs to enter a small amount of information not pertinent to the site or efforts. With an application to create smaller subsets of tables personalized to the user and linked to the entire database, data entry errors will be reduced.

After considering the four application criteria, I decided to rebuild the original database in Microsoft Access. To keep the original foundation and user focus of the database, Microsoft Access was used for its similarities to Microsoft Excel and ease of data extraction. Microsoft Access is a relational management system, in which users can build tables to extract data without destroying the integrity of the original data file. Access also provides a simpler method of altering and correcting data through creation of queries and can work faster with processing larger datasets, such as TMMSN stranding records. Unlike Excel, Access can provide a basis for either a novice or expert programmer to effectively manage data with object-oriented techniques or Visual Basic programming scripts. As opposed to Excel, the multitude of file extensions to export data allows easier importing into analysis programs, such as ArcGIS 9.2.

Another major feature of Access is structure query language, which is a database computer language designed for the retrieval and management of data in relational database management systems, database schema creation and modification, and database object access control management (www.microsoft.com/Access). In simpler terms, the query ability of Access allows users to create subsets of the database necessary to answering specific questions without altering the original data files or having to sift through all database rows and columns. The queries can also be saved for later examination and can overlap between many databases, not just the original data source. Linking between multiple tables can be useful in allowing different users to construct data storage depending on the aspect of their research or intended purpose. For example, a veterinarian pathologist can construct a smaller table for data related to necropsies and then use a common entry column to link that information with the original dataset. This minimizes the amount of users with the entire dataset and maintains the quality of all the data collected.

This program also provides more opportunities for exporting data with reports and forms. Instead of filtering and exporting to another dataset in Excel, users can create forms and tables linked to various queries or tables in Access. This provides a method of consistent reporting that can be built to suit the user at the time, rather than running the risk of altering the original data files. As data is added, the queries, forms, and reports automatically update with each user application, which is also not a feature available in Excel. Unlike Excel, the hierarchy formations possible for database building in Access allow a more positive user environment for storing and analyzing marine mammal stranding events.

The entire TMMSN database was transferred into Microsoft Access and assigned permanent format conversions depending on the fundamental intent of the column described in Section 2.2. Changing the format allows security features to be assigned to the individual columns. The security features help to maintain the original integrity of the data and prevents accidental mistypes and/or other error entries. An example would be a user entering data in *Date Reported* in the format MM/DD/YY would not be able to do so. An error message would pop up instructing the user of the correct format for the entry, which is MM/DD/YYYY. This is also includes preventative measures for users being able to enter temporal data that is outside the range of months (1 to 12), days in a month (1 to 31), and restricting the year to not accept any value outside of database yearly range. Another benefit of redesigning the database in Access is the ability to enter descriptors in the design view of the database. Unlike Excel, users can access this feature and read about the type and format required of data before actually inputting data. Message boxes can also be created to alert users if incorrect data is inserted and detail the corrections to be made. Finally, and most importantly, a key code was assigned to each record, making each record unique and linked through any tables or queries created during the analysis process. Also, the key code allows a method to efficiently alter or add data to the original database and is automatically generated with each row formed in the database.

The next step before attempting to answer the questions posed in this study is correcting errors in the data, or asserting a quality control to the primary database. Columns that underwent a strict quality control and control changes completed are as follows:

Region

Spelling corrections and blank entries were filled. The blank regions were confirmed by the latitude and longitude plot in GIS.

Species

Species scientific names were verified through the International Union for Conservation of Nature (IUCN) (www.iucn.org). A new column was created, title *SpeciesCorrected*, for any changes made to the existing fields. Also, any field with a scientific group name combined with *Unknown*, was labeled *Unknown* in this new column. For example, *Kogia spp.* was recorded as *Unknown.* Also, any blank fields were coded as *Unknown*.

LatitudeCorrected

The original data were divided into two separate columns, one with latitude in degree and the second in latitude minutes. This can cause issues with exporting, since the data will be limited by space and hard to combine in other applications. Therefore, the spatial location columns were converted into one spatial designation by dividing the *Latitude Minute* value by 60 (for 60 minutes in an hour) and combining this proportion to the respective value in *Latitude Degree*. This created one accurate geographical location without concern for compass orientation that could be easily exported and spatially manipulated in GIS. By creating one value, this new column gives one X-Y coordinate resembled to the common geographical output of a hand-held GPS unit. However, the type and system set-up for the handheld units are not known, so no datum corrections could be applied to the dataset.

LongitudeCorrected

This next column was created with the same procedures as **LatitudeCorrected**, except the values are in columns, *Longitude Degree* and *Longitude Minute*.

IDCODE

The last and most vital addition to the analysis database is the unique code for each stranding event with an independent descriptive. This column can be exported in conjunction with any other column and used as a mapping value to identify events. This code is internally locked by the Access program and cannot be altered by a user. The code values for this dataset range between 1 and 3301 and are stored as numeric text to eliminate computational confusion in this study and to replace the initial codes created by the TMMSN. It is important to note that the key code is not limited to a numeric format and can be specified when developing any database.

2.3 Graphical Processing for TMMSN Stranding Event Analysis

The columns above were data derived from the original TMMSN database. The original database and corrections did not provide enough spatial information to answer the proposed study questions. The next descriptions explain how the data was additionally processed to provide for a thorough understanding of the spatial distributions for stranding events. Section 6 will try to assess if these new spatial distributions are beneficial to these studies of stranding events.

A preliminary geographic viewing of the stranding events specified no spatial designation besides the county in which the stranding event occurred. Looking more specifically at this attribute revealed that the identification of such events were due to the occurrence of the event in counties associated with the TMMSN stranding regions (Figure 1.2), rather than county where the event occurred. The distribution of the points in relation to the Texas coastal regions revealed the necessity for a stronger spatial distribution descriptor. In order to answer the questions posed, the following spatial categories were created simply by dividing the Texas coast into three major areas typically referred to and studied in various oceanographic applications. The remaining designations describe the event locations not in the created areas. The formation of those areas as follows for the Column ‘MapLocation’:

MapLocation

NoLocation

This category defines any event that does not have an associated latitude or longitude or has a value of 0.0000 for either latitude, longitude, both. *No Location* also is used to categorize stranding events that occur outside of Texas state lines. Examples of events in this category include locations in Louisiana, Kansas, and the Pacific Ocean. Events in this category have no influence on the conclusions drawn from the analyses in this study and are not critical to analysis of marine mammal stranding events along the coast of Texas.

Inland

This category covers errors in the GPS coordinates entered into the database and any location that is approximately 0.5 miles from an inland body of water, including rivers, coastal and ship channels. *Inland* is different from *NoLocation.* This category includes events that have an actual geographic location, but the location is not accessible by a live marine mammal. Also, this category includes stranding locations where a animal could be transported inshore by either river, flooding, or tide cycles. Evaluating events in this category would require acquiring the paper records at TMMSN, which were not available at the time of the study.

Offshore

This category covers events that occurred up to 1-mile off the Texas coastline. Unlike the previous two categories, these events are completely located within the state boundary and Economic Exclusive Zone for the United States. In email conversations with the TMMSN personnel, open ocean stranding events are possible at buoys and oil platforms and are still documented and/or responded to by the organization if possible. Events in this category also include *Offshore* boating reports called in by various entities, both industrial and recreational. The 1-mile determination is based on the distance that an observer on the shore could see clearly while looking out to the ocean on a calm day. As discussed in Section 1, no scientific literature exists on similar geographical spatial considerations (Figure 2.1)

The next three areas pertain to the commonly studied coastal characteristics in Texas.

Bay

This category includes stranding events that were reported in the bays. Five bays were specified and are shown in Figure 2.2: Galveston Bay, Matagorda Bay, San Antonio Bay, Corpus Christi Bay, and Aransas Bay. Though not all these bays are commonly referred to as bay systems, the volume, length, and width of these features distinguishes these water bodies from the intra- and inter- coastal channels along the Texas coast. From Figure 2.2, there appears to be a significant indentation in the southern area of the state corresponding to the location of the Texas Bight (Vastano et al. 1994). However, the location does not exhibit any considerable separation from coastal passages extending from Corpus Christi to South Padre. The locations were separated from *IntraCoastal* passages by constructing a hard-line boundary across the lowest southern land features. As with the *IntraCoastal* designation, stranding events within 0.5 miles of the bay land boundaries are included in this category. Events in this buffer can be affiliated with the person reporting the stranding or by natural or unnatural hydrology processes in smaller inlets.

IntraCoastal

Moving inland from the shore, this category defines any event within the confines of the Texas coastline, including the intra- and inter-channel waterways, passages between bays, rivers, and estuaries. Locations also include events within 0.5 miles of these features to include animals moved by choice or by unnatural processes, such as river flooding or construction efforts. These events are anything that is not included in a bay or is located towards the open Gulf of Mexico. Figure 2.1 shows an example of an *IntraCoastal* location in Galveston Bay

OpenOcean

This is the last spatial designation to divide the stranding events. These events are any that are located on the open shorelines facing the Gulf of Mexico or fall between the shore 1-mile boundaries between the *Offshore* locations. As with the other categories, the events are also considered if the location falls inland 0.5 miles from the Texas shore as seen in Figure 2.1. Stranding events can possibly be influenced large tidal changes and storm surges, which can create temporary inlets to move further in from the shoreline (Geraci and Lounsbury 1993).

In an effort to further elaborate on the newly created locations, the columns ‘LocationValue’ and ‘LocationComment’ were added.

LocationValue

This column adds descriptors to the column 'Map Location'. The column is designed as a text format with the combination of number and letter codes. The values for this column range from 0 to 2, with 0 representing a stranding event located entirely in water. An example would be a geographical location plotting in the middle of Galveston Bay and is not close in distance to a land feature. A value of 1 signifies an event on the coastline or water's edge. The last value, 2, describes an event not occurring in and near the water. Examples of this value include stranding locations entirely on land, on buildings, or on roads. To show a few of these locations, Figure 2.3 is a snapshot from Google Earth with stranding events mapped. The numeric codes detail the placement of the stranding event, whether the animal stranded entirely inland or in the water. The letter codes define the specific location or a more generalized spatial location to coincide with the 'Map Location'. For example, if an animal stranded in a bay, then the 'Location Value' tells which bay the animal stranded and the placement of the stranding in relation to the water.

LocationComment

To further elaborate and provide even more description, 'Location Comment' gives relatively general details about the stranding location. The general categories are *building*, *road*, *home*, *land*, and *flooding*.

Comments that follow after one of these categories are placed in parentheses and provide a more refined description.

These three columns provide enough information of the stranding event for any person to know whether this is a valid point to investigate or if a recording error exists. If a mapping resource is not available, these columns provide more spatial awareness in order to determine if the event should be considered in a particular analysis. The use of the columns in this research project will be discussed in the methods for each individual research question.

2.4 Mapping Preparation for TMMSN Stranding Event Analysis

The last major reworking of the original database is reformatting the latitude and longitude. The stranding events are recorded from a hand-held global positioning system (GPS) and have no known associated projection. With multiple TMMSN responders to stranding events throughout the state, it is difficult to know what type of unit was used and the knowledge level of the GPS user. The information was also not available during the time of this study. This could explain why the latitudes and longitudes are entered in the database as four separate columns and the degree is separated from the minutes and seconds. However, this format is not compatible with mapping programs used in this research. In order to better export the spatial data, the columns were calculated from degree and minute to decimal degrees. This was done by dividing the ‘Latitude Minute’ and ‘Longitude Minute’ by 60 separately and adding the ratio value to the corresponding ‘Degree’ column. The formatting is now considered decimal degrees and can be easily exported as one column to any program. Both the

'Latitude' and 'Longitude' columns are considered as absolute locations, both showing as positive numbers to provide a simple and basic coordinate reporting level understandable for any user. Yet, when exporting to the mapping programs used in this research, the 'Longitude' had to be converted to negative values. This was done with a script during the data export and was imported as negative numbers into the analysis programs. The negative values are referring to the Prime Meridian as 0 degrees and all locations to the west of 0 are negative and to the east are positive, rather than 0 to 360 degrees. Using a number line system eliminates directionality associated with the values, such as east (E) or west (W). Decimal degrees are also common among oceanographers and can easily be transferred between multiple applications. To not lose accuracy in the position during transfers, the ten-thousandths decimal place was maintained in the column formatting restrictions. Exporting and importing of the series with format restrictions allowed resolution to be equally maintained in any mapping program applied. Once again, the primary goal in the methods was to maintain the simplest data recording option for the original database and maintain a flexible accessibility level for all types of users. The original database and tables created during this research maintained formatting consistent to the original TMMSN database.

The Environmental Systems Research Institute's platform, Geographic Information Systems 9.2 (ArcGIS 9.2), was the primary mapping resource for this project. General Mapping Tools (GMT) was considered, but the unreliability of coastal resolution and coastline source data presented concerns with determining location values. In GIS, coordinates are imported as longitudes and latitudes to position on a map, similar to a one-dimensional x- and y-graph. The points are then compiled into a shape file containing the table imported and storing the locations as points with geographical attributes. Since a basic coordinate is the primary base, the data are considered on a number-line system, where 0 is the center on both the x- and y- axes. Map projections in this GIS must be designed by the user. On initial importing, no spatial coordinate system is defined. However, the map in this program is not built automatically in the code and projected on the same X-Y plane. In this program, a spatial reference must be assigned and the imported points must be projected into this spatial dimension. Various data layers were imported to create the base map, the coastlines, and the associated hydrology for Texas. The layers entered into GIS are presented in Table 2.1, as well as the source of the data layers. The processing and projection order of the layers and stranding events were projected into the Texas Centric Map. This spatial projection was designed and adopted by the state of Texas as the official projection for mapping focusing on the entire state (http://tgic.state.tx.us/standards/tgic-s06.doc). According to the Texas Geographic Information Council, the purpose of this projection is to clearly define an optimal coordinate system to use for geospatial datasets spanning the entire state of Texas, termed the 'Texas Centric Mapping System' (http://tgic.state.tx.us/standards/). The TCMS projection substantially reduces map distortion compared to a statewide projection system and provides true curvature of the Texas coastline. The ability to resolve the curvature along the coastline provides a map to better analyze stranding database attributes, such as the spatial or temporal event attributes. This projection is either spatially designated as a Lambert Conformal or

Albers Equal Area. For this research, the Albers Equal Area was chosen for original layers and layers imported with a different projection were re-projected. The information for the projection is as follows:

Mapping System Name: *Texas Centric Mapping System/Albers Equal Area*

Mapping System Abbreviation: *TCMS/AEA*

Projection: *Albers Equal Area Conic*

Longitude of Origin: *100 degrees West (-100)*

Latitude of Origin: *18 degrees North (18)*

Lower Standard Parallel: *27 degrees, 30 minutes (27.5)*

Upper Standard Parallel: *35 degrees (35.0)*

False Easting: *1,500,000 meters*

False Northing: *6,000,000 meters*

Datum: *North American Datum of 1983 (NAD1983)*

Unit of Measure (or map unit): *Meters*

Additional processing for mapping or analysis procedures in GIS will be discussed in the *Materials and Methods* for individual research questions.

3. HOW ARE STRANDING EVENTS DOCUMENTED AND/OR RESEARCHED IN THE LITERATURE?

3.1 Introduction

Stranding event accounts appear in numerous media avenues from television to newsprint to peer-reviewed scientific journals. Descriptions of events exhibit a wide range of information, from statistical reports to personal accounts at the event site. Though useful for general event comparisons, media avenues do not provide specific details or accurate reporting suitable for use in scientific analysis. To analyze how stranding events have been documented and researched in the literature, it was necessary to limit the extent of information available from the public, academic, and government communities. As mentioned in Section 1, many stranding networks and agencies are monitored both by the federal and corresponding state governments. With the majority of a network's resources dedicated to responding and rehabilitation with stranding events, very little scientific research is conducted and published within the network or agency. The extent of the information available is reported numerically, such as events per year or month. Event site reports and necropsy conclusions will be reported by the state agency or federal government, but such reports are associated with specific initiatives regarding public policy. In the academic avenue, these reports are referred to as 'gray' literature and are commonly not peer-reviewed or published in scientific journals. The data available in reports is also extremely limited and time-consuming to acquire from federal agencies. Though unusual, a few networks do publish in the scientific literature, but the publications often focus on specific stranding events or pathology studies. This type of publication is common with the Texas Marine Mammal Stranding Network (www.tmmsn.org). In order to investigate the extent of stranding event publications, a scientific literature search was conducted from the start of this study until May 1, 2008.

3.2 Methods and Data Preparation

Though scientific data is reported by networks and agencies, the format of the data collection and publications is not consistent and often difficult to validate due to time constraints in acquiring the data or restrictions imposed by the agency. Therefore, to answer this question, only scientific literature validated through the Texas A&M Library system was considered. Scientific literature in this research involves articles published in academic and scientific journals that have been peer-reviewed and cited at least once by marine mammal researchers. Literature confirmation was achieved using the Texas A&M University Library databases and/or required remotely though TAMU Libraries. If a published article was available on a stranding network website, it was authenticated through the Texas A&M system. With articles immediately found in the database queries, the article citations were also thoroughly searched for additional articles to supplement the initial query. Terms processed in the queries included 'marine mammal', 'cetacean', 'beaching', 'dolphin', 'whale', 'die-off', 'strand', 'stranding event', 'whale death', and 'dolphin death'. These terms were derived from key terms documented in Geraci and Lounsbury (2003) regarding terminology written to describe stranded cetaceans. Articles were also filtered to exclude any marine mammal not in the cetacean family, such as *Tricheus* spp. or commonly referred to as manatees. Articles were not restricted geographically and the search was not limited historically, but was limited to May 2008 in order to complete this work. The articles were also limited to the number of stranding events discussed in the research. Since this research emphasizes the study of stranding event databases, articles focusing on a single stranding event with only one marine mammal were excluded.

Articles located in the search and validated for journal authenticity were then entered into a bibliographical database created in Microsoft Excel. The information recorded for each article included: *Article title, Author, Date Published, Source Type, Extent of Stranding Information, Pages with Stranding Information, Geographical Extent, Continent of Data, County of Data, Ocean of Data, and State/Province of Data*. To fill these later columns, each article was read and processed specifically for mention of stranding events. The extent of the stranding events were not considered in the initial collection, but were categorized in the *Extent of Stranding Information* for future work. The columns of interest for these questions were the temporal extent of the data and article publication, as well as the geographical extent of the researched data.

After all the information was entered into the database, about six main research foci were evident. Categories were created encompassing these major topics and each article was color-coded into one of the following seven categories. If articles fell within more than one category, it was recorded in each category. The categories are described as:

Category 1: Diet Studies Conducted on Stranded Marine Mammals

This category was colored red and represents an article in which the primary goal focused on marine mammal diets or feeding patterns using the stomach contents of stranded cetaceans. The titles of these articles typically include the terms ‘stomach contents’, ‘diets’, or ‘remains’.

Category 2: Response or Rehabilitation of a Stranded Marine Mammal

The second category was coded green and represented an article in which the primary focus was on the behavioral response and/or rehabilitation of a live stranded marine mammal. Articles focused on one to three marine mammals rescued from a stranding site and released back into their natural environment. The article accounts the rehabilitation process and the behavior associated during and immediately after the release. This category is one of the more specific categories in terms of scientific focus and the number of stranded cetaceans analyzed.

Category 3: Cetacean Population Analyses or Observations of a Population

The third category is colored gray and categorizes an article where the primary goal of the article is the status of a cetacean population determined by observational monitoring for an extended spatial or temporal series. These articles commonly do not refer to stranding events in the title, but use the quantity of stranding events as one element in monitoring a specific population. These types of articles are important because the extent of the stranding data referred to covers longer temporal scales than the other categories.

Category 4: Pathology or Physiology Studies with Stranded Marine Mammals

This category uses an orange code and refers to any scientific study with a pathological or physiological emphasis. As with Category 1, these studies focus on stranded cetaceans and can include a small to large range of events in the data analysis. This focus, as with the first category, can be beneficial in that scientists commonly extract subsets of stranding events from a larger stranding database.

Category 5: Specific Incident Study of a Single or Mass Stranding Event

Category 5 is coded blue and is a study of a particular and individual event. The primary article focus is the details of the event, including the response and outcome of the event. These articles simply document the basic characteristics of the event, essentially the 'who, what, where, and why' rather than an in-depth analysis of causation or animal response as with the above groupings. The extent is not from a large database and is not particularly useful for this research.

Category 6: Studies with Large Stranding Event Databases – General Analyses of Stranding Events

Unlike the other categories, this last specific grouping refers to articles describing large stranding databases. The code for the category is purple and titles of inclusions commonly include a temporal extent greater than a decade and a specific geographical location, such as ‘Cetacean Strandings in Oregon and Washington between 1930 and 2002” (Norman, S.A. et al. 2004). The spatial locations are across the world and the temporal extents can include historical stranding information. This category is most reflective of the research in this project.

Category 7: None of the Above

Very few articles could fit into any of the above categories, but still included stranding events as a primary focus or in factor analysis. One such example is an article describing cetacean habitat in the Gulf of Mexico and used stranding data as one factor in habitat analysis (Davis, Randall et. al 2002). Another example includes an article emphasizing mortality in all mammals, with cetacean stranding events as one of the major facets investigated (Caughley 1966).

3.1.2 Data Representation

After defining each article into a category or categories, bar plots were constructed in Microsoft Excel for the numbers of articles in each category (Figure 3.1). Bar plots were also made to represent the number articles per year published (Figure 3.2**)** and also to show the number of articles published by decade **(**Figure 3.3**)**.

The next database column prepared for graphical analysis was ‘Continent’. This column denoted the geographical continent where the stranding event data was documented. If the data did not fall into any of the seven continents, the field was left blank. The same procedure was maintained for the remaining geographical columns.

The ‘Country’ column detailed the country in which the stranding events occurred and was further documented to the ‘State/Province’ column. For the ‘Ocean’ column, the major oceans and seas were acceptable entries. Most of the literature documented had corresponding map locations for the data points to also confirm the water location. As with ‘Continent’, if the descriptor could not be determined the field was left blank. If the stranding events occurred in more than one geographical description, all were listed. Such an example would be in the ‘Country’. In the Berrow et al. (1993), stranding events were described in both Britain and Ireland, so both countries were documented.

3.3. Results and Discussion

The basic search provided 151 scientific articles relating to cetacean stranding events: however, not all of the references were cited in this thesis. Figure 3.1 shows the distribution by categories of the database. The greatest number of total articles falls into Category 6. The next largest are Category 5 and 3 respectively. The smallest grouping is Category 2, with only five articles. The percentages the articles compose for each category are represented in Figure 3.4. None category makes up over half of the entire database, with the largest category falling slightly over 30%. Therefore, none of the categories are significantly larger than the others.

The next plots represent the number of articles published per year for the extent of the literature database (Figures 3.2 and 3.3). Since there are only a few publications per year, the bar graph appears congested. However, it is evident that the number of publications increases significantly from the late 1990’s into the present year. To show this increase, the data were grouped into decades and plotted. The increase into the more recent years is also evident in this graph. By the increase present, it would be expected that the publications would increase further to the end of the 2000 decade. However, publication rates are dependent on a multitude of uncontrollable human factors, such as author production, journal review and publication dates, and deadline submissions. Therefore, it is not practical to fit a trend to estimate the number of stranding publications in the near future. It is a simple generalization to assume that the amount of publications will increase, seeing that every decade does increase slightly. The more important note is that the majority of stranding event articles follows after the implementation of the Marine Mammal Protection Act and the initial formations of stranding networks across the world. Yet, compared to the immense amount of cetacean literature not related to stranding events, the overall amount of publications comprises on average only a minute percentage of the scientifically available literature circulating among the marine mammal community.

Figure 3.5 graphs the distribution of the stranding event data in the literature by continent. Africa has the least amount of published stranding literature data, whereas North America has significantly the greatest counts. The location of the stranding event data in the literature for North America does not specifically pertain to the United States, but can also include provinces in Canada and states in Mexico. The remaining continents fall in between the counts for North America and the lower ends, Asia and Africa. Australia, Asia, and South America are close to the same in scientific publications with stranding event data occurring in the respective continents.

The next bar graph, Figure 3.6, breaks down the continent of the data publications into the individual countries in which the events occurred. The bars are also coded according to the continent the country is associated with. The largest, as corresponding to the continent results, is the United States with a significant advantage over the other countries. All the others documented in the literature fall below ten counts. Even with removing the United States count from the graph, no other country has as significantly documented stranding event occurrences.

Figure 3.7 represents the ocean associated with the stranding event literature occurrences. As mentioned, the primary ocean and seas were acceptable descriptors and none of the documented literature included anything more specific. Three of the major oceans are have a significant larger stranding event occurrence than the other oceans, Atlantic, Pacific Oceans, and the Gulf of Mexico respectively. These results correspond positively to the output of the countries and continents. The three largest oceans outline North America and border Europe, which compose the highest terrestrial documentations. The other documented oceans fall from 10 counts and below. The graph also is unique in showing what is not present, in that there are no stranding events documented around Antarctica in the Southern Ocean. The reasoning behind this can be due to low observational data available since there are no stranding networks established or steadily monitored cetacean populations. This is also true for the smaller areas with lower publications, in which the publications are a result of a specific event occurring in the particular area.

The last output of the stranding events is Figure 3.8, which is a bar graph delineating the stranding documentation in the United States by the specific state the events in which they occur. There is no state with a significantly larger count than any other state. Texas has the largest count; however further investigation shows the events are primarily Category 3 (Cetacean Population Analyses or Observations of a Population) with only minimal focus on the stranding events. This pattern is also the same for Alaska, which shows the second largest number of stranding event occurrences in the literature database. The western coastline has the fewest total articles published on stranding events, despite being a heavily researched area for cetacean population studies and having a high coastal population distribution along the California coast. With the skewed distribution from Texas publications, the Gulf of Mexico has the highest proportion of documented stranding event literature, followed by the eastern coastline due to the higher counts in Florida.

3.4 Conclusions

The literature search revealed an increase of publications from the mid 1990's to the present. From first appearance, Figure 3.2 seems to portray a large focus in stranding event research; however the publication counts are small and not close to the number of the available literature for marine mammal populations, behavioral, and/or species observational studies. The increase can be attributed to the awareness and accessibility of longer time series provided by stranding networks, but still demonstrates the need for more thorough studies with large stranding event databases. The trend in

Figure 3.3 is optimistic that the marine mammal research community will have access to more published studies emphasizing stranding events.

With the strict implementations of the MMPA of 1972 and the formation of stranding networks, the United States is leading the stranding event research. However, when examining the breakdown of the states publishing within the continent, Texas is relatively close to Alaska. This similarity can be a result of both states having one stranding network, resulting in a limited data collection and accessibility for scientific research. Also, with these two as the largest states, there are more personnel and volunteers dedicated to sustaining the function and response of the stranding networks.

Finally, the data results for the oceans (Figure 3.7) are not unusual. The three largest bodies of water with documented stranding studies have the largest and consistently similar number of publications. The Gulf of Mexico, though not comparable in size to the coastlines in the Atlantic and the Pacific Oceans, is maintaining a strong presence in the marine mammal community. However, the skew can be attributed to the high Category 3 publications in part with the relationship between the TMMSN and University of Texas – Galveston. From this research and newly released studies concerning climate change and the increase of brevetoxins, the amount of publications regarding stranding events in the Gulf of Mexico will increase substantially in the future (Learmonth 2006) (Tolan 2007) (Fire et al. 2007) (Atlantic Fleet 2008).

4. HOW MANY AND WHAT TYPES OF MARINE MAMMALS STRAND ALONG THE TEXAS COASTLINE?

4.1 Characteristics of the GOM

The GOM of Mexico (GOM) is considered a “1.5 million km^2 semi-enclosed, intercontinental sea” (Davis et al. 1992). The Mineral Management Services (MMS) classifies the average depth of the GOM at 3,500 meters with a large, shallow continental shelf bordering the United States unique only to this area (www.mms.gov). The distinctive bathymetric features and ocean circulation within the GOM form varying localized cetacean habitats suitable for several species. The shelf varies in length from state to state and is extremely broad along the northern portion of Texas, creating a substantially greater amount of coastal shelf shallow water for cetaceans. The Loop Current is the major ocean current entering the Yucatan Straits, traveling northward toward Louisiana, and dropping back down and exiting between Florida and Cuba. This current can form eddies, which will often migrate toward Louisiana and Texas transporting valuable nutrients and an abundance of prey sources (Davis et al. 2002). The strength and duration of these eddies often contribute to the offshore cetacean habitats, creating favorable environments for many cetaceans (Davis et al. 2002). The other large contribution to water circulation in the GOM is the freshwater flow from the Mississippi River. Fresh water inputs transport sediments, pollutants, and nutrients from dissolved fertilizers onto the Louisiana shelf, affecting the spatial and temporal distribution of cetacean habitats (Davis et al. 2002). The seasonal freshwater flow is distributed down shore along the Texas coastline, which also affects coastal cetacean habitats. With a basic understanding of the factors established by the GOM shape and transport, it is possible to research which cetacean species reside in the GOM before investigating the species stranding in Texas boundaries.

4.2 Cetacean Habitat in the GOM

4.2.1 General Species Composition

Approximately 35% of the world's marine mammal species inhabit the GOM. The GOM has 19 species regularly observed in the northern GOM continental slope waters (Davis et al. 1998). Many of the species living in the GOM are permanent residents and do not leave at any time during the year. Few transient species, such as *Orcinus orca*, temporarily enter and leave the GOM in movement from the Antarctica to the northern Atlantic or vice versa. The behavioral patterns of the resident species influence the stranding rates along GOM continental shelf and shorelines. According to Geraci and Lounsbury (1993) and represented in Table 4.3, the following cetacean species have been observed and stranded in the GOM. From the literature search conducted for Question 1, scientific publications have documented the population sizes of the following species in the GOM: *Tursiops truncatus*, *Lagenodelphis hosei*, *Physeter macrocephalus*, *Grampus griseus*, *Kogia spp.*¸ *Globicephala macrorhynchus*, and *Stenella spp.* (Davis et al. 1998). Based on Table 4.3 and the population estimates calculated by Davis et al., the TMMSN database can be examined to see if the stranding events correspond to other GOM locations or are unique to only the Texas shores.

4.2.2 Factors Influencing Cetacean Habitat

As mentioned earlier, the unique shape of the GOM creates a semi-enclosed, secure, and extensive habitat for cetaceans. The GOM is more of a private residence with only two entrances for incoming and outgoing marine mammals. The shape and confined current flow form a strong basis for numerous factors affecting cetacean habitat. The primary factor for sustaining cetacean habitat is prey availability. For cetaceans, the semi-enclosed features support exclusive prey communities, as well as intricate primary and secondary productivity trophic levels. In the GOM, food availability is rarely a concern for inshore or offshore cetacean communities and there are many selections available depending on the habitat location, whether species choose to hunt in the estuaries for juvenile prey or in offshore waters for larger adult prey (Davis et al. 1998).

Cetacean habitat is also influenced by the physical circulation factors discussed in the first paragraph of this section. The fluctuating intensity of the Loop Current can slightly displace the offshore communities by shifting breeding regions for deepwater species or by shifting the group depending on the prey community locations. However, the strength of the current does not decrease the size of the populations, but rather displaces pods either inshore or offshore depending on the eddy movement (Davis et al. 2002). The same reasoning is true for the freshwater sources in the GOM. With a localized, predominant freshwater source, populations avoid stress by often traveling along coastlines away from the plume or simply diverting from Mississippi River during increased freshwater flow. Since Mississippi River discharge is seasonal, high during the late spring to early summer, populations can temporarily populate elsewhere and are not forced to leave the GOM, which is not true for other open ocean river sources (Davis et al. 2002).

The final factor controlling cetacean habitats is the atmospheric patterns in the GOM. Wind and storm forcing pose the most serious threat for coastal cetacean populations and can often displace communities into the unnatural, offshore waters. Moving to deeper waters and further out on the continental shelf can lead to disorientation, but has not been shown to cause large depletions in community size (Geraci 1978). Hurricanes, and other large-scale atmospheric disturbances, can also displace the population home range. Most examples are published in gray literature sources and refer to smaller species moving from offshore or shelf edge into coastal waters as a diversion effort from hurricanes or tropical storms. However, little scientific research has been conducted examining such cetacean displacement, as it is difficult to study habitat during these atmospheric or oceanic transient events.

An additional and common factor influencing the habitat distribution and abundance of species is anthropogenic sources. Coastal cetacean populations can be displaced by the increase of human activity in the bays and channels. According to the NOAA Coastal Trends Report Series, Texas and Florida have experienced a 9.6 million person growth from 1980 to 2003 (Crossett et al. 2004). The GOM accounts for 13% of the United States population and the coastal population has been experiencing a 45 percent growth rate since 2004 (Crosset et al. 2004). The largest population centers along the Texas coast are in Galveston-Brazoria counties, with approximately 2,000 people every square mile. Fast and large population increases can apply stress to the bay and coastal ecosystems, primarily stress on cetacean populations. Stress on any population can be detrimental, especially to coastal cetacean species that reside only in bay systems and do not form groups outside such systems. As the human population increases, the coastal cetacean populations will suffer since anthropogenic influences are a primary cause for destroying various aspects of a habitat from influencing prey abundance to introducing harmful toxins into cetacean communities (Atlantic Fleet 2008).

4.2.3 Inshore and Offshore Species Composition in the GOM

According to Davis et al. (2002), little research had been conducted in the GOM concerning cetacean habitats in deeper waters. An extensive survey by the NMFS and TAMU was conducted to observe cetacean populations in the waters beyond the continental shelf break (Davis et al. 2002). Results from the GulfCET six-year study detailed distribution and abundance of the 28 species in the GOM with the most frequent species observed being the Pantropical spotted dolphins, Clymene dolphins, and spinner dolphins (Davis et al. 2002). The offshore results published minimal sightings of the other remaining dolphin species and known whale species (Table 4.3).

Documented by Davis et al. (1998), the sighting localities of inshore, coastal species were Atlantic spotted dolphins (*Stenella frontalis*) and Atlantic bottlenose dolphins (*Turisops truncatus*). The spotted dolphins resided in the shallowest depths of the continental shelf and even extended to the shelf break. Bottlenose dolphins remain further inland on the continental shelf, extending to the exposed coastline, and into the intricate channel and bay systems along the Texas coast. These findings are also supplemented by Table 4.3, in which both of these species are the primary sightings and stranded species in the GOM as published by Geraci and Lounsbury in 1993. This study and email conversations with the TMMSN personnel also reveal *Tursiops truncatus* to be the most frequently stranded cetacean along the Texas coast. To understand these past observations, it is necessary to learn more about this dominant GOM cetacean.

4.2.4 General Characteristics of *Tursiops truncatus*

Tursiops truncatus, or the Atlantic bottlenose dolphin, is found in the shallowest GOM waters and rarely tends to travel to the edge of the continental shelf and beyond (Geraci and Lounsbury 1993). A large number of scientific publications focus on the populations, compositions, and behavior of this species. This species is also highly social and known for interactions with humans along the coastlines. The bottlenose dolphin is a medium-sized delphinid with slate to light gray solid colorations and usually a pink to white underside (Connor et al. 2000). There is a slight gender dimorphism with males averaging about 250 – 400 centimeters and females reaching a length of 250 centimeters. This species can live beyond 50 years and begins reproductive stages anywhere from 5 to 13 years of age (Fernandez 1998). The reproductive gestation period is about 11 to 12 months and birth is typically to one offspring (Wells and Scott 2002). Multiple researchers have documented the reproductive cycle to reflect seasonal fluctuations, with a “single or bimodal birth season centered in spring/early summer and fall” (Urian et al. 1996) (Ross 1977). Calves remain with the mother until reproductive age and departure from the maternal family depends on dolphin’s gender. Family, or group size, can depend on the location and number of residents in a particular location. For example, Galveston Bay supports approximately three to four and a half groups composed of 5 to 30 animals at any given time (Fertl 1994). Groups are typically composed of females and calves and older males beyond reproductive capabilities (Connor et al. 2000). Juvenile males, close to reaching reproductive potential and weaned from mothers, leave the groups and usually remain in smaller pods of two to four males or stay single. Groups are also considered open societies, allowing interchange in genetic pools between reproductive dolphins. In addition to the group formations, *Tursiops truncatus* also exhibit two types of animal forms.

Besides the unique group formations, research has shown two forms exist among the bottlenose dolphins. Wells et al. 1999 described the unequal density between bays, sounds, estuaries, and offshore resulted in the two sub-populations, termed “coastal” and “offshore”. The two ecotypes exhibit different genetic and behavioral characteristics, as well as a difference in appearance. The coastal type inhabits inshore waters and is generally smaller in body size, weight, and length due to the “increased demands for maneuverability and heat dissipation” (Wells et al. 1999). The offshore variety, on the other hand, is longer in body length and differs significantly in regards to gross anatomy, hematology, and cranial morphology (Connor et al. 2000). Movement between ecotypes, especially coastal groups, seems to be minimal and geographically limited (Shane 1977) (Lynn 1995). A minimal population estimate for the GOM coast calculated by Blaylock and Hoggard (1994) in 1992 was approximately 3,499 dolphins, but the population size was not determined for the ecotype populations. A more recent calculation by Mullin and Fulling (2004) estimate the oceanic stock abundance to be 2,239 bottlenose dolphins, with 1,607 in the northern GOM, with the stock not being uniformly distributed along the GOM coastline. Stocks, or combinations of groups, have been counted at 38, with 33 coastal and five offshore separate stocks (Waring et al. 2001). Understanding the overall species composition and the basic characteristics of the most abundant species in the GOM provides a solid background for analyzing the stranding database and can possible provide necessary explanations for the analyzed results.

4.3 Methods and Data Preparation

After reformatting and applying a quality control (*Refer to Section 2.2)* to the TMMSN database, the *CorrectedSpecies* column was exported into a text file for the procedural steps conducted in this section. First, the column was sorted alphabetically by species name and each was counted using a Visual Basic scripting code and confirmed with queries in Microsoft Access. The repeating species names were tallied and used to form the *Texas Stranding* Frequency in Table 4.1, as well as Tables 4.2, and 4.3**.** As seen in Table 4.2 and 4.3, stranding events were removed that did not include temporal or spatial characteristics along with species identification.

The columns extracted were also used to construct a series of graphs in Microsoft Excel to differentiate between types of cetaceans stranded and the location where the species stranded. For this question, only the difference in the numbers of species stranded was considered and the location distribution will be discussed in later sections.

The extracted Access columns were then imported into GIS with the latitude and longitude values as X-Y coordinates as explained in the *Section 2.3*. The following layers (Table 2.1) were added to complete density maps to show the species stranding events in these layers: *Texas Counties, Rivers,* and *NOAA coastline*. Within GIS, the TMMSN stranding region layers were created by selecting appropriate counties labeled in Figure 1.2 and creating individual shape files named after each region. With these layers designed, two maps were produced with one showing the separation in the individual species stranding events versus *Tursiops truncatus* and one without separating the individual stranded species (Figures 4.3 and 4.4). Figure 4.3 labels each species category uniquely with a differently color symbol, whereas Figure 4.4 maps each point with the same scheme. Point symbols were altered directly by changing the symbol properties in GIS.

The third map (Figure 4.5**)** designates the events as one symbol regardless of species to show the overall density of the entire TMMSN database over the temporal database extent for *Tursiops truncatus*. In addition to the previous figures, county labels were added to the Stranding Network Regions and an inset to show the GOM in relation the exaggerated coastline.

The statistical test used in this section was a z-test to compare between the population proportions of species stranded. For test preparation, the number of species stranded was treated as separate populations within the entire database. Since the sample size was extremely large, independent random samples were drawn using a random number generator in Microsoft Excel. All other parameters were considered unknown and the population size was calculated as a proportion of the entire population. In conjunction with separate species populations, all species excluding *Tursiops* *truncatus* was combined into one population to be included in the analysis. The test was chosen to compare the difference between population proportions with a null hypothesis that no difference exists between the populations. The unknown stranding species were excluded from this analysis, since no species designation was originally determined by the TMMSN. The data were then entered into SPSS and population proportions were calculated. The population proportion values were used to construct a 95% confidence interval and the differences between population proportions were tested with a z-test, an inference tool to compare statistical significance between populations. The inferences about population proportions are based on the z-statistic, or z-score, from a normal approximation curve (Ott and Longnecker 2001). For this test, the population proportions calculated were 0.94029 for *Tursiops truncatus* and 0.0597 for all other species combined.

4.4 Results and Discussion

As seen in Figure 4.1**,** *Tursiops truncatus* dominates the species composition of the database and is not even comparable to the other species. The number of events in the *Unknown* grouping was the only classification to reach more than 20 events from 1980 to 2004. All other species did not pass 20 stranding events as seen in Figures 4.1 and 4.2 where the *Tursiops truncatus* stranding events were removed to better resolve the y-axis. By removing the skew, greater stranding events comprised of *Stenella* and *Kogia* families are visible. The *Stenella* species are smaller pelagic dolphins commonly sighted in the GOM and were one of the dominating sighting groups mentioned in the introduction. Yet, though second in abundance to *Tursiops truncatus*, this species does not represent a significant part of the database. A few of these dolphins are predominantly inshore species (Table 4.1), explaining the slightly higher frequencies due to social natures as previously described in earlier sections. The *Kogia* species are also common frequenters to the GOM and also more common to the southern GOM, meaning this group resides permanently in the GOM (Geraci and Lounsbury 1993) (Davis et al. 2002). Naturally, a permanent residence would explain the higher stranding records in the TMMSN database.

In Table 4.3, stranding events occur only once every 1 to 5 years in the database, explaining the low distribution in the graphs. A substantial number of baleen whales are also not documented in the database and have rare sightings in the GOM. Baleen whales more commonly migrate for feeding and reproduction, this may explain why no species appear in the TMMSN records. Since migratory routes do not extend into the GOM, stranding frequencies may increase near Florida. The rare events that do occur are most likely attributed to baleen whale disorientation during migration, supported by the rare sighting frequencies described by Geraci and Lounsbury (1993).

The *Unknown* category is the second largest grouping, but is a result of data recording errors or the lack of information available from a stranding event and not important for this study. Therefore, the larger increase in the amount of *Unknown* stranding events is not dependent on the physical structure of the GOM or the location of the Texas coastline in relation to the other GOM states.

Investigating the frequencies of the Suborder-*Odontoceti* reveals there are fewer instances where no documentation exists in the TMMSN database. Also, the stranding frequencies between the entire GOM and the Texas coastline vary. Most toothed species are commonly sighted in the GOM and are rarely seen in stranding databases. For the TMMSN records, most *Odontoceti* species are only documented every one to five years and seldom occur at a higher frequency. Only three species in this grouping do not appear in the TMMSN records.

With the Suborder *Mysticeti*, there are a few similarities between sighting frequencies in all the GOM and the coast of Texas. The frequency similarities are with species: *Ziphius cavirostris*, *Feresa attenuata*, *Mesoplodon densirostris and europaeus*, *Grampus griseus*, *Lagenodelphis hosei*, *Tursiops truncatus*. Most of the *Stenella spp.* are also similar in sightings and stranding frequencies. Since the GOM frequencies are based on all sources of stranding data in the GOM, these patterns could be directly associated to occurrences in only the Texas data rather than from other GOM state databases. The differences between sighting and stranding magnitudes can be beneficial for studying population distributions, in that stranding frequencies can help explain population fluctuations.

Substantial research has been conducted on sperm whale populations and habitat in the GOM for the past two decades (Hooker et al. 1999) (Jochens 2005). Yet, few of the published articles address stranding events since the only records available are when the pelagic species strand in the coastal waters. Since one of the largest GOM sperm whale studies has been conducted at TAMU (Jochens 2005), the frequencies reported by Geraci and Lounsbury 1993 may be outdated. Also, the increase in Texas stranding frequencies may be attributed to the increase in deeper-water stranding events corresponding to the increase in oil drilling platform sites. From all GOM species, this is the only species experiencing an increase in stranding frequency compared to sighting frequency.

As for the other differences, most species have a decreased sighting frequency for the Texas coastline in relation to the entire GOM. I speculate these differences could be related to the location of the populations and habitat constraints, since most are considered pelagic in residence. With the large continental shelf outlining the Texas coast, pelagic species are most likely to not come inshore unless stranding. Figure 4.6 maps bathymetric contours to show the extent of the continental shelf, which ends at 200 meter depth. Examining the density of large species stranding events reveals the events are clustered along the shore corresponding to the narrowest section along the Texas continental shelf (Figure 4.6). However, other state boundaries in the GOM do not have as large a continental shelf, which can account for the increased frequencies for species documented by Geraci and Lounsbury 1993.

Fewer toothed species are in the TMMSN database compared to the baleen species. Two of the species, *Orcinus orca* and *Mesoplodon bidens,* are rare in sighting frequencies and also are unknown in terms of temporal residence in the GOM. *Orcinus orca*, the killer whale, is the only possible inshore species. Since Texas is the furthest state westward in the GOM, this could explain why no stranding events have been documented for these species.

The other dolphin, *Delphinus delphis*, does not appear in the TMMSN database, but is commonly sighted in the GOM. According to the IUCN, this species is commonly sighted in temperate and tropical waters of the Atlantic and Pacific oceans. As mentioned earlier in the discussion of baleen frequencies, these stranding events may be a result of the geographical distance between Florida and Texas. The ocean composition is also different from the eastern to the western GOM. Near the entrance of the Loop Current, waters are typically considered tropical by the temperature and salinity compositions, whereas waters near the western GOM are more influenced by freshwater input and can be lower in temperature and salinity (Davis et al. 1998). This physical ocean composition may explain why this species has not stranded along the Texas coastline, but does appear in the stranding records for the GOM.

The output of the population proportions confirmed the visual representation that the strength of species stranding is with *Tursiops truncatus*. With a 95% confidence, the population proportion of *Tursiops truncatus* compared to all other species is significantly different. From the confidence interval derived, every random population sample taken would be composed of 81.82 to 83.87% *Tursiops truncatus* stranding events.

Figures 4.3 and 4.4 show the generalized population density for *Tursiops truncatus* and all other stranded species. The unknown stranding events were removed and only the designated species events were mapped. The first panel in both figures resolves the lack of stranding events in the larger bays and sounds along the coast. The density is primarily along the exposed coastline with a few stranding events offshore. Also, the density concentration is greater along the Galveston and Corpus Christi counties and weakly concentrated in Aransas and South Padre. This can be attributed to the population distributions of the species, typically dolphin species coming in from the outer continental shelf in search for prey. Larger species are the outer stranding events, which is consistent with inability of these species swimming inshore and also avoidance of human activity. Figure 4.6 emphasizes the density of these stranding events to be along the southern coast where the continental shelf is smallest in width. Unlike *Tursiops truncatus*, these other species do not exhibit repeated or high intensity social behaviors and often travel inland during high stress or emergency events. Thus, coastal stranding events are unusual for this group of species.

The second panel shows the greater distribution and does not show any apparent spatial gaps for the entire 400 miles. The error in reported locations is also denser than in the first panel. Another difference is the increased events in all the Texas bays, especially in Corpus Christi where the coastline is barely visual with this map resolution. There are slight intensity decreases along Aransas Bay area and the isolated stretch of barrier islands above the South Padre Stranding region. Offshore events are five times denser than the first panel, which is an artifact of the plotted results discussed earlier. The statistics computed earlier are graphically represented in both Figure 4.3 and 4.4. The final map, Figure 4.5, maps all stranding events regardless of species. The overall density does not appear to differ from the *Tursiops truncatus* panel. An interesting spatial attribute is the absence of any events in Kleberg County inlets and the small number of events in the passage from Kleberg County to most southern boundary of Texas. Figure 4.7 was created using Google Earth to examine the land, water, and population composition of Kleberg County. From initial viewing, the area is not populated except for the western-most boundary, suggesting why stranding events may not be documented. Stranding event rates are dependent on the number of TMMSN personnel available to locate and respond to events. Areas with less coastal developments are more likely to not find stranded cetaceans, since there is a decrease in available response effort. On the other hand, areas with large coastal populations and tourism will have more people available to reporting stranding events. The stranding response effort depends on the number of available responders, meaning the more rural areas along the coastline are often inaccessible and experience a decreased stranding event discovery and response rate. The areas north of Kleberg country are more evenly distributed in human population and coastal population density. The discovery of stranding events is more common, since response teams are readily available to respond to an event.

4.5 Conclusions

Statistically and graphically, little diversity exists between species stranding along the Texas coastlines. The overwhelming presence of *Tursiops truncatus* saturates the entire database, including any random sampling to be done with the database. For the remaining research analysis, only *Tursiops truncatus* was used since the combination of other species were not significantly important as verified by the graphical, geographical, and statistical analysis. Therein, *Tursiops truncatus* stranding events are dense for the entire coastline, whereas all other species are not as dense. All other species also are more clustered in the southern coastline where the continental shelf is narrowest. This could be explained by the population distributions of these species as offshore, pelagic species. Due to these conclusions, I decided to not include these species in any further testing, because of the overwhelming presence of *Tursiops truncatus* and to not introduce any additional spatial biases with these offshore species stranding predominantly in one coastal area.

5. HOW ARE THE STRANDING EVENTS DISTRIBUTED IN TIME ALONG THE TEXAS COAST?

5.1 Introduction

Scientific studies have rarely investigated stranding events on various temporal scales, but rather focused on spatial analysis, observational hypotheses, or measuring single factors affecting habitat. Publications also tend to focus on specific investigations and do not include a temporal scale affect on stranding frequencies. References to temporal scales often refer to grey literature sources for data acquisition and rely on the numbers presented by stranding networks or government. An example is extracting the regularly updated stranding events posted on the TMMSN website (www.tmmsn.org) or published through NOAA technical reports. However, temporal scales and the effect of such scales on cetacean populations appear less in population or observational literature as seen in Section 3.

Through previous discussions, time is an important factor in cetacean habitat structures. One common regulator is seasonality determining cetacean reproductive cycles. The importance of time can even be loosely applied to studying species pods or groups traveling along the coast, prey selections and feeding strategies, and animal psychology. Examples of animal psychology include the weaning of calves, juvenile males leaving the maternal group, older cetaceans stranding and even death rituals (Geraci 1978). Time is also important to the physical environment and habitat response in the GOM, such as the influence of the flow velocity of the Loop Current to optimal temperature and atmospheric conditions affecting hurricane frequencies as discussed in

Section 4. The intensity of the freshwater input and impacts on biological productivity also has associated temporal scales affecting cetacean habitat. For the purpose of this question, temporal scales were constructed for the extent of the database and analyzed independently to reveal temporal trends in the stranding events. Examples of individual scales constructed included event rates for the entire time of the database, decades of time, stranding events each year, and monthly stranding rates.

5.2 Methods and Data Preparation

General preparation was discussed in Section 2. Data was exported from the main database as necessary for each temporal construction. For extraction ease, a script was not used for data exporting and the object-oriented query was used. The data results from the queries were then transported as separate matrices and importing into Microsoft Excel and GIS to analyze.

The data were entered into Excel and graphically represented by area and line plots for stranding events per decade, year, month, and day. From here, curve estimates were constructed for each temporal division to isolate and quantify trends. Each curve estimate created in Excel was reproduced in MatLab to validate accuracy and the correlation of determinant values calculated.

As mentioned previously, the stranding event date was separated from one date string into three individual columns (year, month, day) allowing for easier representation and analysis in both the statistical tests and map products. Maps were built in GIS by importing stranding event locations as X-Y coordinates. For consistency and the ability to transport temporal data between mapping attempts, an individual GIS point shape file was designed for each temporal division. From here, the points were symbolized by the properties of the shape file to create three separate maps. Maps were also created to show the temporal distribution of stranding events by location (Section 6). To complete this, the initial X-Y coordinate table was edited and divided into five separate tables by *Location* column and then each table was transformed into an individual point shape file. From here, the points were represented by temporal distribution as before.

Kernel density distributions were calculated in GIS to show stranding event density by time using *Density* tool under the *Spatial Analyst* menu. Density calculations are useful in determining the frequency of events in a defined spatial area. For each event, the density is considered greatest at the centroid and decreases the further away from the point by a predetermined distance. A distance is determined by a defined radius length and the density of an event is zero at this distance. As the radii are composed around each event, the sum of the overlaps for intersecting radii is calculated for each raster cell. With a kernel density, a curved surface is applied over each point, where the surface value is largest at the event location and decreases with the increasing distance from the event center. A varying volume surface is constructed around the event and the density for each raster cell is calculated by the abundance of volume surfaces overlaying the event's center. The curve formula applied by GIS program is a quadratic equation with the highest value at the center of the event. Unlike other density methods, the kernel density spreads out the quantity of the event distance from each event location rather than using a predefined shape neighborhood, such as a rectangle to calculated distance. For the purposes of this study, kernel density is more suitable, by providing a smooth density output and applies positively to examining probable animal distributions in a spatial context. With the concentration of stranding events either dependent or independent of another stranding, a curved increase of distance from an event center in all directions is more plausible. For example, with a mass stranding event, cetaceans will be clustered tightly in a small area rather than equally spread out relating to a strong influence around one animal and less relationship between animals the further from the event center cetacean. By conducting a neighborhood density, the neighborhood shape must be defined and would be an equal distance search around the event, which may falsely represent the true density of a mass stranding event. In both cases, the larger a set area means the more generalized output raster to be created.

Preparation for running a kernel density includes setting an input point feature, population field, raster output, raster cell size, search radius size, and units for cell and radius size. Each temporal run was conducted with the following stationary parameters: Raster cell size = 100 meters, Search radius size = 10,000 kilometers. The search radius seems large, but actually represents the radius to consider events in the density calculation. Using a smaller radius would be extremely limiting and result in very little high density areas. The larger radius encompasses the entire Texas coastline and state for stranding events. The radius determines how far to look for points, with a larger radius providing a stronger density analysis than a smaller search radius. The raster cell size is set small to smooth the output results. A larger cell size provides a false representation of the true density distribution, because the cell size is square on the map with a predetermined length. Caution usually must be taken with defining cell size, as the output resolution depends on length in the x-y direction. The raster dataset is the result of the density calculation, and in this study, there is not a concern with specifying a small cell size. The cell size is dependent on the area analyzed and the computing capability available. To produce a smaller, more resolved output, a smaller cell size is necessary. There is typically a balance between computing capability, cell size, and test output. For the purposes of this analysis, 100 meters was chosen to represent density distribution resolution and to provide computable results based on the technology available. The number is arbitrary and does not relate to any element of a stranding response or the ability of responders tending to an animal.

After the raster is produced and added as a layer on the map, the density scale was reformatted to show the number of events per quarter mile. The scale color pattern was assigned to indicate low from high number of events. The scale ranged from green to red, where green represented low densities and red indicated the highest density locations. Finally, the scale levels were divided into five equal intervals based on the density result range. This division was arbitrary, but chosen to show the color intensities with enough resolution to distinguish between color level indicators.

The temporal scales for the density distribution analyses were divided into decades: 1980 – 1989, 1990 – 1999, and 2000 – 2004. A decadal separation provided a substantial number of value points for each density calculation and was also chosen to coincide with the temporal calculations conducted earlier in Excel. Minimizing the range of years for this analysis would produce outputs with low density distributions along the coast, as there would be less events per year for the calculations. The outputs of the kernel density functions are Figures 5.1, 5.2, and 5.3. The output grids are displayed as rectangular grids from the most northern to southern event, forming a large square over the coast line and a majority of the state. This is difficult to analyze in relationship to the shape of the coastline. To correct this issue, a 5-mile buffer was applied to the bay and coastal passages as processed for the spatial distribution of the stranding events. A new shape file was created and vectors drawn around the buffer outline. Using the raster calculator, it was possible to extract the area of the density distribution output to the shape file to show the distribution around the shorelines. The extent of the shape files varies dependently on the locations of the events and the reduced density grid simply excludes inland events. Each of the stranding events was symbolized as a black circle and mapped underneath the density grid. A transparency was also applied to the density grid in order to resolve the coastline and stranding events. Once again, the grid intensity was scaled based on the range of the scale to show event per square mile.

5.3 Results and Discussion

The graphical outputs show large variation in the stranding event counts per year (Figure 5.4). Initial viewing shows no defined linear increase or decrease in stranding events. The event numbers are low at the start of the database and linearly increase slowly to 1990. Starting in 1990, the events exhibit a sharp cyclic pattern and then decrease toward the end of the decade until 2004. The later end of the database does not show a steady increase beyond 2004.

Linear trend lines (Figures 5.5) were the worst fit attempt for the data, whether the entire database was considered or the temporal series were divided into decades. The coefficients of determination (r-square) were all below 0.2, meaning a linear trendline was only able to account for approximately 0 to 20% of the stranding event variability. However, stronger than the later decades, 1980 to 1989 reveal a strong linear correlation (R^2 = 0.8464), but this does not assist with forecasting into 1990 nor continuing forecasting efforts past 2004 (Figure 5.6). The strong linear trend from 1980 to 1989 is most likely attributed to the growth in TMMSN personnel and responders able to respond to more stranding events, since the organization began in 1980. The cyclic pattern from 1990 to 1999 explains the weak linear trend in the data. However, the shape of the linear trend shows a decrease from the 1990 to 1999. The last plot shows an extremely weak linear fit from 2000 to 2004, which can be attributed to the few data points in this analysis. Overall, as seen in Figure 5.5 and 5.6, a simple fitting explanation is inconclusive to explain the trends and variability in the stranding database and emphasizes that more than one factor influences the stranding rates per year.

Excluding the 1990 – 1999 decade, there is little variability in the database with the event counts falling right at 150 per year and lower. Yet, the cyclic fluctuations in the 1990’s mask any existing trend. Smoothing attempts were conducted to mitigate the cyclic effect from 1990 to 1999. Figure 5.7 represents the application of a moving average as the primary attempt to smooth the time variability. This smoothing can diminish fluctuations in the stranding events and reveal a more consistent trend for the entire database. Using this method requires the user to define an averaging period, or the number of data points to average to represent a data point. The length of the period determines the start of the smoothed line. For instance, a period of three will average the first three events and continue by moving to the next three points for remaining events. Each average is plotted for the corresponding year. Using a period of three starts the curve at the third x-axis designation. In this research application, a 3-period average starts at year 1982. To show the effects of smoothing, periods of 2, 3, and 4 were applied to the entire dataset. However, higher periods were not applied, because smoothing would remove five years of points reducing the time duration of the data below 20 years, making for weak forecasting capabilities.

All three smoothing attempts were applied on one graph in Figure 5.7. The first run (Period = 2) smoothes the dataset relatively well by eliminating the cyclic fluctuation in the early 1990's, but shows the linear increase in the events from 1990 to 1995. The other two attempts are not quite as clear in resembling the amplitudes of the yearly events and depart in shape from the original dataset. This first curve manages to follow the original data pattern, as well as resemble the closest to the curve shape in the later end of the time series. The second run (Period = 3) mimics the unsmoothed curved by at a much lower amplitude and does minimize the cyclic fluctuations. Finally, the last attempt (Period = 4) smoothes the curve greater than the first curve, but the integrity of the curve is lost in the later years of the dataset, where the output of the smoothed curve is significantly greater than the actual data.

Despite attempts to reduce variability in the 1990's with curve smoothing and estimations, it is not feasible to forecast the yearly stranding event levels after the year

2004. The inability to forecast future events may be due to the relatively short temporal length of the database and the influence of multiple and unidentifiable factors affecting stranding rates. It is sufficient to assume that more than two decades are needed to accurately generalize basic trends of stranding events, whether it is an increase, decrease, or steady-state in the number of stranding events. Since data acquisition is slow and dependent on the cooperativeness of the TMMSN, it may be feasible to compare the entire stranding database to other databases from around the United States, as well as international databases with longer time series. Combining different sources of stranding databases may provide strong information in determining if marine mammal stranding events are globally rising or decreasing. In addition, the complexity of the polynomial curves supports the interaction of multiple factors, biological, environmental, or anthropogenic, affecting the stranding rates from 1980 to 2004, thus invalidating any forecasting attempts.

In an attempt to isolate one factor possibly controlling the fluctuations in the center of the database, I examined one of the most studied climate applications and prominent sources of variability in weather. One of the major proposed components for influencing physical and biological ocean parameters and responses is the presence or absence of an El Nino or La Nina Oscillation event. Though these events relate to warming or cooling phenomena respectively in the Pacific Ocean, the effects can influence the oceanographic and atmospheric responses in the Gulf States and GOM. According to NOAA, the El Nino actually is defined as the El Nino-Southern Oscillation (ENSO) and is an ocean-air coupled event with global impacts occurring about every three to eight years (http://www.elnino.noaa.gov/). The ENSO event is the major contributor to interannual variability in climate and weather patterns throughout the world, including responsibility for unusual weather patterns along the Texas coastline. Typical effects in North America include warmer winters in the Midwest states and cooler atmospheric temperatures in the southwest states. The atmospheric changes can cause warmer or cooler ocean temperatures in the GOM depending on the fluctuations in air temperatures along the state of Texas. The ENSO events have also been attributed to decreased hurricane activity in the Atlantic Ocean, which directly impacts the physical state of the Loop Current in the GOM (NOAA 1994). Though only recently studied in the cetacean community, these drastic series of climate and weather changes can alter cetacean habitat in the GOM and possibly cause an increase in stranding events along the coast (Learmonth et. al 2006).

The alternate oscillation to the warm component of ENSO is the cold phase, or La Nina. Opposite to the warm pool transition across the Pacific Ocean, the La Nina is the movement of a cold pool intensifying and traveling across the Pacific Ocean. The effects caused are also opposite to the ENSO effects, meaning a drier atmospheric effect in the southwestern states. An atmospheric drying would affect ocean parameters by increasing evaporation, which would also affect cetacean habitats. For example, a dramatic dry period could cause severe coastal evaporation in the coastal channels or closing of passageways between the open ocean coasts and the coastal passages. This example is entirely speculative and has not been documented in the literature, but is feasible and supported by stranding events that are in close proximity to rivers or coastal streams as seen in Figure 5.8.

The effects El Nino and La Nina have on Texas are only recently observed in the scientific literature and very little information exists describing the general affects specific to the Texas coast. However, scientific studies have documented the fluctuations of precipitation and direct effects on estuary salinities in Texas (Tolan 2007). The state of Florida does provide generalized atmospheric and oceanographic responses to these two events (http://www.floridadisaster.org and http://noaa.org) to include:

El Nino – Above average precipitation, Sever weather influences by the altered orientation of the atmospheric jet stream oriented from west to east over the northern Gulf, lower air temperatures, enhanced cyclogenesis in the GOM, and decreased frequency of hurricanes

La Nina – Lower precipitation rates, increased atmospheric dryness, warmer air temperatures, increased hurricane activity

Most of these attributes listed also affect the northern GOM and can affect Texas coast. The alterations affect air and ocean temperatures and circulation patterns, which directly influence cetacean habitat as mentioned previously and in Section 3. Figure 5.9 plots the cetacean stranding events and the severity of El Nino and La Nino events for the span of the database. All events, regardless of severity, fall in yearly decreases of stranding events except for two moderate El Nino cycles in years 1994 and 2002. The 1994 moderate ENSO event also is the highest stranding event recorded. These results were an attempt to explain the variability in the 1990's, but the lowest number of El Nino and La Nina events occurred in this decade. It seems more probable to estimate that the influences of these oscillations actually create a more favorable habitat for cetaceans in Texas and results in considerably fewer stranding events. Though not statistically supported, it is important to investigate the oscillation versus stranding events further, specifically by correlating coastline responses of sea surface temperature, ocean currents, and atmospheric events (storms, wind changes, frontal patterns) to stranding events. One other parameter of interest would be sea level variability, which has been shown to be seasonally dependent and altered considerably by ENSO events as a factor in controlling the rates of cetacean stranding events as shown in research conducted by Kennedy et al 2007. The seasonal dependency of sea level variability is also another important factor for analyzing the next temporal designation – monthly comparisons of stranding events.

5.3.2 Investigating Stranding Events by Month

The next temporal scale analyzed is the monthly stranding events by year and from 1980 to 2004. Unlike the yearly event analysis, there is a significant cyclic fluctuation pattern in graphs, accentuating a seasonal variation. The first graph, Figure 5.10 plots the monthly stranding events for the entire database from 1980 to 2004. Seasonal trends are apparent starting around 1985 and increasing in intensity until 2004. The seasonal patterns expose large increases in the spring months (February to April) and significant lower events in the summer (May to August). Though a little unusual to consider February as spring, further analysis into the days of the months reveals a stranding increase late in the month of February to late April, which can experience unusual warm weather along the Texas coast. For the rest of the year, stranding rates seem to be lower through the summer and fall months (May to November). From November onto until February, the stranding event rates tend to increase slightly, but not experiencing the same intensity as seen in the spring months.

To better illustrate the seasonal intensity fluctuations, Figures 5.11 to 5.13 plot the individual year stranding events by month. From 1980 to 1989, the more intense spring stranding events occur later in the decade with the largest magnitudes in the months of March and April. In the 1990's, the strongest spring intensities are in the earlier years, both 1992 and 1994, which are also years with the two largest total events. However, in 1992 the largest magnitude is in March and for 1994 the highest is in April. For both decadal series, the stranding events tend to increase in the early winter months into the spring months. For the half decade, 2000 to 2004, the magnitude of the stranding events follow the patterns in the 1990's, with the highest values in the month of March. An unusual year is 2001, in which the peak falls in February rather than March or April.

A moving average smoothing was applied as an effort to reduce the decadal variability in 1990 to 1999. Figure 5.14 shows the application of a 3-period smoothing, which calculates and plots the average value for every three counts. Other attempts, the 2 and 4 period smoothing, failed to smooth the dataset and/or maintain the seasonal fluctuation. The result shows an evident curve in the March months, starting low in the 1980's, peaking in 1994 and reducing down to 2000. Beyond 2000 shows a slight increase and decrease at the end of the dataset. A curve fit to the smoothed average did not prove significant correlation of determination results, due to the lower March events in years 1980, 1985, 1991, 1995 and 1999.

The next series of plots, from Figure 5.15 to 5.17 separate and individually plot the months by year for each decade in the dataset. Three plots were created by decades representing the total stranding events per year within the decade. From 1980 to 1989 the highest March amplitudes are the later part of the decade, with the exception of 1984. The last few years in this decade (1986, 1987, and 1988) show an unusual small decrease from the month of March to April, which is not evident in the remaining years. The other years peak in March and fall back below ten events in April. This slope change will affect the curve estimating ability. For 1986 through 1988, a 6^{th} degree polynomial fit accounts for 80 – 90 % of the seasonal variability (R^2 = 0.8491 to 0.9041). However, the years with a localized, sharp increase experience worse correlation coefficients with a 6^{th} degree polynomial (R^2 = 0.5014 – 0.6543). The 6^{th} degree polynomial in both investigations was the strongest curve fit, but is not practical for the following reasons. The first is the balance between simplicity and accuracy. Six coefficients can be cumbersome to calculate and difficult for many levels of users. Forecasting capabilities, as shown earlier, are not mathematically possible with this type of fit. Second, the shape of the curve falls below zero around August through October, which does not accurately represent a stranding event and can create complications in using the curves to forecast monthly stranding events. Finally, the fittings are conducive only to the direction of the x-axis, ranging from January to December. Shifting the extent of the axis can change the shape of the curve and also the ability of the fitting in explaining the amplitude variability. Further analysis is needed to better isolate the magnitude of the seasonal trends in the database.

The second 1990 decade graph, Figure 5.16, is slightly different in population distribution. Little stair decreases are not as common and one does occur in 1994 and 1996, but it actually increases from March to April rather than decreasing as before. The remainder of the years rapidly decreases. Unlike Figure 5.15, a polynomial curve fit explains for 80 to 88 % percent of the event variability for all years. However, the same complications exist in using this extensive equation for prediction of future events. Finally, the last Figure (5.17) only graphs 2000 to 2004 years, but the curve shapes are similar. The unique difference in this plot is the plateau in year 2004, which is also the last complete dataset. Curve fits ranged in r-square values from 0.7393 to 0.9244. The highest variability explanation is the year 2004, which is positive for forecasting seasonal trends through 2010, which will be done when the TMMSN publishes the stranding events for 2005 to 2007. As with the previous two examples, caution has to be exercised for the area of the curve below 0 events, which occurs in June to July from 2000 to 2004.

The final plot, Figure 5.18 compares the total number of stranding events for each decade by month. This plot combines the overall seasonal distribution by averaging each month for each decade year and combining the totals for each month per year. Curve fittings were applied to each range resulting in the r-square values on graph. The variability accounted for ranges from approximately 78 to 86%, with the highest r-square value for 1990 decade. The decreases below zero events are evident and extend from June to late July with each curve showing an increase in late August to early October and a decrease in December. The spring seasonal flux is accurately predicted for the first two decades, but not for 2000 to 2004, which actually starts in late January. This curve, though at the end of the database, does not accurately represent the bimodal reproductive seasonality evident in earlier figures. The same reasons of concern exists for these curves as before, with the length of the polynomial equation, the inability to accurately forecast, the fluctuation below zero in the summer months, and the direction of the x-axis. Yet, the ability of these curves to explain a large amount of variability may be useful in future forecasting efforts or for constructing temporal scales in modeling developments.

Despite the inability to develop an equation calculating the frequency and amplitude of the curves, conclusions can still be drawn from the graphs and statistics. As discussed earlier, the large monthly peak for March in 1992 was an unusual mortality event along mid-Texas bay ecosystem coinciding with die-offs in birds and fish (Colbert et al. 1999). However, the monthly spring increases for the rest of the database correlate to the reproductive cycles in *Tursiops truncatus*. Breeding season is bimodal, occurring in both the late fall and early spring. The first mode reflects in the event increases starting in late November, which often transition into the early spring, or the second and larger reproductive season. Though not completed in this study, it is possible to correlate the animal size and/or estimated age from stranding event data to confirm this hypothesis.

5.3.3. Examining the Kernel Density Distributions

The spatial distribution of stranding events by time is also important to examine. The first density distribution map, Figure 5.1, reveals the event distribution from 1980 to 1989. The scale represents the number of stranding events per mile, ranging from 0 to 1.75 events. The highest intensity, represented in red, occurs along Galveston Bay and northern Jefferson County. Dense (red) areas also are prevalent in the Corpus Christi southern bay edge and coastlines in Nueces and San Patricio counties. There is an isolated incident in the western bay boundary, where there is a visible clumping of events as seen in Figure 4.5. The next density map, Figure 5.2, shows a different density distribution. The coastline from Jefferson County to Brazoria County is saturated with stranding events. The extent even travels into the southern boundary of the Galveston Bay and is approximately twice as dense the same location in the previous decade. The other noticeable difference is the scale increase, where the densest areas have a stranding event occurring where the largest distribution ranges from approximately 2 to 3.5 events per mile, which is doubled from 1980 to 1989. Finally, the large mortality event documented by Colbert et al. (1999) is evident by the red and orange rings in Aransas Bay. The northern two yellow ovals are also indicators of the 1992 mortality event. The third larger oval in the southwest corner of Aransas Bay also isolates a relatively large number of the events and was also a heavily sampled area in determining the causal factors for 1992 mortality event. The last decade density plot extends from 2000 to 2004 and is similar in scale to 1980’s. The highest density bracket represents one to two animals per mile. Unlike the other two density maps, the high density extents are decreased spatially, meaning there is less extent along the coastline in Galveston, Brazoria, San Patricio, and Nueces counties. For example, there is not a continuous highly dense line from both ends of Galveston Bay. In this figure, two low density areas fall in the northern and central Galveston coastline, reflecting the decrease in events from the unusual variability in the mid-1990s. Unlike the other two plots, a small high density circle appears in the very southern coastline near South Padre.

Figure 5.19 shows the density distribution in stranding events from 1980 to 2004. The highest density levels in red represent 0.5 to 1.2 events per mile. The high density areas occur in eastern Jefferson County, the entire Galveston Stranding Network Region into Brazoria County and in Matagorda and Aransas bays. Two of the five isolated high density zones occur in bay ecosystems, with the remainder along the intra-coastal and open ocean regions in the northern coastal boundary closest to Louisiana. Another unique factor is despite the high event occurrence in Corpus Bay, the events are not clustered closely enough. Comparing this observation to the next closest bay, Aransas, the results vary significantly with higher density in the southern Aransas boundary. This can be contributed to the difference in the coast length, whereas Aransas has less bay coast lines compared to Corpus Christi. The same is true for the western boundary of Galveston Bay. The steady increase high densities along Galveston and Brazoria counties are can be attributed to the large human population densities creating a higher stranding effort response. To compare the three decadal plots, Figure 5.19 was created. This figure compiled the three raster grids within GIS and subtracted the three graphs from one another starting with the high density scale, 1990 to 1999. The plot scale starts at 0 and reaches a difference of 1.128 stranding events per mile. Therefore, according to this calculation, the darker green colors imply no difference between the three decades, whereas the red areas are locations exhibiting the largest change between decades. Initial map viewing shows large variations in Galveston and Brazoria coastlines, as well as localized density differences in Aransas Bay and Matagorda Bay. These differences can be influenced by the unusual mortality event in 1992. The changes in the northern coastlines can also be influenced by the high events from 1992 to 1996. The unique area is the shipping channel and sea wall entrance to Galveston Bay, which has experienced no minimal density difference among the three decades. This can be explained by numerous causes, but is primarily influenced by the severe anthropogenic activity. The northern entrance of the Corpus Christi Shipping Channel has shown no difference in distribution, most likely due to the same high level of human activity. With the heavy boating traffic in both channels, many bottlenose dolphins are socially attracted to these areas, which positively correlate to stranding rate increase with boat strikes, pollution, and constantly fluctuating prey abundances.

5.4 Conclusions

Investigating the various temporal scales provided valuable information for stranding event rates and forecasting abilities. The plots illustrated how the stranding event rates have increased early in database history, experienced unusual cyclic fluctuations from 1990 to 1999, and then receded in a more steady cycle. However, linear fitting proved inconclusive in explaining the overall database temporal trends and the cyclic variability in the middle of the database affects any forecasting attempts beyond 2004. There is not enough evidence known for the environmental, biological, or anthropogenic factors influencing stranding rates per year to explain the temporal distribution in the dataset.

The monthly trends also provide substantial information important in future project development. The seasonal fluctuation in stranding rates correlates positively to the bimodal reproductive cycles in *Tursiops truncatus* populations documented by Wells et al. (1999). The next step in seasonal analysis would be to estimate the cycle amplitude with a harmonic smoothing and curve estimation and to isolate influential factors controlling the stranding rates. The equation formulation would then coincide with the yearly curve estimates for forecasting or suitability model development.

Finally, the density distribution calculations by temporal distribution proved successful in revealing areas with high stranding intensities on the order of one to three events per mile. Each result displays a high intensity localized distribution in Galveston, Brazoria, Nueces, and San Patricio counties. Though some of the intensity could be attributed to an unusual mortality incident in 1992, the remaining areas are most likely caused by the human influences as all counties are extremely populated. These areas also contain the state's two major shipping channels, resulting in frequent boat, shipping, and tourism activity. As discussed in earlier sections, the anthropogenic influence is one of the most common causes for stranding events and is reaffirmed by the kernel density distributions.

6. HOW ARE THE STRANDING EVENTS DISTRIBUTED IN SPACE ALONG THE TEXAS COAST?

6.1 Introduction

As with the temporal investigations, little scientific research has focused on evaluating spatial trends in large stranding event databases. Typically, the bulk of publications isolate and study a particular area in which data is available, rather than combining data from multiple sources to investigate an area for stranding event trends. This section focuses on using the entire TMMSN database to determine spatial trends in along the Texas coast.

The first void in the database was the vague spatial information available. General plotting of the event locations showed a unique distinction along the Texas coast among both species and in time. Points were located everywhere within Texas boundaries, and beyond, but as seen in Figure 4.5 the unrealistic events can be distinguished by the latitude and longitude. The six locations were developed by dividing the Texas coast into three main stranding regions (Section 2). The first location values were *NoLocation* and *Inland*. *NoLocation* only have zeros recorded for the latitude and longitude values. The second refers any location with coordinates that falls outside of half-mile from any body of water or flood zone. Events were classified into this category, in order to not disregard any data that could have been a true stranding event and not an error in recording. For example, several events map on housing areas not near the coast and are not a location for a marine mammal to strand. These points can also occur on barrier islands. The next four classifications (*Offshore, Open Ocean,* *Intracoastal*, and *Bay*) are the primary spatial designations analyzed in these sections and address the realistic stranding events. The basic maps constructed earlier in this document show events are stratified along and within the coastal boundaries and can indicate population differences, such as presence of offshore and inshore ecotypes, by general location (Section 1). The basic distinctions in these categories are by which coastal zone the events occur. The first, *Offshore*, defines events beyond the 1-mile buffer boundary of the Texas coast outline in Section 4. Conclusions from Section 4 demonstrated the *Offshore* stranding events were commonly offshore-residing species after removing *Tursiops truncatus*. The next category, *Open Ocean*, specifies stranding events falling along the shoreline, just beyond the surf zone, or higher inland from the berm of the exposed coast. The next, *Intracoastal*, addresses the events falling between the Texas bay boundaries and the *OpenOcean* boundary. These locations are in coastal waters, inner estuaries, wetlands, shipping channels, rivers, man-made passages and small inlets. The final choice represents all remaining events occurring in the Texas bays or within 0.5 miles of the bay coastlines. Bay boundaries were differentiated from coastal channels by closing of the southern-most land features creating a closed water body. In most cases, this boundary was drawn along shipping routes between the bay areas. An elaborated classification of the location events will be discussed in Section 6.2

The next emphasis will compare the stranding events by location value and compare the location values to the TMMSN stranding regions. Part of the analysis also considers how quality control efforts influence stranding events per location and basic densities of locations along the coastline. Finally, species comparison between locations will also be examined. This section addresses the importance for enhanced spatial designations to evaluate stranding events, as well as how such spatial designations aid in researching factors affecting cetacean population distributions and habitat.

6.2 Methods and Data Preparation

The analysis for this section follows the previous section regarding data preparation and export for graphs and maps. The *MapLocation* column was the primary factor investigated for this section. The data was exported with object-oriented queries and was transported as individual matrices into Microsoft Excel and GIS. The Excel functions were represented as stacked bar graphs, bar graphs, and line-area plots. The line-area plots mapped location by decades to better analyze the event differences by location. Bar graphs were constructed to analyze species per location and temporal patterns with the location values. Tables were also constructed to aid the graphical representations and for statistical calculations outlined in the following section.

Stranding event locations were plotted within two map programs. The TMMSN stranding event data were entered in by the *LatitudeCorrected* and *LongitudeCorrected* values to determine *Location Category*, *Value,* and *Comment* inputs. The accuracy with the geographic layers can vary slightly depending on the projection used and imagery features also may not be current for the entire coastline. Therefore, using two applications allowed me to verify the geographic events occurring on land, water, in bays, coastal waterways, or the open ocean. After initial import, each point was assigned an individual marker representing five of the six locations, with *NoLocation* not necessary for plotting.

Using the layers outlined for GIS in Section 2, the original database events were also imported, evaluated, and labeled. The locations assigned in the first application, Google Earth 4.0, were also imported to compare the values assigned previously. Discrepancies between the two programs were extracted and re-evaluated in both programs. For *MapLocation*, discrepancies in labels occurred primarily with river extents and bay boundaries. Since the river extent layers were more recent remotely sensed images in Google Earth and the flood zones could be identified in the remote sensing layer applications, these were ultimately decided by the geographic location in Google Earth. However, for the bay boundaries, the process was slightly more complicated.

To determine the extent of the bay boundary from a coastal passage, vectors and buffers were created within GIS using the *NOAA shoreline* layer and *waterways,* a shipping channel vector layer provided by the TPWD. The layers provided simple and definite boundary extents for the bays and these vectors were matched to Google Earth images by map location in decimal degrees and by matching shoreline features. The questionable *Location* categories were reassessed and assigned a value accordingly to the comparison between both locations.

The final processing of the *Location* designations includes assigning a color scheme used throughout all representations in this research. The colors are as follows: Offshore (red), NoLocation (blue), Open Ocean (green), IntraCoastal (orange), Inland (yellow), and Bay (purple). Each color represents all stranding events within that location or the quantity in a respective location and is consistent throughout any outputs in this Section. The location values were plotted with data points removed during the quality control process outlined in Section 2. To reiterate, the removal included event data missing vital spatial or temporal information in the original database format. Figure 6.1 graphs the original data versus the event removals with the quality control guidelines. The removal of stranding events for this specific analysis occurred only in the *NoLocation* category, which is not pertinent to answering this research question in that approximately 98.70% of the original dataset was analyzed.

The next spatial consideration was the definition of boundaries of the TMMSN Regions. Figures 6.1 and Figure 1.2 present the original stranding region designations and GIS output of the regions. The Regions are designated solely by Texas state county boundaries. Using the *Counties* layer available from the TPWD, selections were made to extract counties relevant to the regions as defined by the TMMSN (http://tmmsn.org) (Tarpley 1987). Extraction was conducted with the 'Select by' tool in GIS, in which all features, including the county area, were highlighted and exported as an individual layer. The respective layers were assigned a unique color and label to be used in further analysis.

The last data preparation necessary was combining the spatial scales with temporal scales. Analysis in this section examines the spatial extent primarily on the year and decade scales. From Section 5, the decadal scales are defined from 1980 to 1989, 1990 to 1999, and 2000 to 2004. These were constructed by compiling the *coastline* and *counties* layers to create the Texas coastline. Stranding events were selected by the year attribute and extracted to individual point files and then categorized and colored accordingly to *MapLocation* to be added to the layers.

6.3 Results and Discussion

The results presented are a combination of comparing location categories individually and with scales addressed in previous sections, such as by species and in time. The spatial extents overlap with previous sections and thus were saved from the earlier sections to be presented here. Before proceeding into the sub-sections, it is first important to see the general location distribution. Of the 3258 events represented, approximately 62% are considered *OpenOcean* events followed by a significantly lower number of *IntraCoastal* events accounting for 15.0% of the entire database population (Figure 6.2). The next designation, *Bay*, constitutes for 9.2% of all events. Finally, the remaining three locations account for less than 6.0% of the entire database. From this figure alone, the *OpenOcean* category overwhelmed the spatial extent categories, but at the same time confirmed spatial separation is necessary and beneficial. Though separated from the largest category, the combination of *Bay* and *IntraCoastal* accounts for 25% of the database population and can easily skew statistical analyses if no location designations were assigned to the events. Also, as shown in previous discussions from Sections 3 and 4, there can be variations among species, which influence the temporal patterns of abundances within the habitat and possible influence the stranding rates. The results do start to show how these spatial designations can be beneficial markers in investigating the variability among and within species groups and temporal patterns in these stranding records.

6.3.1 Graphical Representations for *MapLocation* Values

The next representations isolate species composition per spatial location. As shown in Section 3, *Tursiops truncatus* statistically represents the entire TMMSN database and does so by the location category seen in Figure 6.3. This representation uses stacked bar comparisons to isolate the number of *Tursiops* from all other species. For all locations, *Tursiops truncatus* comprise approximately 85 % to 99 % of location values. The lowest composition is in the *NoLocation* category, which is not a primary interest in this research, to the highest in the *Bay* category, where only three events of 297 are not *Tursiops*. The next figures, 6.4 and 6.5, combine the location categories into one bar for the two groups to re-emphasizes the dominance of *Tursiops truncatus* to the entire database. The percentages and abundance in *OpenOcean* events are evident in these representations. Figure 6.5 graphs the percent composition of both general groups instead of by event count. The most change is the top three categories: *Offshore, NoLocation,* and *OpenOcean*. The *Offshore* and *NoLocation* categories have a 14.39 % and 10.36 % decrease respectively in composition for the entire database. The largest designation, *OpenOcean*, shows a decrease in composition of 6.41% in *Tursiops truncatus*. On the Figure 6.5, the percentages of events by group for each location are labeled in the location bar. The average composition is 61% for *OpenOcean* events and the graph also reveals a decreased progression to *IntraCoastal* and *Bay* events. However, there are no statistical differences between the location compositions of all species and *Tursiops truncatus*.

The next group of bar charts, Figures 6.6 and 6.7 compares the remaining spatial species composition of the database after excluding the skew created by *Tursiops truncatus*. Figure 6.6 shows stacked bar plots for all species designations outlined in Section 2 and labeled on the x-axis. On the plot, there is an absence of *Bay* events. From Figure 6.4., only three events occur in bays that are not *Tursiops truncatus* and examining the events reveals the species are unknown. Since the species were not identified for these three events, each could possibly be a *Tursiops truncatus*. The other noticeable effect is the dominance of *OpenOcean* events with all other species. Designations were also added to this figure to separate whale and dolphin species. The whales are signified by five-point stars and four-point stars representing the dolphin species. The most obvious is the larger whale species are predominantly stranding in either the *OpenOcean* or *Offshore* locations. This correlates positively with Table 1.3, where these species are primarily offshore residents and would either strand offshore or drift inland to the exposed coastlines. Yet, few of the species (*Kogia breviceps*, *Ziphius cavirostris*, and *Physeter macrocephalus*) were found also in *IntraCoastal* locations. These very few events could be attributed to mistake in offshore travel, disorientation, bodies sinking to the bottom, or following prey too far inshore. Using the database to reference the condition of these animals shows most animals were in middle to late stages of decomposition. Therefore, it is more difficult to identify the causes for these events and these events can merely be artifacts of ocean transport bringing these animals further inland or other factors, such as increased anthropogenic activity, influencing cetacean habitat distribution along the Texas coast.

The next group of symbols represents the dolphins in Figure 6.6. For most of the dolphin species, stranding events occur either in *Offshore* or *OpenOcean* locations. Unlike the whales, there are more *IntraCoastal* stranding events with the dolphins, especially in the *Stenella* family. As before, there are no dolphin species, besides *Tursiops truncatus*, in the *Bay* locations. This observation also parallels to Figure 3.1, in which most dolphin species reside on the continental shelf and in shallower coastal waters, and must travel inland either by naturally occurring coastal currents or choice before stranding.

The final observations for species versus *LocationValue* are represented in Figure 6.7. This graph separates the stacked bars into individual bars for each species. The total number of stranding events for each species is also added to this representation. The shorter color bars represent zero events for location, whereas taller bars equate to more stranding events. In most cases, the total is due to events falling in the *OpenOcean* category. This is not true for *Grampus griseus*, *Baleaenoptera borealis*, few *Stenella* species, and *Physeter macrocephalus* wherein the total stranding events are attributable to a few events in various locations. Overall, this plot reiterates the conclusions stated above where the offshore populations typically strand beyond one-mile or along the exposed coast and *OpenOcean* location events are the most common for all cetacean species, including *Tursiops truncatus*. These several plots emphasize the need to isolate species within locations to investigate and refine the environmental factors influencing habitat distribution.

6.3.2 Graphical Representations by Gender

Gender analyses were considered only with *Tursiops truncatus*. Reasoning for not including the other species stranding were the low numbers of identifiable species present compared to the amount of unknown stranding events, the statistical skew of *Tursiops truncatus* in the database, and having a stronger understanding of the *Tursiops truncatus* population structure. This graph, Figure 6.8, is a line-area plot of location versus gender for *Tursiops truncatus* stranding events. As before, the three gender categories are *Female*, *Male*, and *Unknown* based off the recordings in the TMMSN database. The second and third strongest locations by gender are *IntraCoastal* and *Bay* stranding events, respectively. Finally, the remaining locations experience little fluctuation in counts per gender classification. The smaller location categories are *Offshore* and *Inland* stranding events. The count values for the three highest counts per *LocationValue* have the data values labeled. Proportionally, *OpenOcean* events for all genders are higher, with the *Male* value the highest. The *Male* classification is also the greatest for the three highest location categories. In this study, the *Male OpenOcean* events account for approximately 70% of the three largest *LocationValue* classifications. The *Unknown OpenOcean* and *Female OpenOcean* stranding events account for approximately 76% and 71% of the three largest LocationValue categories. A variation occurs between *Unknown* and *Female*, where *OpenOcean* events are higher for *Unknown* than *Female* events. However, this is not true for the *IntraCoastal* and *Bay* categories, where *Female* stranding events are higher. To better compare these trends, Figure 6.9 was created to show the change in *Gender* values per *LocationValue*.

In Figure 6.9, the *LocationValue* is plotted along the x-axis with each line representing one of the *Gender* values. In this graph, the *OpenOcean* skew is still present for all three *Gender* values and lower for all other location classifications. The magnitude variation is also evident in this graph where the *Male* stranding events are greater than the other two categories in all locations except for *NoLocation*. The *Female* and *Unknown* stranding event counts fluctuate by *LocationValue* and do not show as steady a trend. The values for each *Gender* are shown and there is not a clear majority of one gender type for any *LocationValue*. In the *OpenOcean* category, *Male* stranding events account for only 41% of the total *Gender* stranding events. For *IntraCoastal* location, *Male* stranding events are approximately 47% and comprise only 45% of the *Bay* stranding events. Compared to the total number of *Male* stranding events, the *OpenOcean Male* events total approximately 60%. From the total number of *Female* stranding events, the *OpenOcean Female* events total close to 70%. Finally, the *Unknown* stranding events account for 62% of the *OpenOcean* location events.

Both Figure 6.8 and 6.9 continue to support the dominance of *OpenOcean* stranding events regardless of species distinction. Increases in *Male* stranding events are also present, regardless of *LocationValue*. As with the conclusions in Section 4, the increase in *Male* stranding events reflects the *Tursiops truncatus* population structure. When male *Tursiops truncatus* reach reproductive maturity, they leave the family group to find non-related maternal groups (Wells and Scott 2002). During this group transition, males are known to travel alone or in smaller groups with only one to a few other males of the similar age. Geraci and Lounsbury (1993) also state “mortality rates seem higher in males than females in species presumed to be polygynous". Polygynous refers to mating patterns, in which dominant males reproduce with multiple numbers of females in the same or related species (Geraci and Lounsbury 1993). Therefore, younger, reproductively sound males though able, may not be allowed to reproduce if older males are around the same group. Since the older males exile the younger, less-experienced males, they are forced to travel along and feed along with group support. These reasons support why an increase in *Male* events is higher both by species and by location, since *Tursiops truncatus* resides in all of the major locations developed in this study.

Another support of the increased *Male* events can be related to the male behaviors, which often differ from female behaviors. Since most females tend to stay within family groups, the behavior is more reflective on the behavior of the group in calf rearing and protection, rather than a focus on individual behavioral patterns. Males, on the other hand, leaving the group may be involved more in single, high-risk behaviors, such as curiosity-influenced patterns and interactions with human activities. Examples of such include entanglement with coastal fisheries, tourist-based influences, and pollution interactions by accidental investigation, etc. (Geraci 1993). Since juvenile males do not feed for the well-being of the group, the following of inshore prey may also inflict a higher stranding rate. Studies and videos have shown many unique feeding behaviors involving one to a few *Tursiops truncatus*. One particular method, known as beach hunting, actually involves partial stranding on beach shores (Sargaent et al. 2005). The method involves an animal hydroplaning in the shallow surf zone to corral particular prey and driving the prey out of the water by forcing the prey to beach. The beaching is achieved by the dolphin also partially hydroplaning at the water's edge (Sargaent et al. 2005). Sargaent and authors documented the behavior to include complete onshore purposeful stranding at around five years of age and the behavior has a precise procedure dependent on the ability to correlate the tidal ranges to the coastal habitat. Males leaving the group are typically older than five years and, if partaking in this method alone, have a higher risk of beaching while hunting and not being able to move back into deep enough water, which could be a potential cause for stranding. Also, cetaceans may not be able to correctly correlate tidal fluctuations to coastal habitat structure, especially if disoriented or in an unfamiliar location. Another similar method includes the collaboration of few *Tursiops truncatus* in unison creating a small surge out of the coastal waters along a sandy mud bank to force small fish onto the banks for feeding (Duffy-Echevarria et al. 2008). This highly adaptable foraging strategy is another example of strand-feedings and can also result in a permanent stranding event if a dolphin independently re-strands to feed on another fish or performs the behavior alone. These behaviors, if not precisely executed, can be detrimental. Foraging strategies can provide probable explanations as to why male stranding events are higher than females as a result of the younger, inexperienced male societal behaviors for all location designations.

6.3.3 Graphical Representations by Decade and Year

The next major *LocationValue* comparisons are combining spatial and temporal scales to reveal trends in the TMMSN stranding database. Figures 6.10 and 6.11 are the same graphical representation, except that the total number of stranding events is added to Figure 6.11. In the first, the largest stranding density by location is close to 200 events down to zero events at any given year. The greatest variation in any location occurs in *OpenOcean.* Upon initial observation, the variability in this location does not smooth at anytime during the temporal database span. The pattern reflects the similar cyclic pattern introduced in Section 5.4 around 1994 and slowing in the 2000's. The greatest change from a high event occurrence to low occurrence is from 1994 to 1995. *IntraCoastal* and *Bay* stranding events show very little variability except in the 1990 decade. Each experiences a slow increase until the 1990's, in which the occurrence counts resemble the *OpenOcean* oscillation. High values occur the two years before the largest event counts in 1994 and then shows a gradual decrease and subtle increase in the 2000's. However, no *LocationValue* experiences a similar overall trend in event counts which further supports the necessity for these spatial designations. To compare the locations to the entire database, Figure 6.11 adds the total trend to the graph. The *OpenOcean* trend line is extremely similar to the total variability, including proportional magnitude of change for the majority of the database. The exceptions are in year 1992 and from years 2000 to 2004. In the year 1992, the amount of *OpenOcean* stranding events actually decreases significantly in proportion to the other data lines. The dip is however explained by the sudden increases in both the *Bay* and *IntraCoastal* events, which in addition will explain the second largest total peak in the year 1992. Figure 6.12 divides the locations into individual bars to evaluate the year 1992 events. This graph shows the proportional heights of the counts and reveals the *Bay* stranding events to be higher than *IntraCoastal* stranding events. Until this point in the research, *Bay* stranding events have not had a significance influence in the distributions of the other locations. This observation provides more support for the need to spatially separate stranding events and to not rely only on the data classifications provided by the TMMSN. To further examine the magnitudes and changes in variability, each *LocationValue* curve was separated into decades. Decades were an arbitrary choice to separate the time scale into manageable units. Decades are a common time frame used in many websites and grey literature regarding stranding events. The decades chosen for this analysis were years 1980 to 1989, 1990 to 1999, and 2000 to 2004.

The first division, Figure 6.13, graphs the *LocationValue* counts from years 1980 to 1989. Increasing the resolution resolution for the three locations of interest (*OpenOcean*, *IntraCoastal,* and *Bay*) shows varying patterns. *OpenOcean* counts start an unusual cyclic trend in 1984 and a small harmonic motion starting in year 1986 and continuing until year 1989. The *IntraCoastal* stranding events are small occurrences until year 1985, where an increase is experienced from years 1985 to 1986. From year 1986, the event counts remain level through the end of the decade. When the total number of events is added, as in Figure 6.14, the trend mimics *OpenOcean* trend. Small differences in count numbers occur in year 1986 with the *IntraCoastal* increase and in year 1998, where the peak is increased by the rise in *Bay* stranding events. As for the *Bay* stranding occurrences, there is little to no activity until the year 1988.

The next decade, from years 1990 to 1999, illustrates a different pattern. Figure 6.15 compares the results and the total number of stranding events is added to Figure

6.16. As with before, each of the major locations varies significantly in extent. The first thing to notice is the decrease in *OpenOcean* and *IntraCoastal* occurrences into the 1990’s. However, the *Bay* events are level in the start of the decade. The unique event in the year 1992 is resolved in both figures. The levels of *OpenOcean* stranding events level off, whereas the greatest increases occur for both *Bay* and *IntraCoastal* occurrences. Another significant impact is the higher *Bay* stranding events, which is another unusual occurrence. After this year, the curves decrease for the majority of the decade, except for a slight increase in year 1994. After this point, the cyclic trend in *OpenOcean* dictates the curve shape. However, the cyclic amplitude drops greatly in 1998, and is where the two of the three major locations decrease. The *Bay* stranding events, though, experience an increase at the end of the decade. When adding the total event numbers to the graph (Figure 6.16), the influence from the major year 1992 *IntraCoastal* and *Bay* event increases is visible. In 1992, the second largest peak is entirely contingent on the stranding events in these two locations and not on *OpenOcean* events. The rest of the decade for *OpenOcean* stays true to the total events line.

The final decade comparison, from years 2000 to 2004, is shown in Figures 6.17 and 6.18. The decreases in *OpenOcean* and *IntraCoastal* occurrences change in year 2000. From 2000 to 2001, the trend shows an increase in *OpenOcean* stranding events, while the *IntraCoastal* stranding events decrease. The *Bay* events decrease slowly from year 1999 and continue until year 2004. The *OpenOcean* stranding events generally increase until year 2002 and sharply decrease for the timeline remainder. This is opposite for *IntraCoastal* stranding events, which increase slowly from 2002 to the end of the database. Adding the total stranding events does not show a similar mimic shape as the previous two decades. The total events increase in year 2001 and level slowly from year 2002 to year 2003, finally decreasing in year 2004. This is the only curve not familiar to the *OpenOcean* trend. The amplitude change for total stranding events is due to the additive effect of the slight increases in occurrences for all other *LocationValue* designations. The decrease at the end of the database is attributed to the large decrease in *OpenOcean* stranding events and only level to slight increases in the other locations. Assessing all temporal graphical representations shows not only the dominance occurred in *OpenOcean* designations, but also how the spatial designations can account for trends and variations in the total events. The prime example of such an influence of the minor locations is the unusual mortality event during the year 1992 documented by Colbert et al. (1999). Two hundred and twenty (220) *Tursiops truncatus* events were documented along Matagorda, San Antonio, and Aransas bays, with stranding events in both the coastal channels and between the bays. This example provides strong support for more resolved spatial designations when investigating marine mammal stranding events. The ability to extract the influence spatially provides more details useful to develop future forecasting models and to isolate phenomenon, such as the 1992 mortality event in the TMMSN stranding database. However, this is only one major event resolved from these analyses. In order to assess the long-term affects with spatial designations, more data is necessary. Though not in this research, curve fittings and harmonic calculations can be applied to each location as a starting point to better identify forecasting trends for each location. By adding this future work, it might be possible to start isolating factors causing stranding events and relate factors to the influence from the marine environment to better forecast future stranding events in Texas.

6.4 Conclusions

These analyses reiterated conclusions from previous sections, such as the influence of *Tursiops truncatus* in all *LocationValue* categories for all species. A unique aspect of this conclusion is the presence of only *Tursiops truncatus* in Texas bays. Larger whales and offshore dolphin species stranding events primarily fall in the *OpenOcean* and *Offshore* categories, which can be attributed to the population characteristics of these species as discussed by Geraci and Lounsbury in 1993.

Temporal trends by location revealed *OpenOcean* stranding events mimicked the temporal trends of the total stranding events. The unusual mortality event published by Colbert et al. (1999) and discussed in Section 5 influenced the *Bay* and *IntraCoastal* categories and caused significant decrease in the *OpenOcean* stranding occurrences in year 1992. Also, dividing the temporal scales by the decades chosen in this work created a higher resolution to evaluate stranding locations detailing the shifting distributions between the three major *LocationValue* categories.

Finally, the maps with *LocationValue* by year showed how the events are clustered in major areas along the Texas coastline. Two major groups of clusters were present in the maps. The first was more circular in shape occurring predominantly in the Bays or inner waterways and the second resembled a line clustering typically occurring along the exposed Texas coasts or *OpenOcean* locations. The clusters could also be defined by Texas county boundaries, with major groupings either from Sabine-

Galveston-Brazoria County or San Patricio-Nueces County lines. However, further analyses is necessary to statistically quantify the temporal resolution of event clusters. Spatial statistics can also be later applied to investigate the distances between the northern or southern clusters and how the clusters may shift along the Texas coast in time. These future studies can possibly be applied to expanding previously known population characteristics for species and to isolate causes for stranding events as documented in the scientific literature.

These analyses proved the importance of creating spatial designations as a means to enhance the TMMSN stranding data. Figure 6.19 plots the event counts for the hypothesized *LocationValue* for each TMMSN Stranding Region. If no further spatial designation could be applied, then the counts would not vary. Yet, this does not occur and there is actually a strong variability between location and Stranding Region. Though *OpenOcean* events dominant the *LocationValue*, the two others locations influence other temporal and spatial scales, as reflected by the unusual mortality event of 1992. Examples of the importance in stranding location designations were also shown in the species and temporal discussions, as well as in the magnitudes between spatial values. Yet, this location categories created may not be the only situations applicable to understanding stranding rates. Minimizing the length of the coast and isolating specific incidences in the stranding database may improve the effort to forecast stranding events in the future, as well as determine factors impacting cetacean habitat distribution. The ability to isolate the 1992 mortality is only one spatial example from developing more elaborate spatial characteristics for the stranding data. The conclusions from both the graph and map representations show that the location categories are important and contribute positively to examining the factors impacting stranding event rates and how the factors are influenced by the surrounding marine and coastal environments.

7. STUDY CONCLUSIONS AND FUTURE DIRECTIONS

7.1 Study Conclusions

The TMMSN stranding database is an excellent tool for studying cetacean populations and can supplement habitat distribution studies in the GOM by providing information about the population range of individual species. The data collected and recorded provides a vast amount of information regarding the status of a cetacean group or population and how the various environmental factors can affect different species. Financial balancing and time constraints in the TMMSN organization does not always allow dedication towards maintaining a reliable and maneuverable database. The database was not in strong form to extract data to analyze. The primary objective of this research, therefore, was to create a better system to record, store, and transport data. The original TMMSN database was removed from Microsoft Excel and rebuilt in Microsoft Access. Four main factors were considered in choosing an application (Section 2). In Access, each event was sorted through and gaps in the event's records were corrected. Each record attribute was also designed with data entry limitations to restrict entry errors in the future. Finally, each event was assigned a unique key code, independent of any previous designation from the TMMSN. The database rebuild was tedious and time-consuming, but the end product will be extremely beneficial to any stranding network in that it is similar in appearance to the original database, data entry can be controlled and restricted by a primary user, and data can be isolated simply into new tables and linked to the entire database without destroying the integrity of the entire database. After redesigning the original database into a usable application, the four study questions posed could be evaluated and answered.

The first questions focused on how stranding events are documented within the marine mammal research community. The literature search provided 151 publications documenting stranding events world-wide. The main focuses from each publication were grouped into seven categories. Each category emphasized a discrete element in a stranding event, from physiological or behavioral observations to temporal or spatial stranding extents in a defined location. The greatest number of publications fell into the highlighting studies with large event databases, in which the focus was a general reporting of events. The least published category was articles studying the response or rehabilitation of a stranding marine mammal. After evaluating the categories, all articles were compared for the year of publication and the location in which the events occurred in. Graphical representations demonstrated the immense publication rate in North America, primarily in the United States. The United States publications directly reflect the federal implementation of stranding regions enacted from the Marine Mammal Protection Act of 1972. No other country has an established government hierarchy to regulate and support regional stranding networks. Yearly trends also revealed a positive increase in the volume of stranding research published from years 2000 to 2008. Looking at the oceanic spatial attributes, events primarily occurred in the Atlantic and Pacific Oceans, and the GOM. The similar patterns in the Pacific and Atlantic Oceans are not only dependent on the United States, but also publications produced by European and Asian countries, as well a few contributions by South America. However, the GOM events are largely dependent on publications from Texas. The high number of publications from Texas is related to the TMMSN's affiliation with the University of Texas Medical Branch in Galveston, which conducts necropsies for all Texas stranding events. The current Director of TMMSN is also a respected pathologist at University of Texas and is one of the primary researchers publishing in Texas; therefore, the publication rate is composed primarily of studies focusing on pathological or physiological responses in stranded cetaceans. Despite the potential bias from Texas stranding publications, the GOM states are currently focusing research efforts towards using stranding events to investigate climate change and the increase in brevetoxins on the cetacean community.

The next section examined the species composition within the TMMSN database. Graphical and statistical analyses revealed little diversity in the Texas stranding populations, with *Tursiops truncatus* accounting for approximately 80% of the stranding database. After isolating this skew, the second largest group was unknown species, in which no species designation could be made. This designation could be strongly related the condition of the animal stranded, in which the body was too decomposed to identify the species. However, despite this category, there were observations of a multitude of whale and dolphin species stranding along the Texas coasts. Of the 28 species known to inhabit the GOM, 20 have appeared in the TMMSN stranding records. Mapping the locations of these species revealed a pattern in southern Texas, where the majority of events occurred on the coast with the narrowest width of continental shelf (Figure 4.6). The events not in this location were spread out elsewhere along the coast and were not clustered. These species did not strand in any Texas bay. Performing a similar analysis with *Tursiops truncatus* confirmed the skew in the database, in that geographical locations are heavily distributed in all parts of the coast, including the bay systems. Though the database is strongly influenced by *Tursiops truncatus*, the presence of other species can be important when investigating habitat distributions of pelagic species, as well as providing information about the present status of an offshore population. For example, increases in stranding rates for any one of these species could indicate trouble within a population and/or indicate a population shift in the GOM.

The next question addressed the temporal patterns in the database by isolating and investigating yearly and monthly trends. Results for the entire database demonstrated no apparent trend from 1980 to 2004, due mainly to the cyclic fluctuations from years 1992 to 1998. Attempts to reduce the variability proved inconclusive. Forecasting attempts were not possible, due constraints in reducing the variability and more so, the inability to isolate one biological, environmental, or anthropogenic factor controlling stranding rates. Numerous environmental factors influence the stranding rates in each year, as evident in the variability from years 1992 to 1998. Expanding the dataset for years 2005 to 2008 may aid in determining if the cyclic pattern re-occurs, or is only unique in the mid-1990's and will not affect future stranding rates. However, to be entirely supportive of this hypothesis, more data is necessary. To answer if stranding rates are increasing, data should be collected from other states in the Gulf of Mexico and compared against the Texas dataset.

The monthly stranding events were also evaluated and a more definite trend appeared than in the yearly analyses. A substantial pattern emerged from these studies, primarily demonstrating bimodal stranding peaks during all years. The first, and dominant, peak is from late February to early May and the second occurs in the late fall to early winter months. These two peaks correlate the breeding patterns of *Tursiops truncatus*, documented by Wells et al. 1999, in which this species experiences a bimodal reproduction in the GOM. However, future directions would be to quantify the amplitudes of the monthly stranding peaks as a stronger estimation to forecast stranding rate. Isolating the amplitudes would provide more reliable estimates than relying on the total events per year.

The last temporal analyses involved performing density distribution calculations per decade for the stranding data. Results provided high stranding densities in Galveston, Brazoria, Nueces, and San Patricio counties. Though the densities in Nueces and San Patricio counties were reflective of the 1992 mortality event (Colbert et al. 1999), the other areas are strongly influenced by anthropogenic activity, especially housing the state’s two major shipping channels and are also the most populated coastal counties in Texas. This study supports the idea that cetacean habitats and populations can be altered by anthropogenic sources and alterations can be isolated from stranding event data.

The final question concentrated on isolating spatial trends in the Texas stranding events. Previous analysis demonstrated the influence of *Tursiops truncatus* in the TMMSN database and also showed this species was the only stranding in the bays. To address this issue and to investigate clusters resulting from the density distributions, location categories were formed based on the event's relation to the Texas coastline. Of the six locations developed, approximately 68% of stranding events fell within the *OpenOcean* category. The next largest categories were *IntraCoastal* and *Bay*, which accounted for a combined 25% of the database. The temporal distributions for these locations did not follow the trend for the total events. Separating the locations by decades showed the influence of both *Bay* and *Intracoastal* stranding events on the entire database, especially in years 1992, 1994, and from 2001 to 2004. The effect in 1992 can be explained as mentioned earlier, but there are currently no unusual events to explain the variability among locations.

Graphical representations were an attempt to further investigate the result of the density distributions. Clusters were defined as more than 5 events within a mile and resembled either one of two shapes, a circle or line. Line clusters were present along the Sabine-Galveston-Brazoria county lines, whereas circle clusters were more common in south Texas along the San-Patricio-Nueces county boundaries. The clusters formed did correspond to the kernel density distributions calculated in Section 5. Future work with these maps would be to apply density distributions by location to isolate areas of interest within each individual location category and to statistically asses the distance between cluster events over time, as well as statistically define the differences in distribution and clusters between the north and south Texas coast.

The final spatial analysis attempted to demonstrate the importance of the location categories for the TMMSN. Since the TMMSN is structured into response regions, the location values would be beneficial in organizing response efforts within each stranding region. The graphical output plotting the developed location values and the TMMSN stranding regions revealed that each region has a different location profile. The Galveston region predominantly experiences *OpenOcean* stranding events as opposed to Port Aransas, where *IntraCoastal* and *Bay* stranding events are more common. Once again, the variation among stranding regions emphasizes the importance that multiple factors influence stranding rates and one coastal area does not necessarily respond equally to environmental influences as another. To better express the need to evaluate and define spatial attributes of stranding locations, statistical analysis could be performed to quantify the location differences between regions. Also, after quantification, these location values should be useful in isolating specific incidences influencing various parts of the Texas coast, as well as examining the factors influencing stranding rates more in-depth.

7.2 Future Work

This research is part of what information stranding events can explain about cetacean communities and the marine environment. The first step before proceeding into more detailed analyses would be to update the database with data from years 2005 to 2008. After updating the database, I intend to share the new database system with the TMMSN and eventually other GOM stranding networks, in an effort to promote more reliable data storage and consistency among stranding networks. As far as the extended database analyses, I will elaborate on the studies presented in this research in an effort to better isolate trends both temporally and spatially in the data. Also, I hope to evaluate the evident temporal and spatial trends with other descriptors available in the database, such as the condition of the animal stranded, the age of the animal, and the length of the animal. The research will be directed into further testing environmental, biological, or anthropogenic factors affecting Texas stranding rates, such as attempting to isolate unique incidences similar to the unusual mortality event in 1992 to investigating location factors on event rates. With these studies, I hope to isolate and quantify the influential factors determining the temporal and spatial trends in the database, to eventually estimate the magnitude and location of future stranding events along the Texas coast. Ideas for estimating stranding events include constructing suitability models to incorporate real-time environmental data and produce a map representation available to TMMSN stranding regions. Expanding the database into a forecasting tool is the ultimate goal, in that it will aid the TMMSN in organizing response efforts and with increasing efficiency in data reporting, and will serves as a novel technique in monitoring cetacean population distributions and habitat sustainability, such as habitat responses to climate change or anthropogenic influences. For example, increases in human population and pollution sources into the coastal ocean may result in increased stranding rates and therefore can serve as an indicator for the health of a coastal marine mammal population.

LITERATURE CITED

Atlantic Fleet Active Sonar Training, Department of the Navy. 2008. Cetacean stranding report. Atlantic Fleet Active Sonar Training EIS/OEIS Appendix E, E-1-E-48 *in* Atlantic Fleet Active Sonar Training Environmental Impact Statement/Overseas Environmental Impact Statement. NOAA National Marine Fisheries Service.

Berrow, S.D. and E. Rogan. 1997. Cetaceans stranded on the Irish coast, 1901-1995. Mammal Review, 27(1), 51-76.

Blaylock, R.A. and W. Hoggard. 1994. Preliminary estimates of bottlenose dolphin abundance in southern U.S. Atlantic and Gulf of Mexico continental shelf waters. NOAA Technical Memorandum, NMFS-SEFSC-356.

Borcard, D., P. Legendre, and P. Drapeau, 1992. Partialling out the spatial component of ecological variation. Ecology, 73, 1045-1055.

Caughley, G. 1966. Mortality patterns in mammals. Ecology, 47(6), 906-918.

Colbert, A.A., G.I. Scott, M.H. Fulton, E.F. Wirth, J.W. Daugomah, P.B. Key, E.D. Strozier, S. B.Galloway. 1999. Investigation of unusual mortalities of bottlenose dolphins along the mid-Texas coastal bay ecosystem during 1992. NOAA Technical Report NMFS 147, 1-23.

Constantine, R., D.H. Brunton, and T. Dennis. 2004. Dolphin-watching tour boats change bottlenose dolphin (Tursiops truncatus) behavior. Biological Conservation, 117, 299-307.

Crossett, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed. 2004. Population trends along the coastal United States : 1980 to 2003. NOAA Coastal Trends Report Series, 1-47.

Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen, K. Mullin. 1998 Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. Marine Mammal Science, 14(3), 490-507.

Davis, R.W., J.G. Ortega-Ortiz, C.A. Ribic, W.E. Evans, D.C. Biggs, P.H. Ressler, R.B. Cady, R.R. Leben, K.D. Mullin, and B. Wursig, 2002. Cetacean habitat in the northern oceanic Gulf of Mexico. Deep Sea Research Part1: Oceanographic Research Papers, 49(1), 121-142.

Duffy-Echevarria, E.E., R.C Connor, and D.J. St. Aubin, 2008. Observations of strand-feeding behavior by bottlenose dolphins (Tursiops truncatus) in Bull Creek, South Carolina. Marine Mammal Science 24(1), 202-206.

Fernandez, S. 1998. Age, growth, and calving season of bottlenose dolphins, Tursiops truncatus, off coastal Texas. Fishery Bulleting of the Fish and Wildlife Service, 98, 357-365.

Fertl, D. 1994. Occurrence patterns and behavior of bottlenose dolphins (*Tursiops truncatus*) in the Galveston Ship Channel, Texas. Journal of Texas Science, 46, 299-317.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgeway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. Journal of the Acoustical Society of America, 108, 417-431.

Fire, S. E., D. Fauguier, L.J. Flewelling, M. Henry, J. Naar, R. Pierce and R.S. Wells. 2007. Brevetoxin exposure in bottlenose dolphins (*Tursiops truncatus*) associated with Karenia brevis blooms in Sarasota Bay, Florida. Marine Biology, 152, 827-834.

Geraci J. R. (1978) The enigma of marine mammal strandings. Oceanus, 21(2), 38-47.

Geraci, J.R. and V.J. Lounsbury. 1993. Marine mammals ashore : A field guide for strandings. Texas A&M University Sea Grant College Program Publication TAMU-SG-93-601, College Station.

Geraci, J.R., J. Harwood, and V.J. Lounsbury. 1999. Marine mammal die-offs: Causes, investigations, and issues. Pages 367 - 395 *in* Conservation and Management of Marine Mammals, Twiss, J.R. and R.R. Reeves, eds. Smithsonian Institution Press, Washington DC.

Hooker, S., H. Whitehead, and S. Gowans. 1999. Marine protected area and the spatial and temporal distribution of cetaceans in a submarine canyon. Conservation Biology, 13(3), 592-602.

Jasny, M., J. Reynolds, C. Horowitz, and A. Wetzler. 2005. Sounding the Depths II: The rising toll of sonar, shipping, and industrial ocean noise on marine life. National Resources Defense Council. New York, NY. (http://www.nrdc.org/wildlife/marine/sound/contents.asp).

Klinowska, M. 1985. Cetacean live stranding sites relate to geomagnetic topography. Aquatic Mammal, 1, 27-32.

Learmonth, J.A., C.D. MacLeod, M.B. Santos, G.J. Pierce, H.Q.P. Crick, and R.A. Robinson. 2006. Potential effects of climate change on marine mammals. Oceanography and Marine Biology, 44, 431-464.

Lusseau, D., B. Wilson, P.S. Hammond, K. Grellier, J.W. Durban, K.M. Parsons, T.R. Barton, and P.M. Thompson. 2006. Quantifying the influence of sociality on population structure in bottlenose dolphins. Journal of Animal Ecology, 75, 14-24.

Lynn, S.K. 1995. Movements, site fidelity, and surfacing patterns of bottlenose dolphins on the central Texas coast. M.S. Thesis, Texas A&M University, College Station.

Marine Mammal Commission 2007. The Marine Mammal Protection Act of 1972 as Amended 2007. NOAA National Marine Fisheries Service. Washington D.C. http://www.nmfs.noaa.gov/.

McDonald, M.A., R. Nairn, A. Johnson and D. Hardin. 2001. Increases in deep ocean ambient noise in the northeast pacific west of San Nicholas Island, California. Journal of the Acoustical Society of America, 120(2), 711-718.

Morimitsu, T., T.Nagai, M. Ide, H. Kawano, A. Naichuu and M. Koono. 1987. Mass stranding of odontoceti caused by parasitogenic eighth cranial neuropathy. Journal of Wildlife Diseases, 23, 586-590.

Mullin, K. D. and G. L. Fulling. 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico. Marine Mammalogy, 20(4), 787-807.

NOAA. 1994. El Nino and climate prediction – Reports to the nation on our changing planet. A publication of the University Corporation for Atmospheric Research pursuant to National Oceanic and Atmospheric Administration Award No. NA27GP0232-01. UCAR Boulder, CO.

Norman, S.A., C.E. Bowlby, M.S. Brancato, J. Calambokidis, D. Duffield, P.J. Gearin, T.A. Gornall, M.E. Gosho, B. Hanson, J. Hodder, S.J. Jeffries, B. Lagerquist, D.M. Lambourn,B. Mate, B. Norberg, R.W. Osborne, J.A. Rash, S. Riemer and J. Scordino. 2004. Cetacean strandings in Oregon and Washington between 1930 and 2002. Journal of Cetacean Resource Management, 61(1), 87-99.

Ott, R.L. and M. Longnecker. 2001. An introduction to statistical methods and data analysis. 5th edition. Duxbury Wadsworth Group Publication, Thomson Learning, Inc., Pacific Grove, CA.

Ross, G.J.B. 1977. The taxonomy of bottlenose dolphins *Tursiops* species in South African waters, with notes on their biology. Ann. Cape Prov. Mus. Nat. Hist., 11, 135-194.

Sargaent, B.L., J. Mann, P. Berggren and M. Krutzen. 2005. Specialization and development of beach hunting, a rare foraging behavior, by wild Indian Ocean bottlenose dolphins (*Tursiops* sp.). Canadian Journal of Zoology 83(11), 1400-1410.

Shane, S.H. 1977. The population biology of the Atlantic bottlenose dolphin, *Tursiops truncatus* in the Aransas Pass area of Texas. M.S. Thesis, Texas A&M University, College Station, 28 pp.

Southall, B.L., R. Braun, M.D. Gulland, A.D. Heard, R.W. Baird, S.M. Wilkin and T.K. Rowles. 2006. Hawaiian melon-headed whale (*Peponocephala electa*) mass stranding event of July 3-4, 2004. NOAA Technical Memorandum NMFS-OPR-31, 1-73.

Sperm Whale Seismic Study in the Gulf of Mexico: Summary Report, 2002-2004. 2005. Ann Jochens ed., U.S. Department of the Interior, Marine Minerals Management Service, Gulf of Mexico OCS Region. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/2006/2006-034.html.

Tarpley, R.J. 1987. Texas Marine Mammal Stranding Network. The Southwestern Veterinarian, 38(2), 51-58.

Tolan, J.M. 2007. El Nino-Southern oscillation impacts translate to the watershed scale: Estuarine salinity patterns along the Texas Gulf Coast, 1982 to 2004. Estuarine, Coastal, and Shelf Science, 72, 247-260.

Urian, K.W., D.A. Duffield, A.J. Read, R.S. Wells and D.D. Shell. 1996. Seasonality of reproduction in bottlenose dolphins, *Tursiops truncatus*. Journal of Mammalogy, 77, 394-403.

Vanselow, K.H. and K. Ricklefs. 2005. Are solar activity and sperm whale *Physeter macrocephalus* strandings around the North Sea related? Journal of Sea Research, 53, 319-327.

Vastano, A.C., C.N. Barron and E.W. Shaar. 1995. Satellite observations of the Texas current. Continental Shelf Research, 15, 729-754.

Wells, R.S. and M.D. Scott. 2002. Bottlenose dolphins (*Tursiops truncatus* and *T. aduncus*) Pages 122-128 *in* W.F. Perrin, B. Wursig, and J.G.M. Thewissen, eds., Encyclopedia of Marine Mammals Academic Press, San Diego, CA.

Wright, A. 2005. Lunar cycles and sperm whales (*Physeter macrocephalus*) strandings on the north Atlantic coastlines of the British Isles and eastern Canada. Marine Mammal Science, 21(1), 145-149.

APPENDIX A

TABLES

GIS Source Layers Compiled to Analyze TMMSN Stranding Events			
Layer Name	***Data Source***	***Spatial Projection***	***Datum***
Texas Counties	University of Texas Bureau of Economic Geology	UTM Zone 15	NAD83
mnrbays (Minor Bays)	Texas Parks and Wildlife Department	Lambert Conformal Conic	NAD83
mjrbays (Major Bays)	Texas Parks and Wildlife Department	Lambert Conformal Conic	NAD83
NOAA shorelines	National Oceanographic and Atmospheric Administration	None	NAD83
State boundaries	United States Geological Service Coastal and Marine Geology Program	GRS 80	NAD83
Texas rivers	Texas Commission on Environmental Quality	Lambert Conformal Conic	NAD83

Table 2.1 GIS Source Layers Used to Construct Research Maps.

The six layers listed above were downloaded from the respective sources and imported into ArcGIS 9.2 to serve as baseline shape files for constructing stranding event analysis maps. All layers were imported into GIS and projected to the Texas Centric Mapping Projection explained in Section 2.4.

GENERAL DATABASE DESCRIPTION		
Number	**Percentage**	**Detail**
3301	100	*Total number of all documented points*
236	7.1493	*Points with NO spatial location*
164	4.9682	*Points with NO temporal location*
19	0.5756	*Points with NO species identification*
43	1.3026	*Points with NO desirable data*
3258	**98.6974**	*Total number of points used in data analysis*

Table 4.1 TMMSN Database Description Based on Data Entry.

The table highlights columns of interest from the original TMMSN database. Features not of interest were events without spatial or temporal locations and/or species identification. Points with no desirable data included any event missing all three of the listed interests. The bold values indicate data removed and percent available for analysis. The blue number shows the total number of events for analysis.

SPECIES STRANDED IN THE GULF OF MEXICO

Total Number Stranded	Number Used in Analysis	Scientific Species Name	Common Name
1	1	Balaenoptera acutorostrata	Minke whale
1	1	Balaenoptera borealis	Sei whale
8	8	Feresa attenuata	Pygmy killer whale
1	1	Globicephala macrorhynchus	Short - finned pilot whale
4	4	Grampus griseus	Risso's dolphin
12	12	Kogia breviceps	Pygmy sperm whale
11	11	Kogia sima	Dwarf sperm whale
1	1	Lagenodelphis hosei	Fraser's dolphin
1	1	Mesoplodon densirostris	Blainville's beaked whale
3	3	Mesoplodon europaeus	Gervais' beaked whale
8	8	Peponocephala electra	Melon - headed whale
7	7	Physeter macrocephalus	Sperm whale
3	3	Pseudorca crassidens	False killer whale
10	10	Stenella attenuata	Pantropical spotted dolphin
15	15	Stenella clymene	Clymene dolphin
5	5	Stenella coeruleoalba	Striped dolphin
10	10	Stenella frontalis	Atlantic spotted dolphin
9	9	Stenella longirostris	Spinner dolphin
2	2	Steno bredanensis	Rough - toothed dolphin
5	5	Trichehus manatus	West Indian manatee
3077	**3055**	Tursiops truncatus	Atlantic bottlenose dolphin
3	3	Ziphius cavirostris	Cuvier's beaked whale
104	**83**	Unknown	No clear designation
3301	**3258**	TOTAL	TOTAL

Table 4.2 Species Stranding Events in Texas According to the TMMSN Database.

The table lists the presence of stranding events by species as appearing in the database. Both the scientific species name and the common name are listed. The 'TOTAL' represents all data fields in the TMMSN records. The red numbers highlight data points used in Section 4 analysis.

Family	Common Name	Location Sighted	Sighting Frequency	Season	Gulf of Mexico Stranding Frequency	Texas Stranding Frequency
Cetaceans in the Gulf of Mexico Waters and Associated Stranding Frequencies						
Suborder Mysticeti (Baleen Whales)						
Balaenidae (Right Whales)						
Eubalaena glacialis	Northern Right Whale	Offshore	Rare	Jan - Mar		
Balaenopteridae (Rorquals)						
Megaptera novaeangliae	Humpback Whale	Coastal	Rare	Winter		
Balaenoptera physalus	Fin Whale	Pelagic	Rare	Winter		
Balaenoptera musculus	Blue Whale	Pelagic	Rare	Unknown		
Balaenoptera borealis	Sei Whale	Pelagic	Rare	Dec - Mar		
Balaenoptera acutostrata	Minke Whale	Pelagic	Occasional	Winter		
Balaenoptera edeni	Bryde's Whale	Pelagic, Inshore	Rare	All Year		
Suborder Odontoceti (Toothed Whales)						
Physeteridae (Sperm Whales)						
Physeter macrocephalus	Sperm Whale	Southern	Common	All Year		
Kogia breviceps	Pygmy Sperm Whale	Southern	Common	All Year		
Kogia simus	Dwarf Sperm Whale	Southern	Common	All Year		
Ziphiidae (Beaked Whales)						
Ziphius cavirostris	Cuvier's Beaked Whale	Pelagic	Common	All Year		
Mesoplodon (Beaked Whales)						
Mesoplodon densirostris	Blainville's Beaked Whale	Pelagic	Common	All Year		
Mesoplodon europaeus	Gervais' Beaked Whale	Pelagic	Common	All Year		
Mesoplodon bidens	Sowerby's Beaked Whale	Pelagic	Rare	Unknown		
Delphinidae (Dolphins)						
Orcinus orca	Killer Whale	Inshore	Rare	Unknown		
Pseudorca crassidens	False Killer Whale	Pelagic	Occasional	All Year		
Feresa attenuata	Pygmy Killer Whale	Pelagic	Common	All Year		
Globicephala macrorhynchus	Short-finned Pilot Whale	Inshore, Pelagic	Common	Dec - May		
Grampus griseus	Risso's dolphin	Pelagic	Common	All Year		
Lagenodelphis hosei	Fraser's dolphin	Pelagic	Rare	All Year		
Tursiops truncatus	Bottlenose dolphin	Inshore, Pelagic	Common	All Year		
Delphinus delphis	Common dolphin	Pelagic	Common	All Year		
Steno bredanensis	Rough-toothed dolphin	Pelagic	Occassional	Unknown		
Stenella longirostris	Spinner dolphin	Inshore, Pelagic	Common	All Year		
Stenella clymene	Clymene dolphin	Pelagic	Common	All Year		
Stenella coeruleoalba	Striped dolphin	Pelagic	Common	All Year		
Stenella attenuata	Pantropical spotted dolphin	Inshore, Pelagic	Occasional	All Year		
Stenella frontalis	Atlantic spotted dolphin	Inshore, Pelagic	Common	All Year		

Table 4.3 Cetaceans Observed and Stranded in the Gulf of Mexico. The tables provides the scientific name, common name, general location, observance of population and stranding frequencies in the Gulf of Mexico and the TMMSN stranding database. The box colors signify the following : Blue – Rare events only documented from scientific literature, Green-One event every 1 to 5 years, Purple-Event frequency greater than 1 event a year, Orange-Event frequency greater than 12 events a year, Red-Event frequency greater than 50 events a year, Gray-No Documentation in the TMMSN database

APPENDIX B

FIGURES

Figure 1.1 National Marine Fisheries Service Marine Mammal Stranding Jurisdictions.

The map shows the five federal jurisdictions formed by the NMFS to monitor and regulate United States stranding events. The number of states per jurisdiction is based on the NMFS zoogeographic regions.

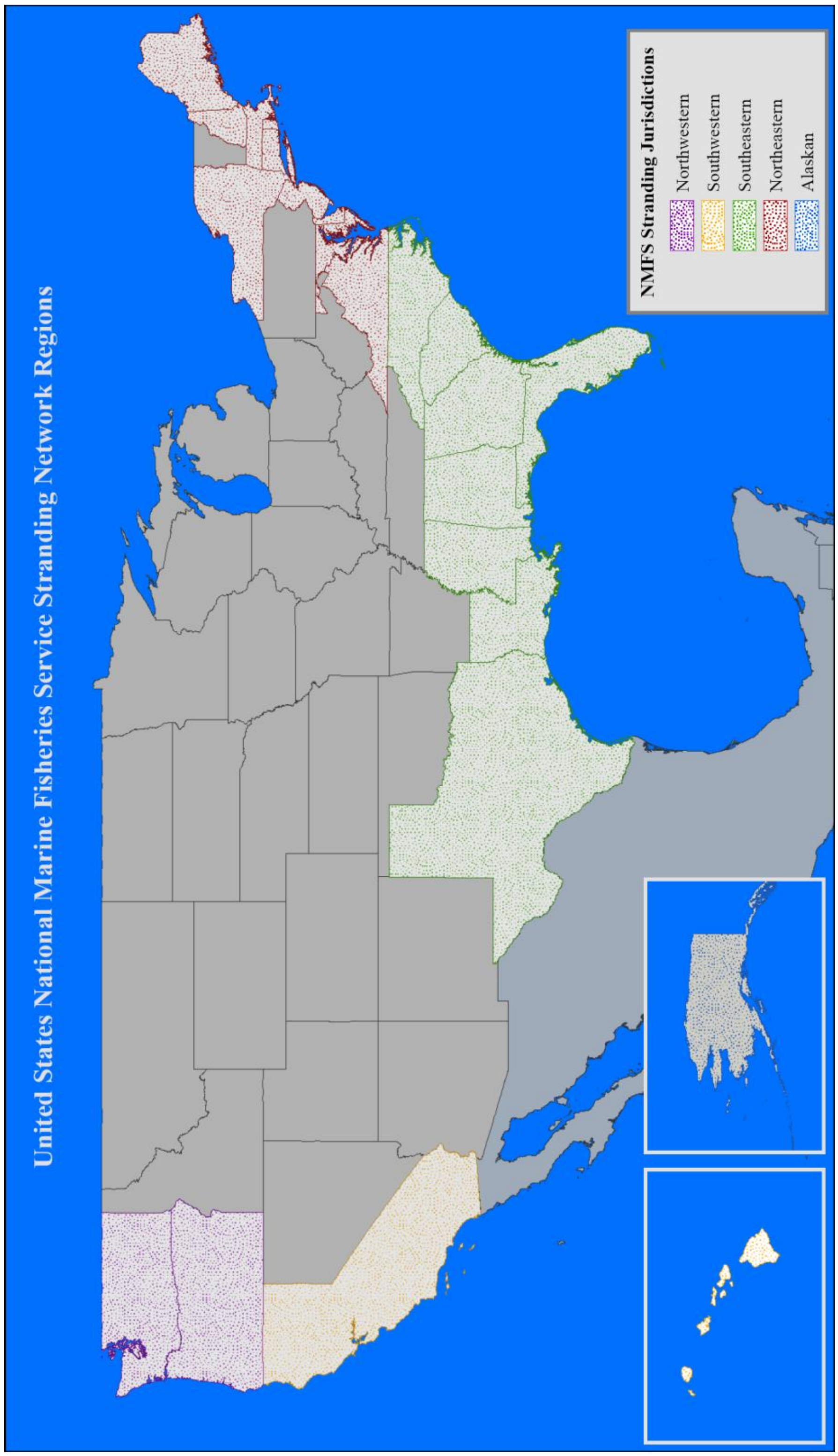
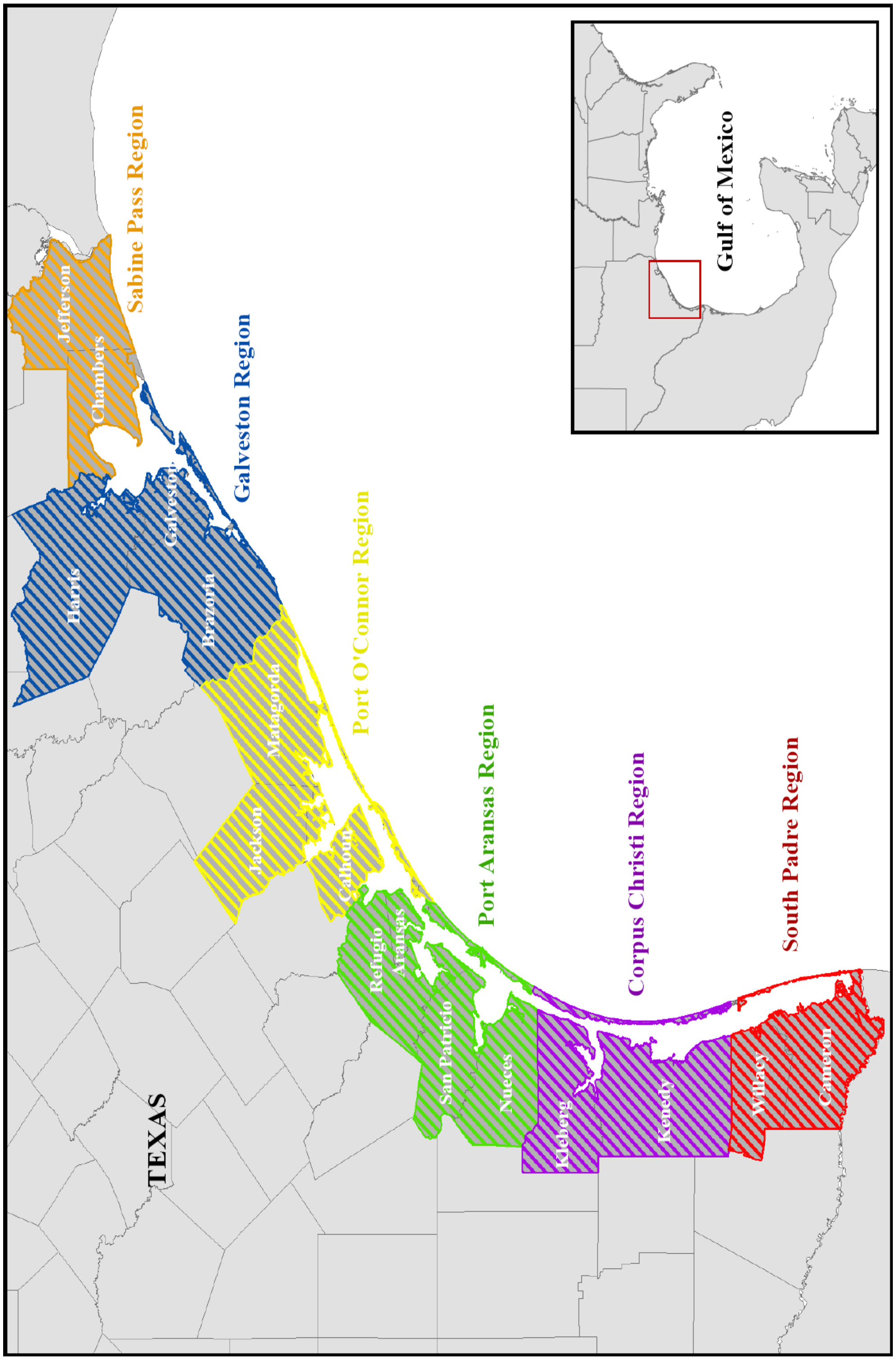

United States National Marine Fisheries Service Stranding Network Regions
NMFS Stranding Jurisdictions
Northwestern
Southwestern
Southeastern
Northeastern
Alaskan

Figure 1.2 Texas Marine Mammal Stranding Networks.

The map shows six of the seven TMMSN response regions. The regions are designated by Texas county lines and used to organize the response capabilities of the TMMSN. The seventh region is the western portion of Louisiana and was only recently formed in the past year.


Sabine Pass Region
Galveston Region
Port O'Connor Region
Port Aransas Region
Corpus Christi Region
South Padre Region
Jefferson
Chambers
Harris
Galveston
Brazoria
Matagorda
Jackson
Calhoun
Refugio
Aransas
San Patricio
Nueces
Kleberg
Kenedy
Willacy
Cameron
TEXAS
Gulf of Mexico

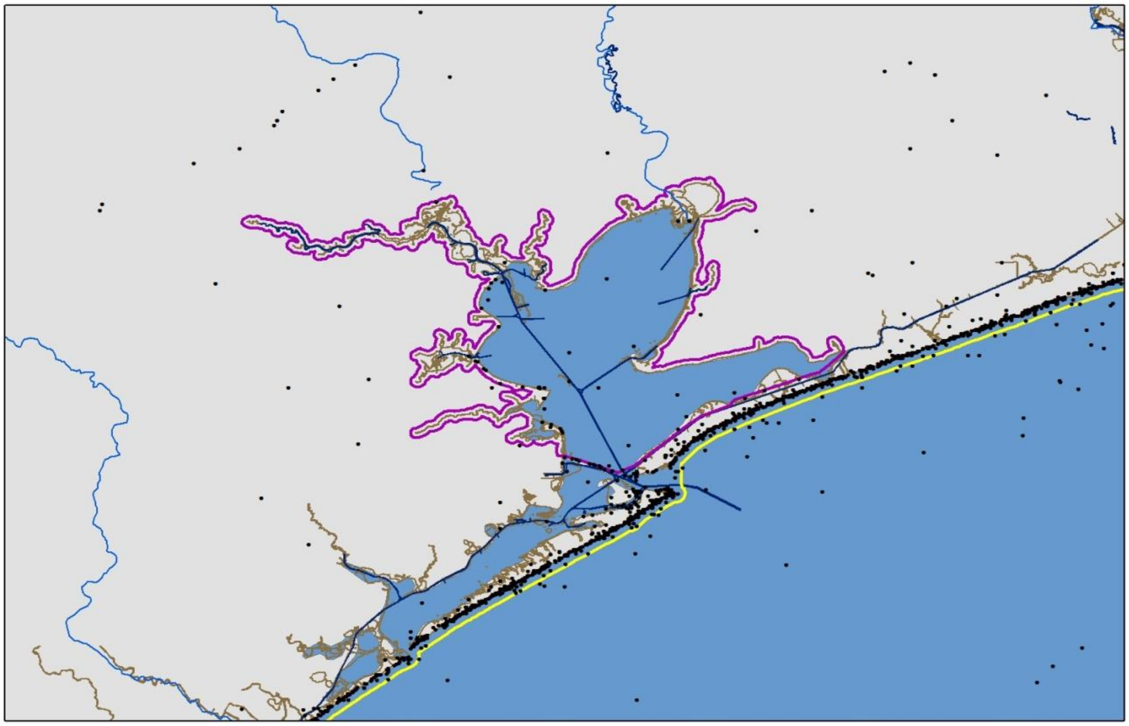


Figure 2.1 Boundaries for Determining Stranding Event Locations.

This map uses Galveston Bay as an example location for determining stranding event location along the Texas coast. The black circles are stranding events. The dark navy lines are Texas coast shipping channels. The yellow line represents a 1-mile boundary from the coastline. Everything inland of this line to a half-mile on the exposed coast was designated as an *OpenOcean* event. All events beyond this line are considered *Offshore* stranding events. The purple line is a half mile buffer around Galveston Bay. All points within this area are labeled as *Bay* stranding events. The events between the bay and the exposed coast are designated as *IntraCoastal* stranding events. Events outside of the buffers created and not within 1-mile of water were labeled *Inland*.

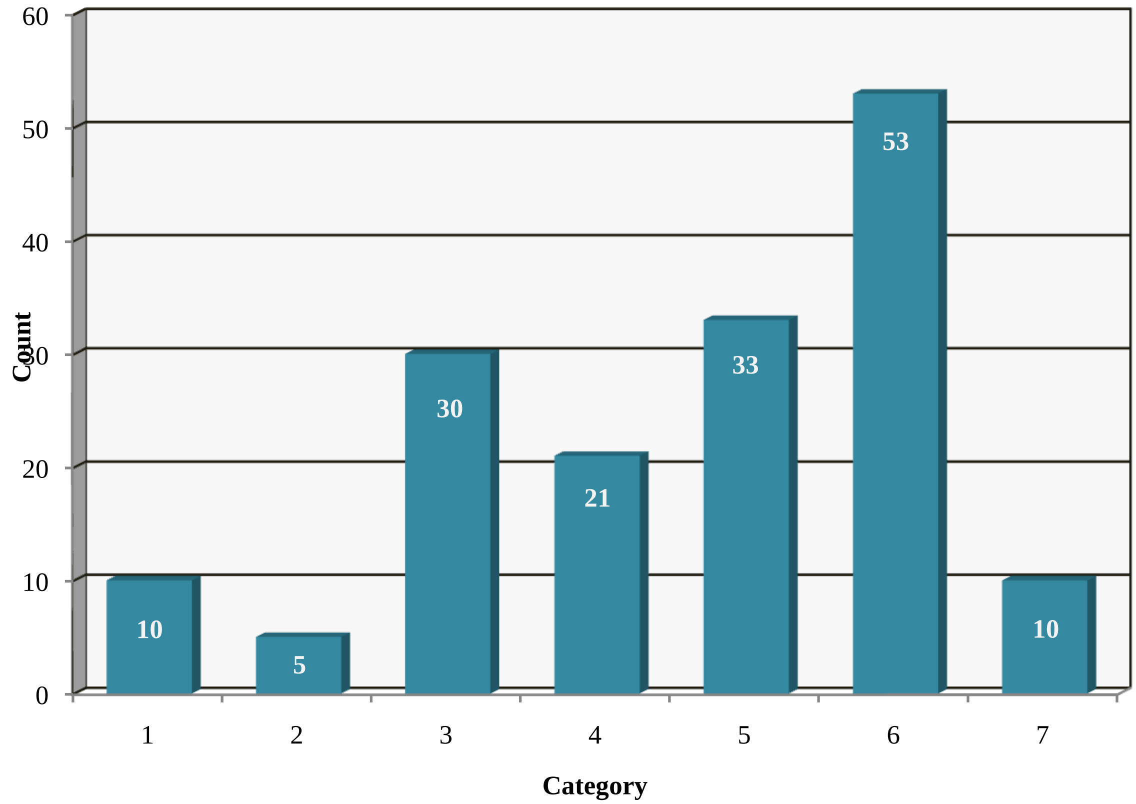


Figure 3.1 Stranding Event Literature by Category.

Seven categories were created as a result of the literature search conducted in Section 3. The category descriptions are detailed in Section 3.2. The lowest category focuses on studies with stranding responses or rehabilitated cetaceans. The largest category is articles emphasizing large stranding event database studies.

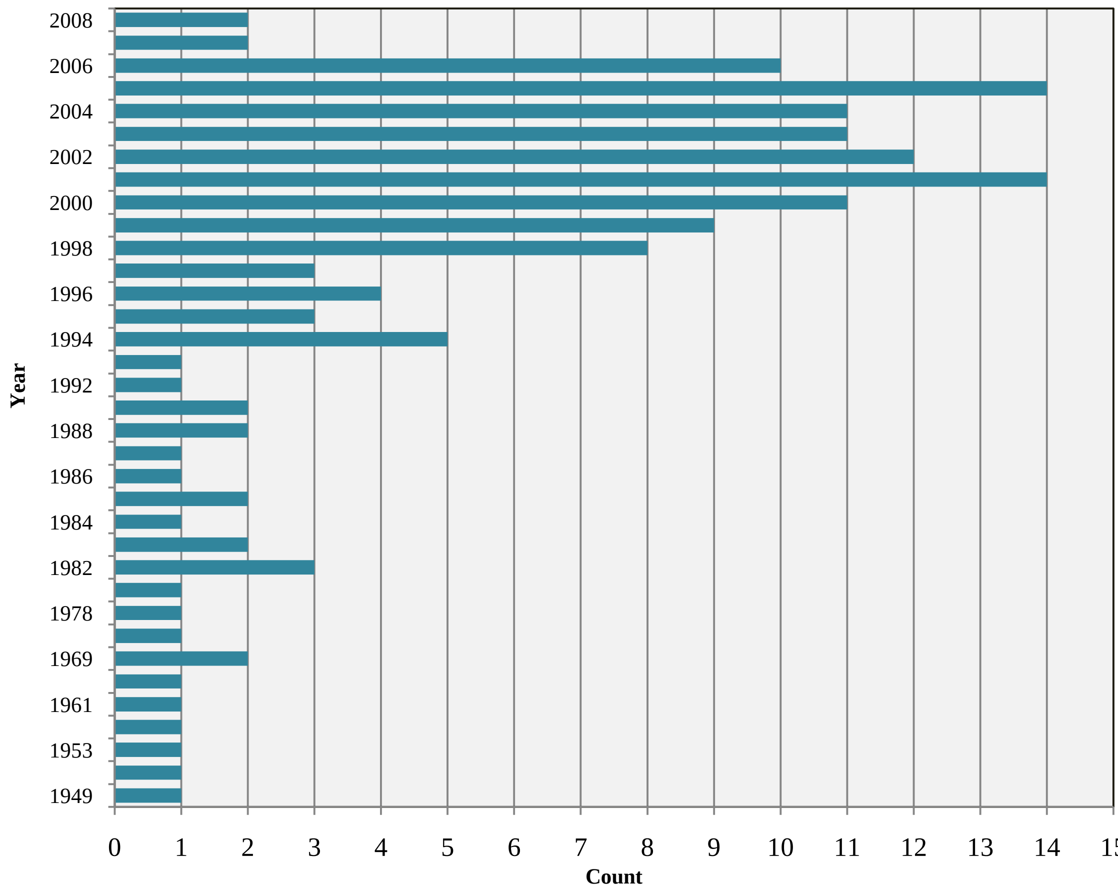


Figure 3.2 Number of Stranding Event Articles Published per Year.

This graph plots the publication year of the stranding event study versus yearly counts. The published literature is weak historically, but increases in the late 1990's and into the 2000's. Since the literature ceased in May 2008, it is not possible to know if year 2008 publications will increase beyond the numbers in year 2005.

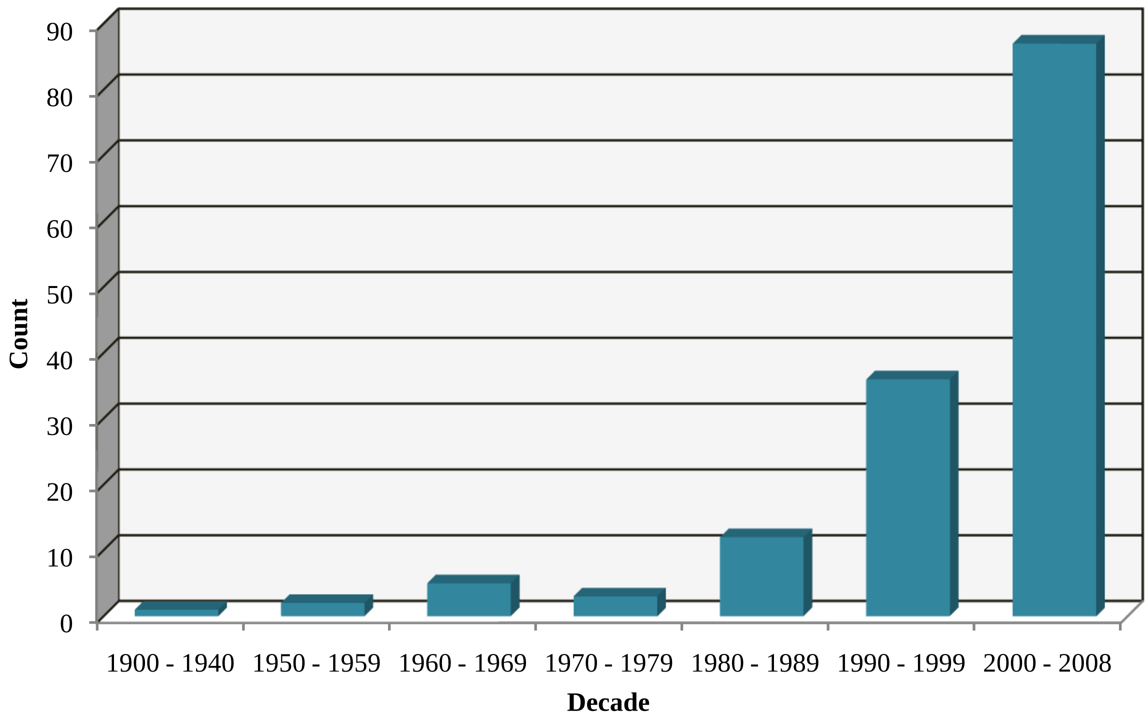


Figure 3.3 Number of Stranding Event Articles Published per Decade.

This figure summarizes the article publication years by decades. Since there are few papers in the early 1900's, the decades were combined until year 1950. Combining the article years into decades shows a present increase in publications. The increase is a result of a surge in marine mammal conservation and policy internationally during the 1970 decade.

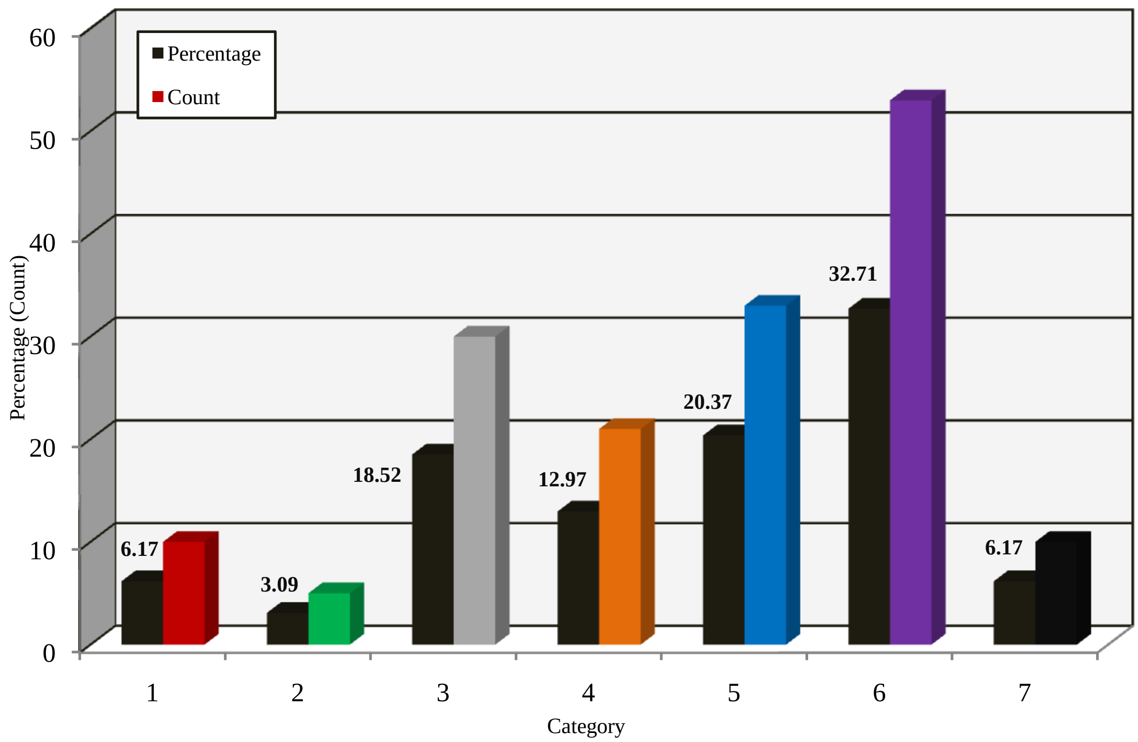


Figure 3.4 Comparing Literature Categories of Peer-Review Marine Mammal Stranding Events.

This graph details the seven categories of stranding event literature as discussed in Section 3.2. The first column in each series is the percent composition of that category in relation to the other categories. The second colored column is the publication count number for each category. Category 1 focuses on diet studies. Category 2 emphasizes stranding response or rehabilitation. Category 3 is studies about cetacean populations and Category 4 pertains to pathological or physiological studies. Category 5 summarizes studies regarding a single mass or stranding event with more than one cetacean involved. The final two categories, 6 and 7, involve studies with large stranding event databases and articles not falling in any of the six main groupings respectively.

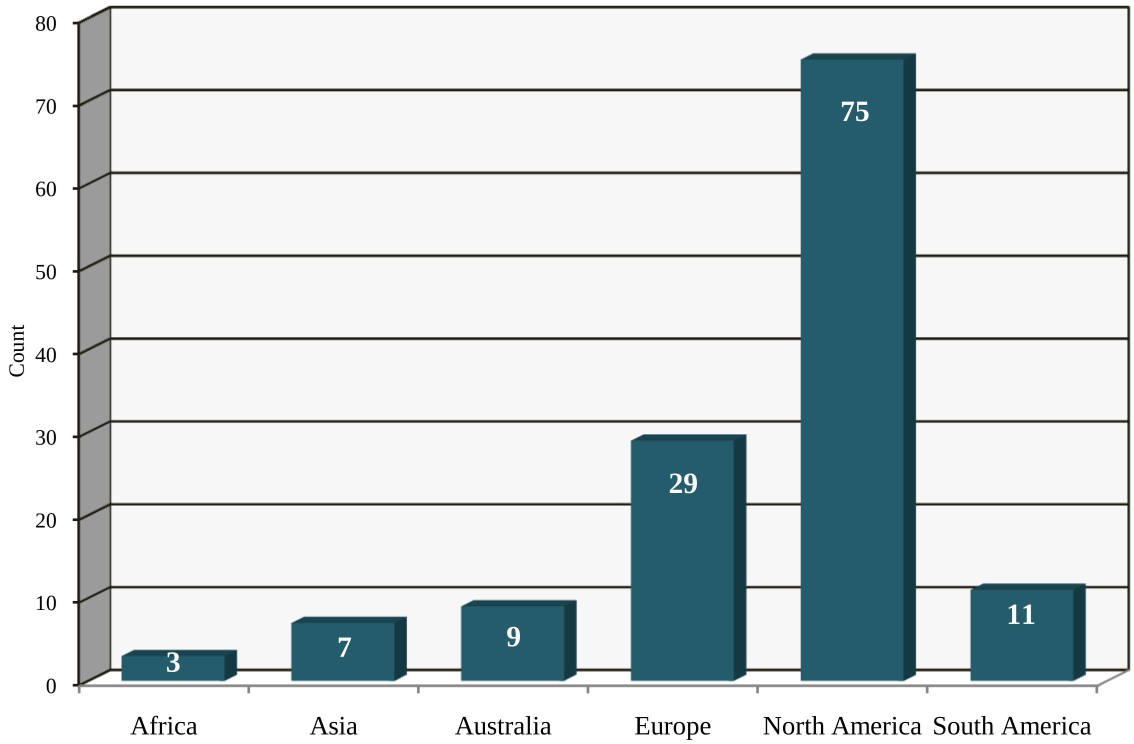


Figure 3.5 Stranding Event Data in Scientific Literature Graphed by Continent.

This graph plots the continent location of the data analyzed from the literature review articles. North America, including Canada, the United States, and Mexico, has the greatest number of publications and the lowest continent publishing stranding event research is Africa. The larger amount of publications is attributed to the large conservation efforts resulting from the Marine Mammal Protection Act passed in 1972, which created the United States stranding regions and networks.

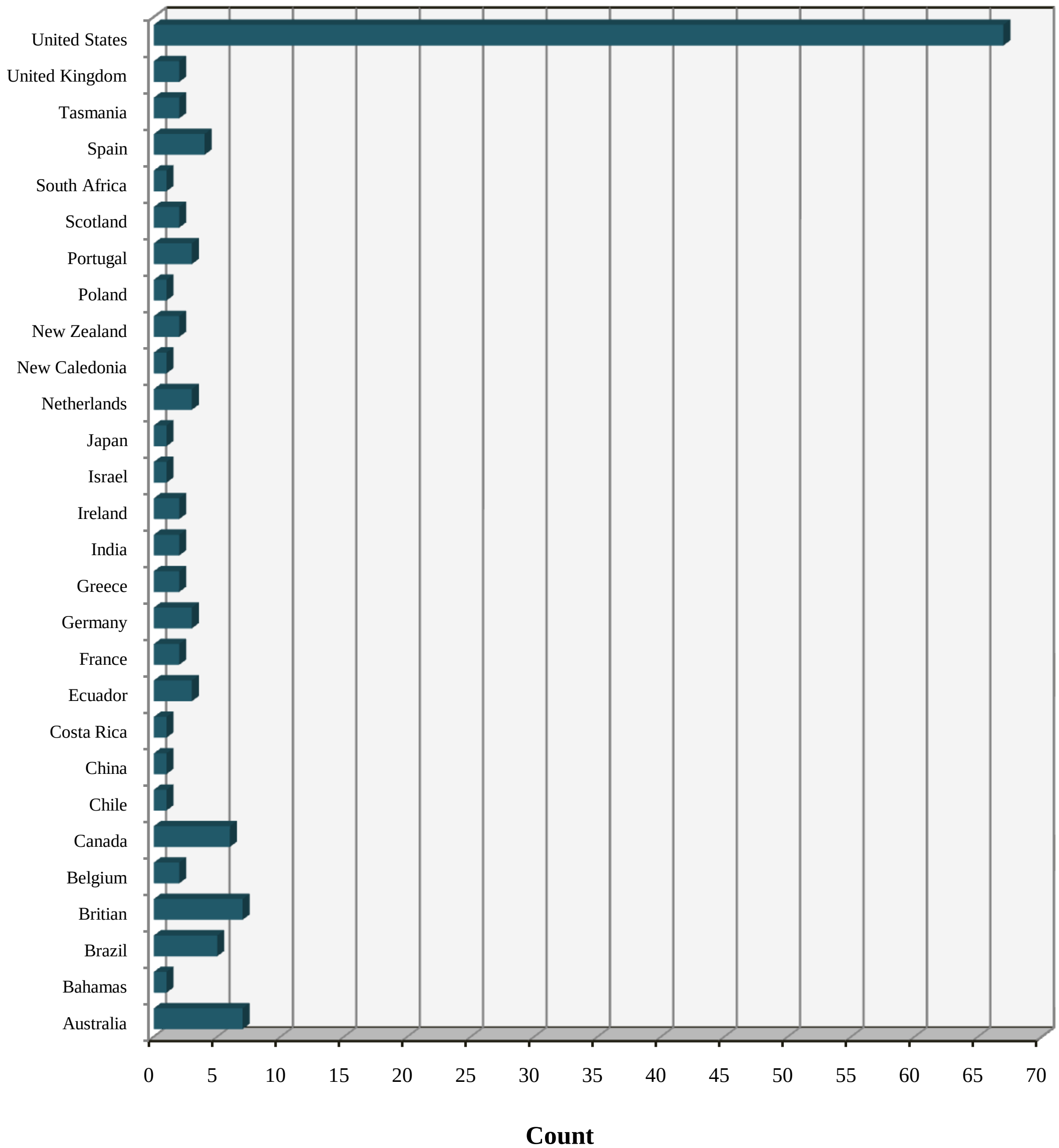


Figure 3.6 Stranding Literature Represented by Country of Stranding Occurrences.

This graph plots country of stranding data versus the article count. As mentioned in Figure 3.5, the United States is responsible for the greatest amount of scientific publications and no other country is close in publications. The second largest country publishing stranding event articles is Britain, which is due to the thorough stranding event database maintained by the United Kingdom Natural Museum of History.

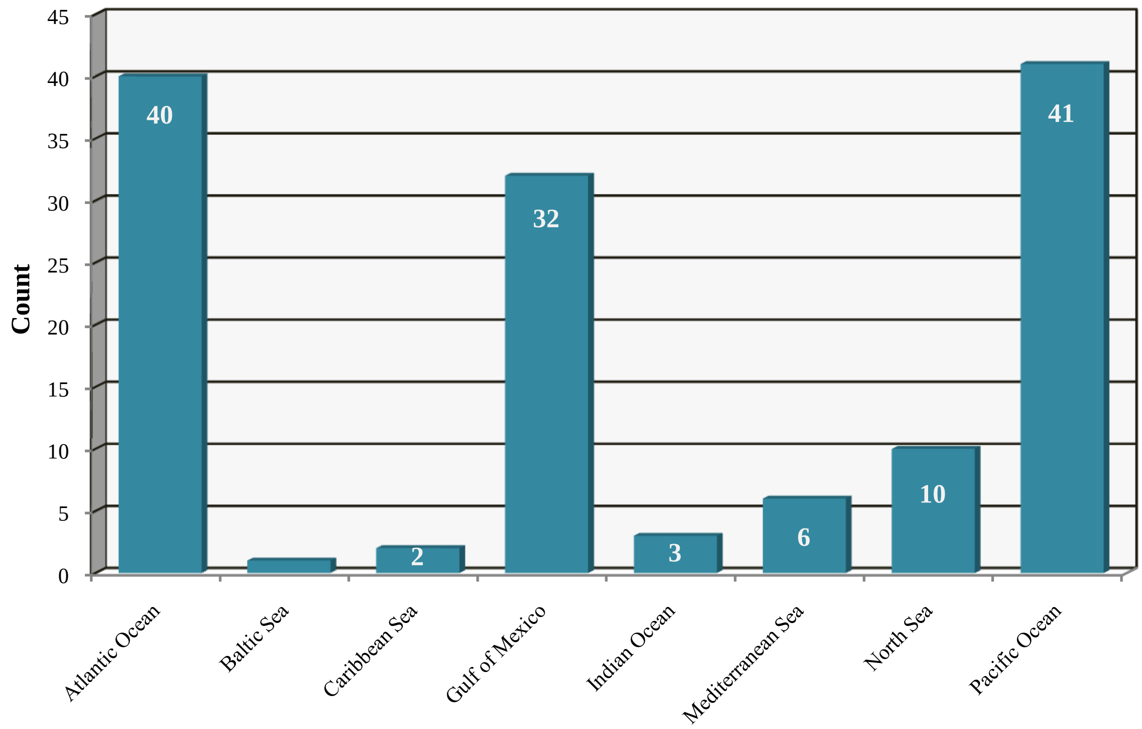


Figure 3.7 Stranding Event Ocean Occurrences from Scientific Literature.

This graph plots the ocean in which the stranding events occurred from the publications included in the literature search conducted in Section 2. Since the United States is the largest stranding event publisher, the largest ocean events are in the oceans surrounding the North American continent. However, the Pacific and Atlantic Oceans are slightly skewed by scientific studies published in Asia, South America, Australia, and Europe respectively regarding cetacean stranding events. The larger count for the Gulf of Mexico is attributed to the large publications from Texas and Florida as seen in Figure 3.8.

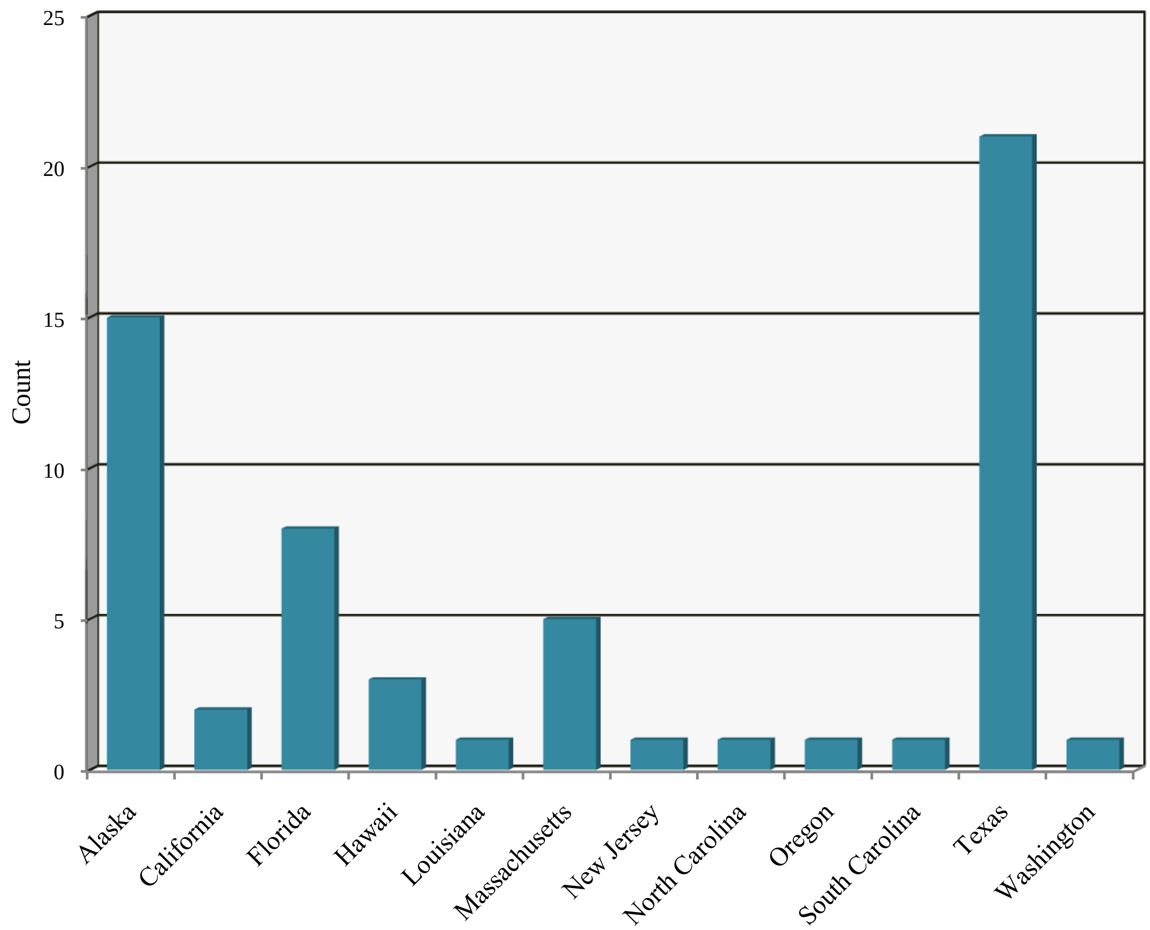


Figure 3.8 United States Stranding Event Data Classified by State Occurrence.

The graph plots the number of stranding event publications by state. The highest states publishing are Alaska and Texas and the lowest are tied between six states. The large values for Texas are attributed to the higher publication rates in Category 3 (population analyses) and Category 4 (pathological and physiological emphasis).

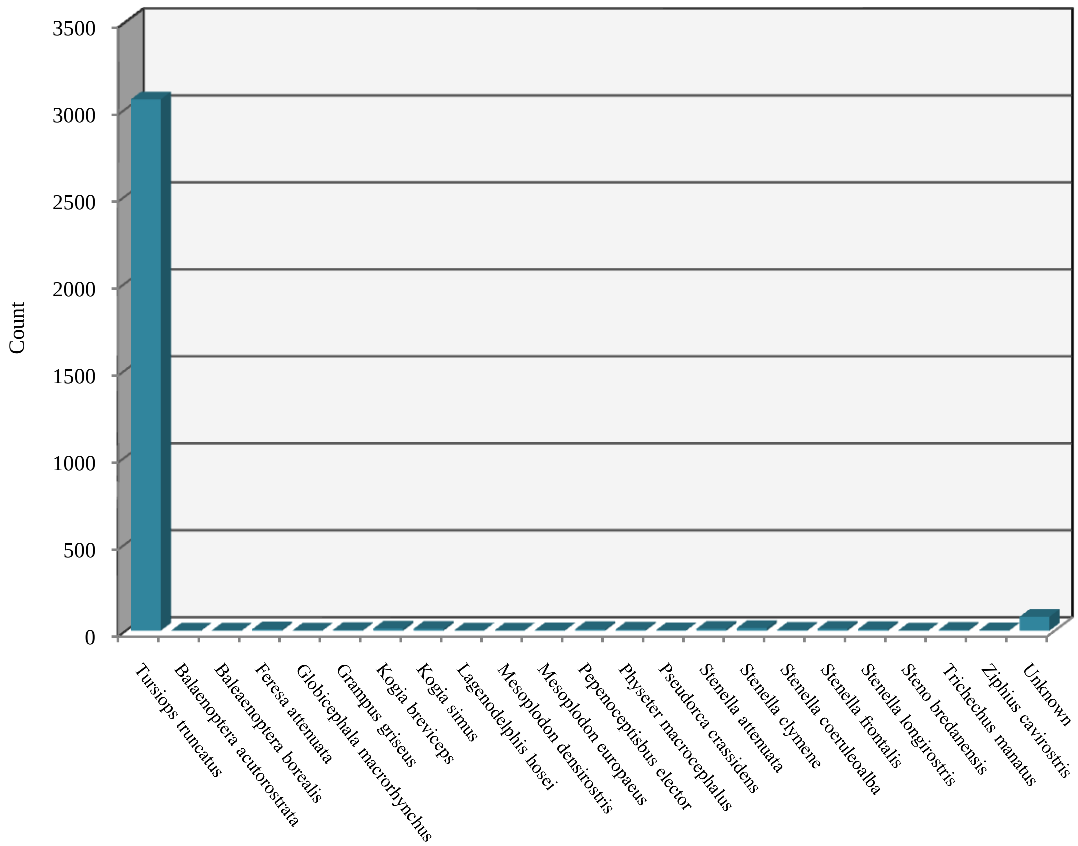


Figure 4.1 TMMSN Stranding Events by Species.

The graph includes Tursiops *truncatus* stranding events with all other documented species. The graph is heavily skewed by the extremely large number of events. The next largest is the Unknown category, which does not represent any one species.

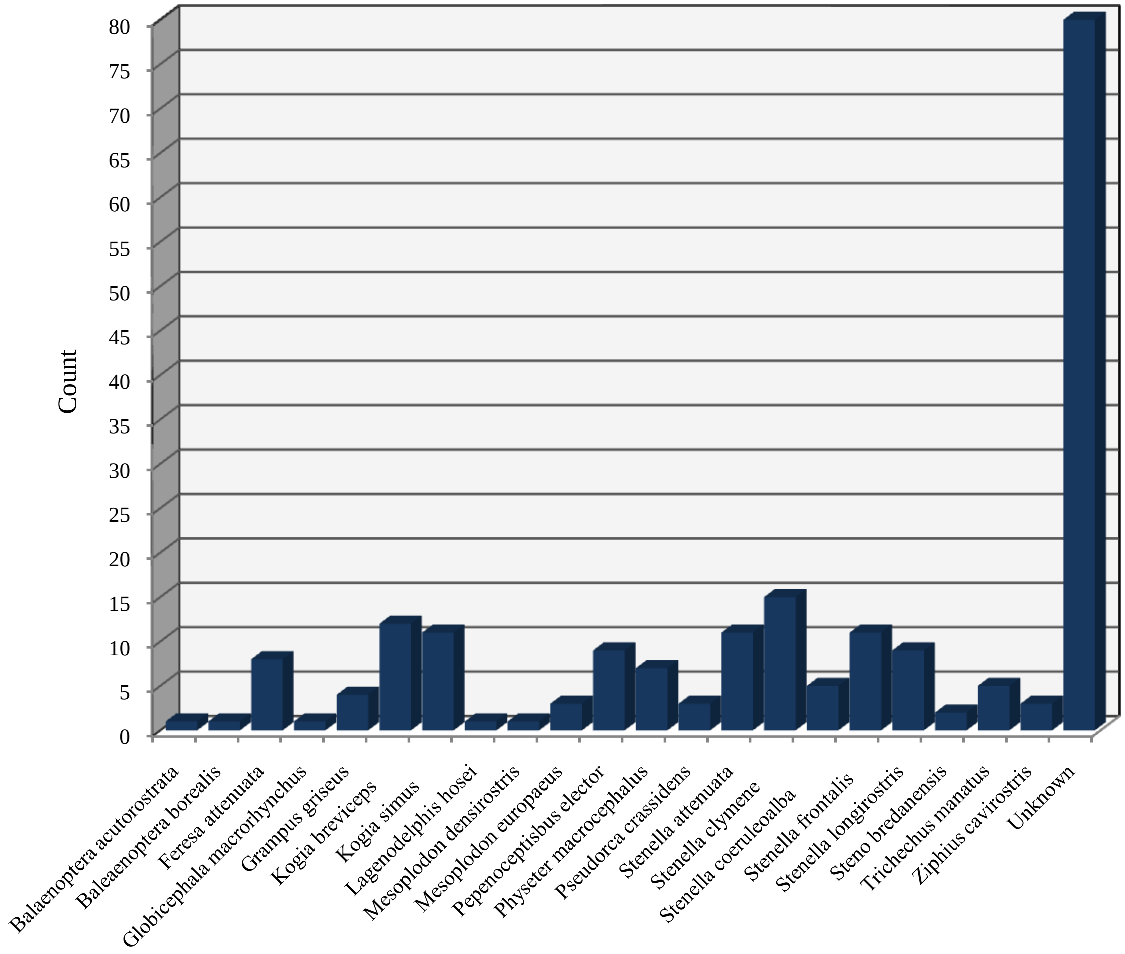


Figure 4.2 TMMSN Stranding Events Versus Species (Excluding *Tursiops truncatus*).

The graph plots the TMMSN events by species identification. Tursiops *truncatus* events were removed from the graph to resolve the small values of other species stranded in Texas. Whale stranding events are increasingly low compared to dolphin stranding events. The *Unknown* category refers to events with no species designation in the TMMSN database.

Figure 4.3 Marine Mammal Stranding Events by Species from 1980 to 2004.

The left panel shows all species stranding, excluding *Unknown* and Tursiops *truncatus* events. The density for this panel is low and the majority of the events occur on the ocean-exposed coastline. The right panel maps all Tursiops *truncatus* events. The density is significantly greater and stranding events occur along any piece of the coastline.

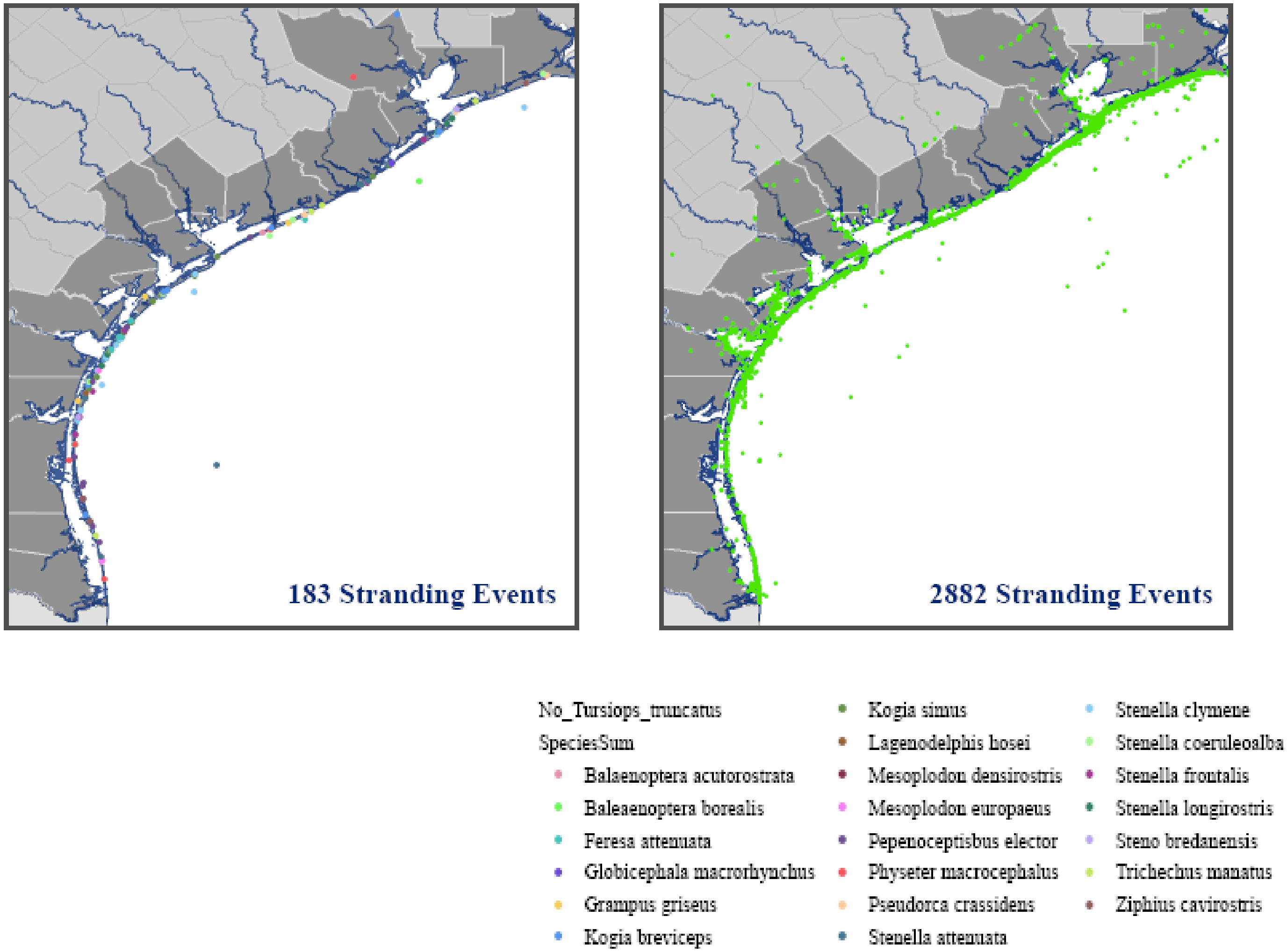

183 Stranding Events
2882 Stranding Events
No_Tursiops_truncatus
SpeciesSum
Balaenoptera acutorostrata
Baleaenoptera borealis
Feresa attenuata
Globicephala macrorhynchus
Grampus griseus
Kogia breviceps
Kogia simus
Lagenodelphis hosei
Mesoplodon densirostris
Mesoplodon europaeus
Pepenoceptisbus elector
Physeter macrocephalus
Pseudorca crassidens
Stenella attenuata
Stenella clymene
Stenella coeruleoalba
Stenella frontalis
Stenella longirostris
Steno bredanensis
Trichechus manatus
Ziphius cavirostris

Figure 4.4 Marine Mammal Stranding Events Divided by Species Groups – 1980 to 2004.

The two panels compare the location densities for stranding events by two groups. The left panel combines all species, including *Unknown* category. The right panel plots only Tursiops *truncatus* stranding events. There are about 15 times more stranding events of bottlenose dolphins than all other combined species.

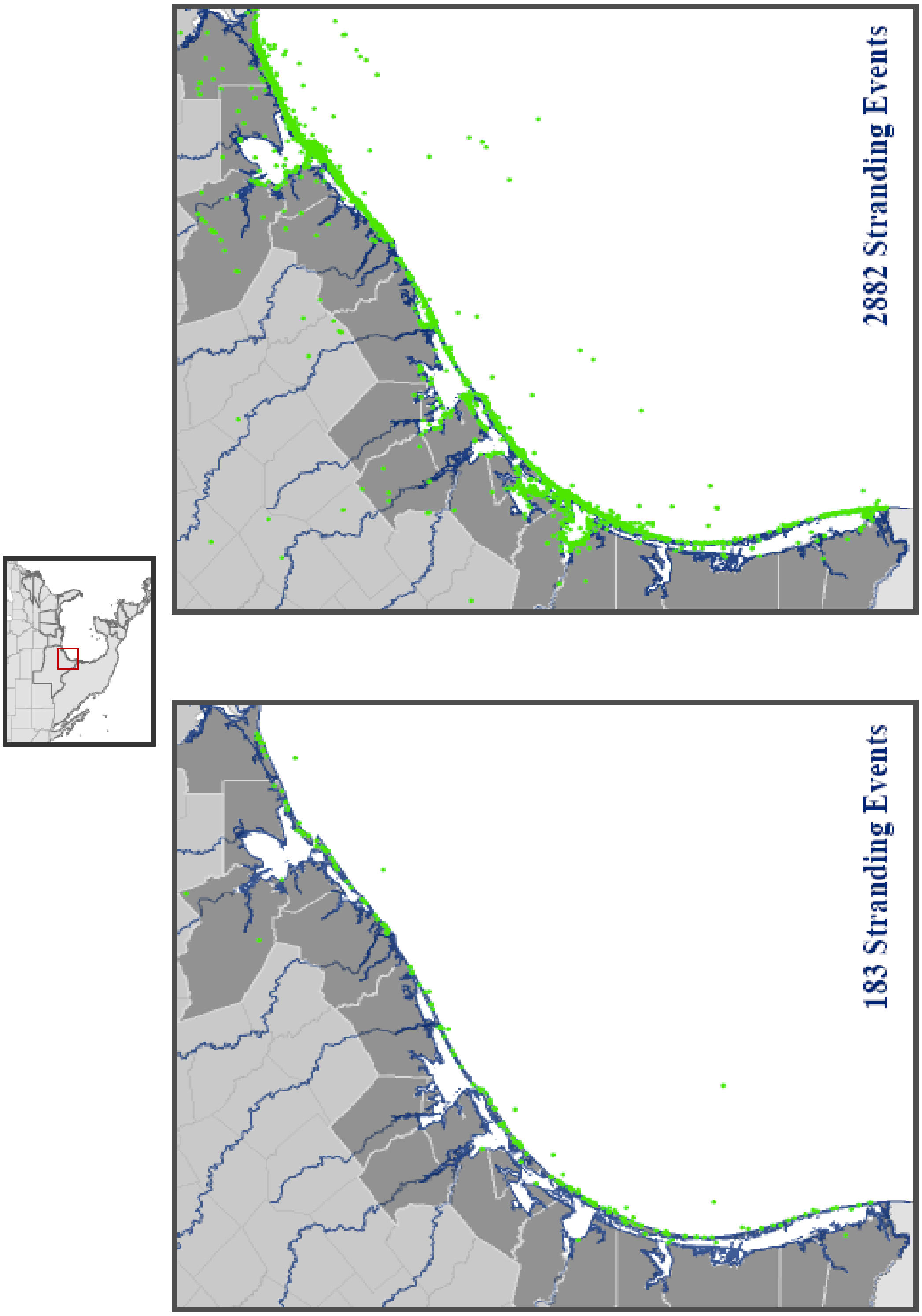
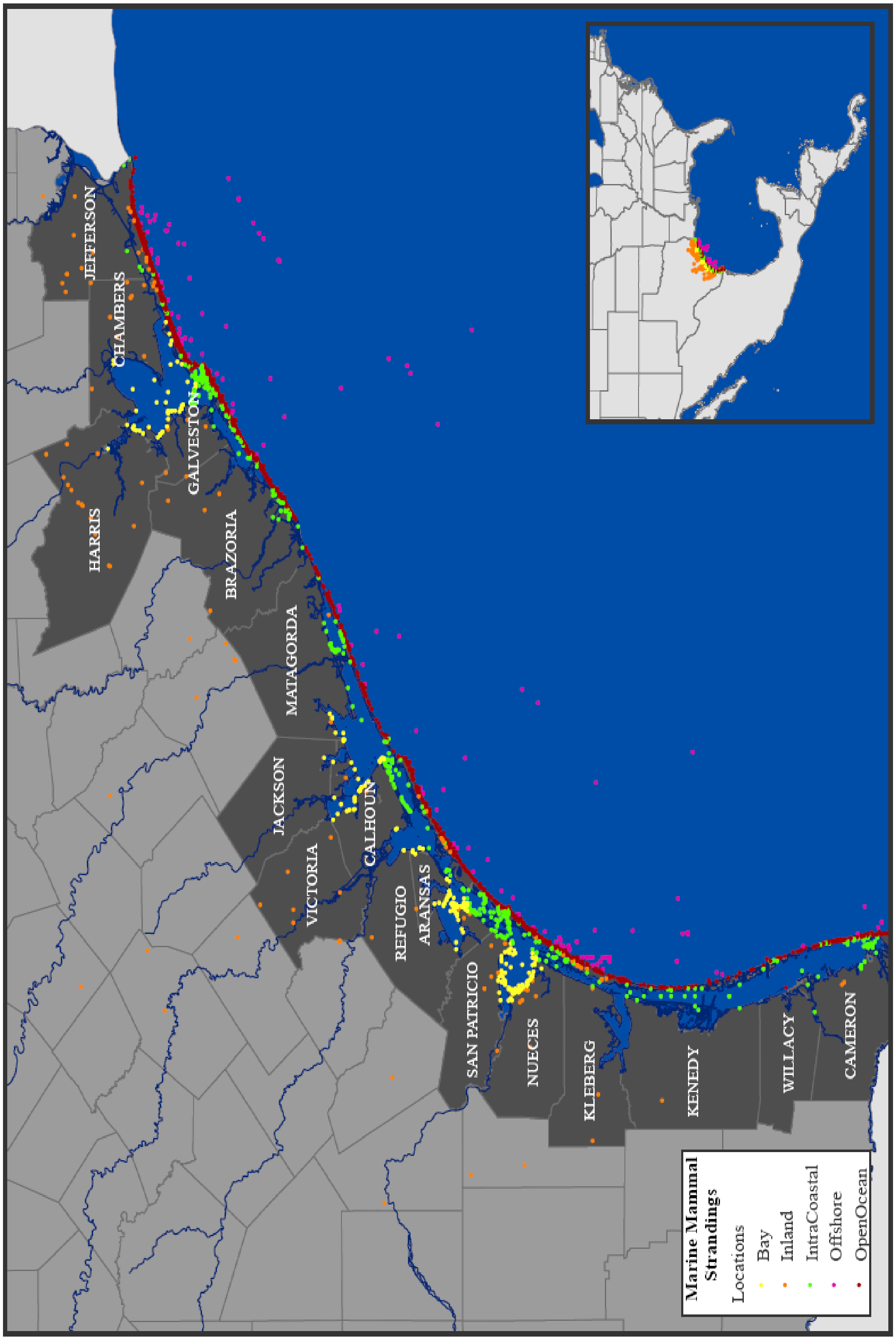

2882 Stranding Events
183 Stranding Events

Figure 4.5 Map of the Texas Coast with TMMSN Stranding Events from 1980 to 2004.

The events are mapped in TCMS/AEA projection and symbolized by location the stranding occurred. The density of events is strong for the middle and northern coastline, but relatively weak in Kleberg County to the southern state line in Cameron County.


JEFFERSON
CHAMBERS
GALVESTON
HARRIS
BRAZORIA
MATAGORDA
JACKSON
CALHOUN
VICTORIA
REFUGIO
ARANSAS
SAN PATRICIO
NUECES
KLEBERG
KENEDY
WILLACY
CAMERON
Marine Mammal Strandings
Locations
Bay
Inland
IntraCoastal
Offshore
OpenOcean

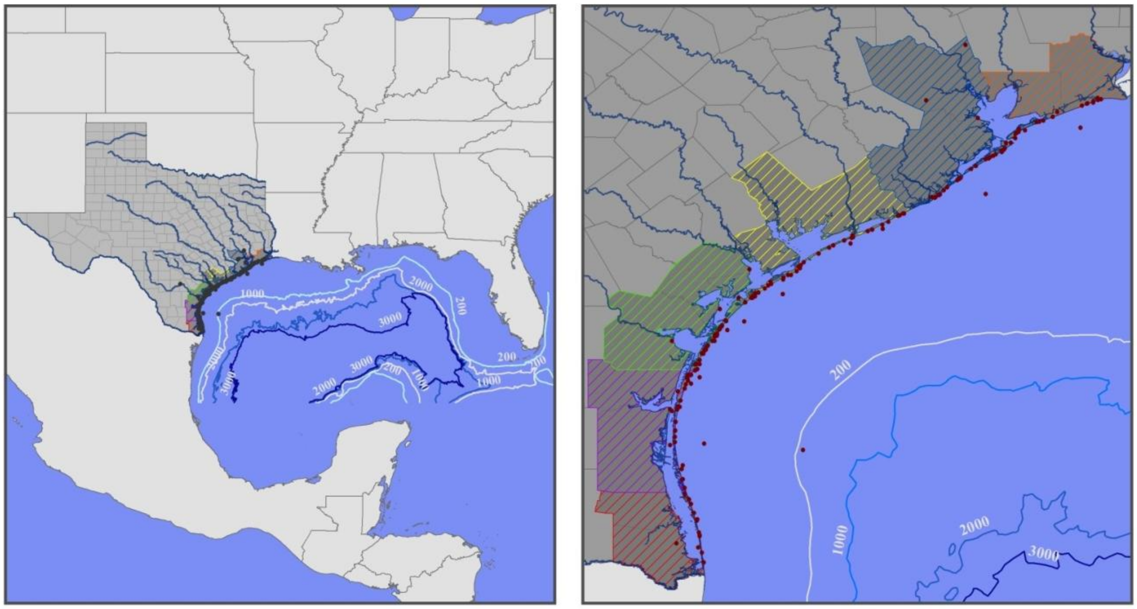


Figure 4.6 Panels Representing Species Stranding Events in Relation to the Continental Shelf.

The left panel shows Texas and the Gulf of Mexico continental shelf. The stranding network regions are also highlighted by corresponding colors discussed in Section 1. The right panel maps stranding events for all species except *Tursiops truncatus* and *Unknown* events. The event density is more concentrated along the shortest length of the continental shelf in southern Texas. Along the northern coastlines, the densities are less frequent where the continental shelf width is greatest.

Figure 4.7 Images from Google Earth 4.0.

The inside panel shows the state of Texas with Kleberg County boxed. This area has no significant number of stranding events, which is most likely related to the low human coastal population evident in the first panel.

Figure 5.1 Density Distributions of *Tursiops truncatus* from Years 1980 to 1989.

The map shows the results produced from performing a kernel density spatial distribution as outlined in Section 5.2. The scale indicates stranding event per quarter mile, with red showing approximately one to two events. Dark green represents no events per quarter mile. The highest densities of events occur in the Galveston Shipping Channel and in the Corpus Christi Bay Shipping Channel.

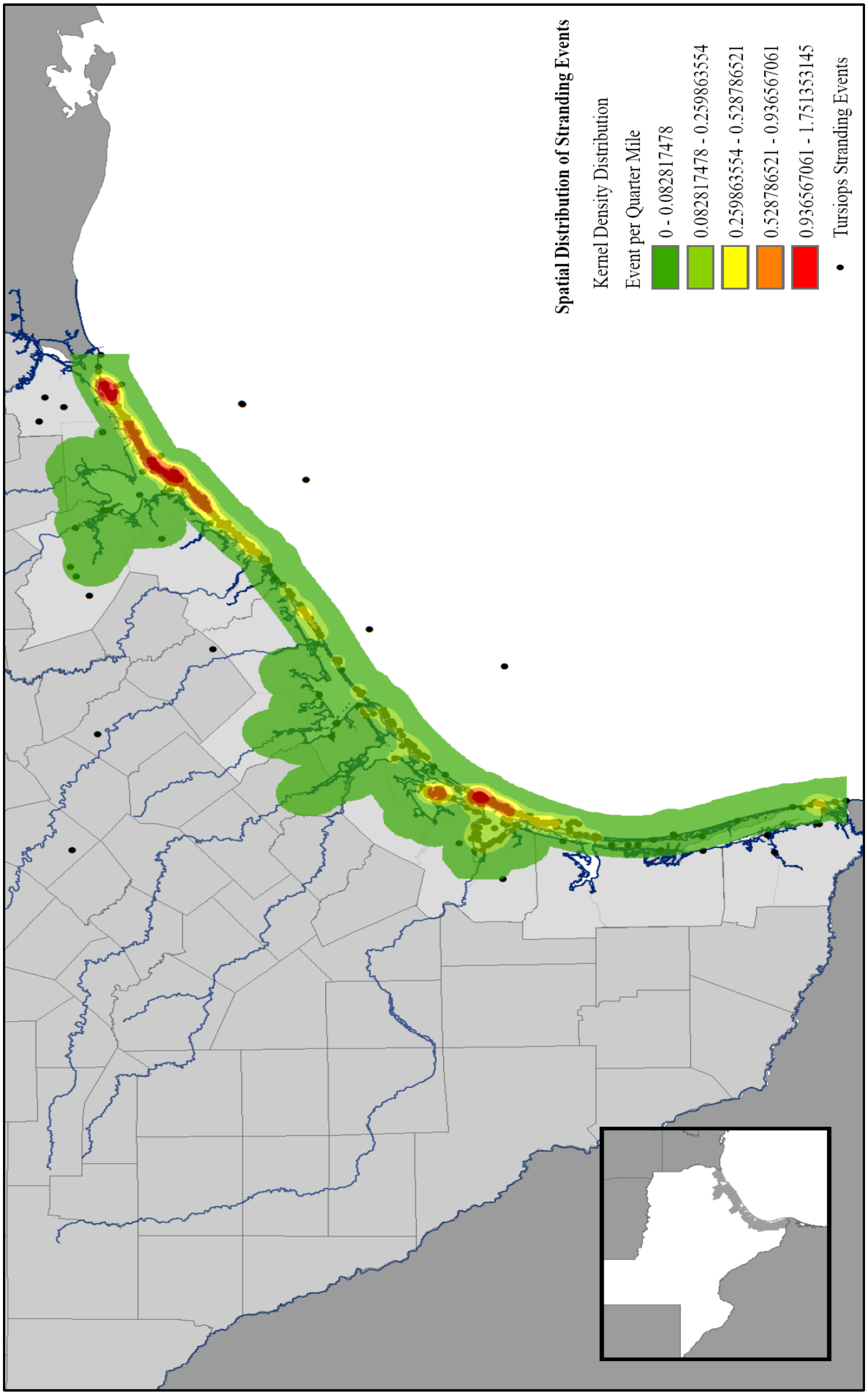

Spatial Distribution of Stranding Events
Kernel Density Distribution
Event per Quarter Mile
0 - 0.082817478
0.082817478 - 0.259863554
0.259863554 - 0.528786521
0.528786521 - 0.936567061
0.936567061 - 1.751353145
Tursiops Stranding Events

Figure 5.2 Density Distributions of *Tursiops truncatus* From Years 1990 to 1999.

The map shows the results produced from performing a kernel density spatial distribution as outlined in Section 5.2. The scale indicates stranding event per quarter mile, with red showing approximately two to three and a half events. Dark green represents no events per quarter mile. The highest densities of events occur in the Galveston-Brazoria County coastlines, Corpus Christi Bay Shipping Channel, and Port Aransas Bay.

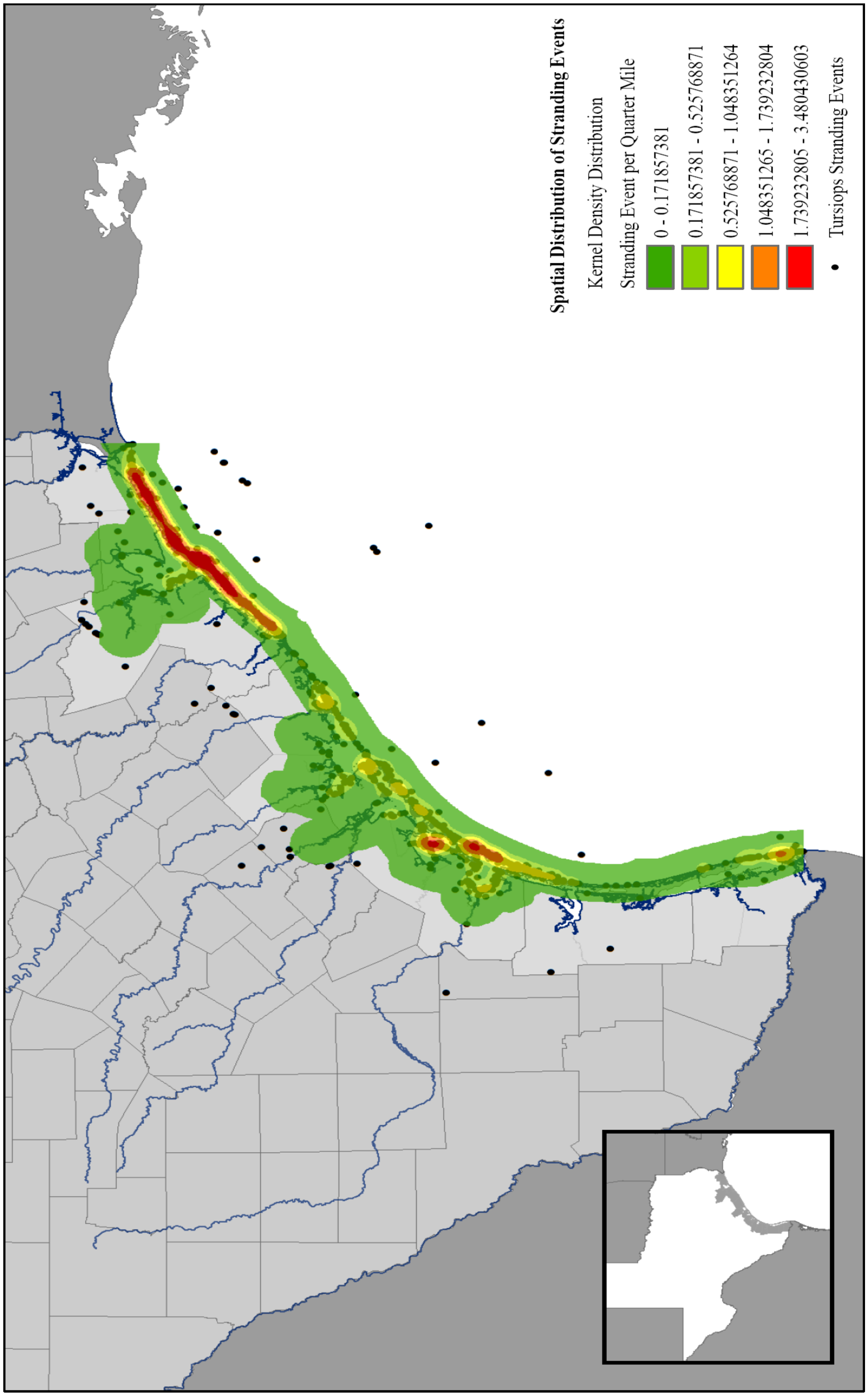

Spatial Distribution of Stranding Events
Kernel Density Distribution
Stranding Event per Quarter Mile
0 - 0.171857381
0.171857381 - 0.525768871
0.525768871 - 1.048351264
1.048351265 - 1.739232804
1.739232805 - 3.480430603
Tursiops Stranding Events

Figure 5.3 Density Distributions of *Tursiops truncatus* From Years 2000 to 2004.

The map shows the results produced from performing a kernel density spatial distribution as outlined in Section 5.2. The scale indicates stranding event per quarter mile, with red showing approximately one to two events. Dark green represents no events per quarter mile. The highest densities of events occur in the Galveston-Brazoria County coastlines, Corpus Christi Bay Shipping Channel, and South Padre County.

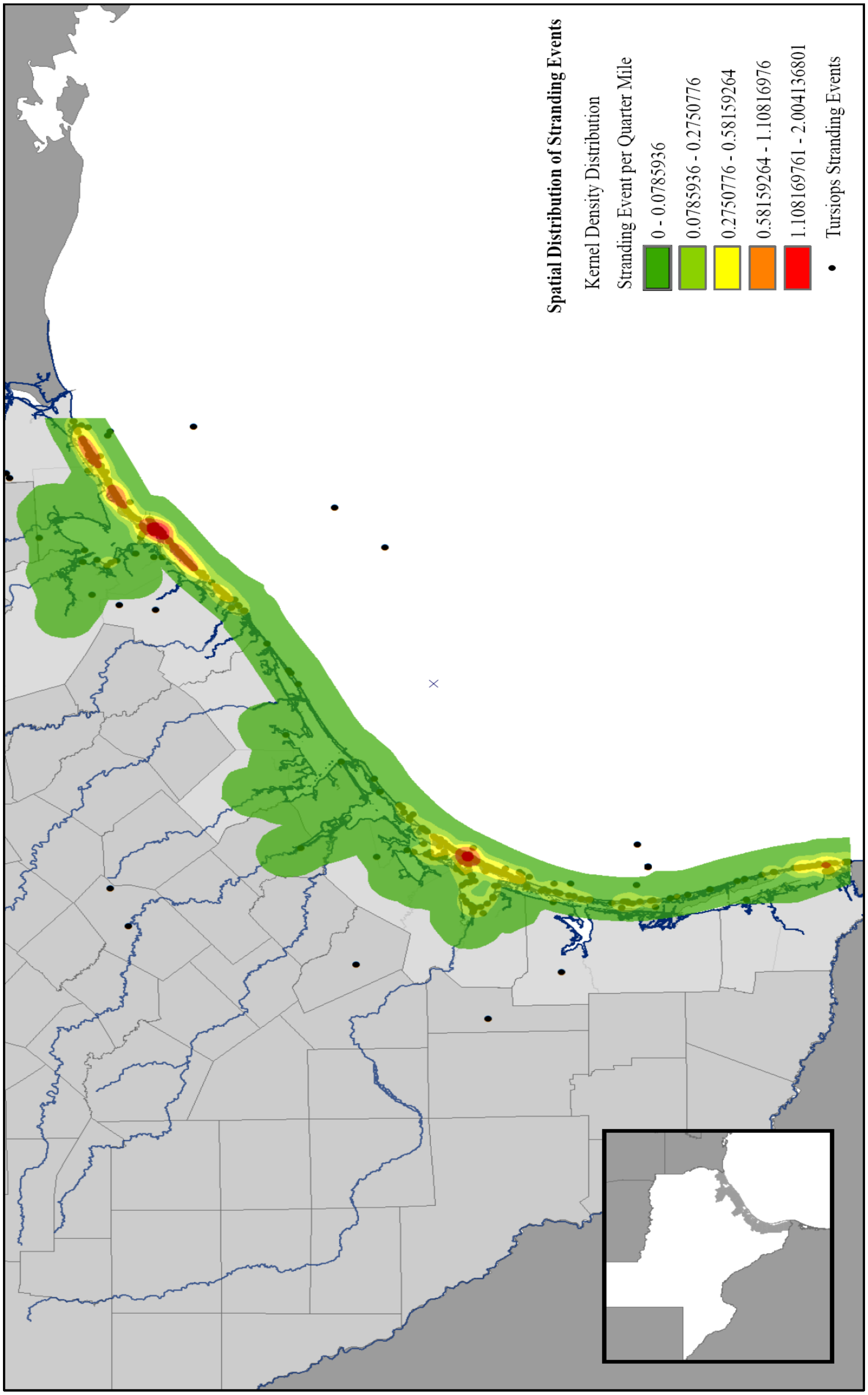

Spatial Distribution of Stranding Events
Kernel Density Distribution
Stranding Event per Quarter Mile
0 - 0.0785936
0.0785936 - 0.2750776
0.2750776 - 0.58159264
0.58159264 - 1.10816976
1.108169761 - 2.004136801
Tursiops Stranding Events

Figure 5.4 TMMSN Stranding Events From 1980 to 2004.

The total stranding event counts are graphed according to year the stranding events occurred. There is no obvious linear trend from years 1980 to 2004 and the counts are extremely variable in distribution. A unique cyclic variability occurs from 1990 to 1997, which does not appear anywhere else in the database.

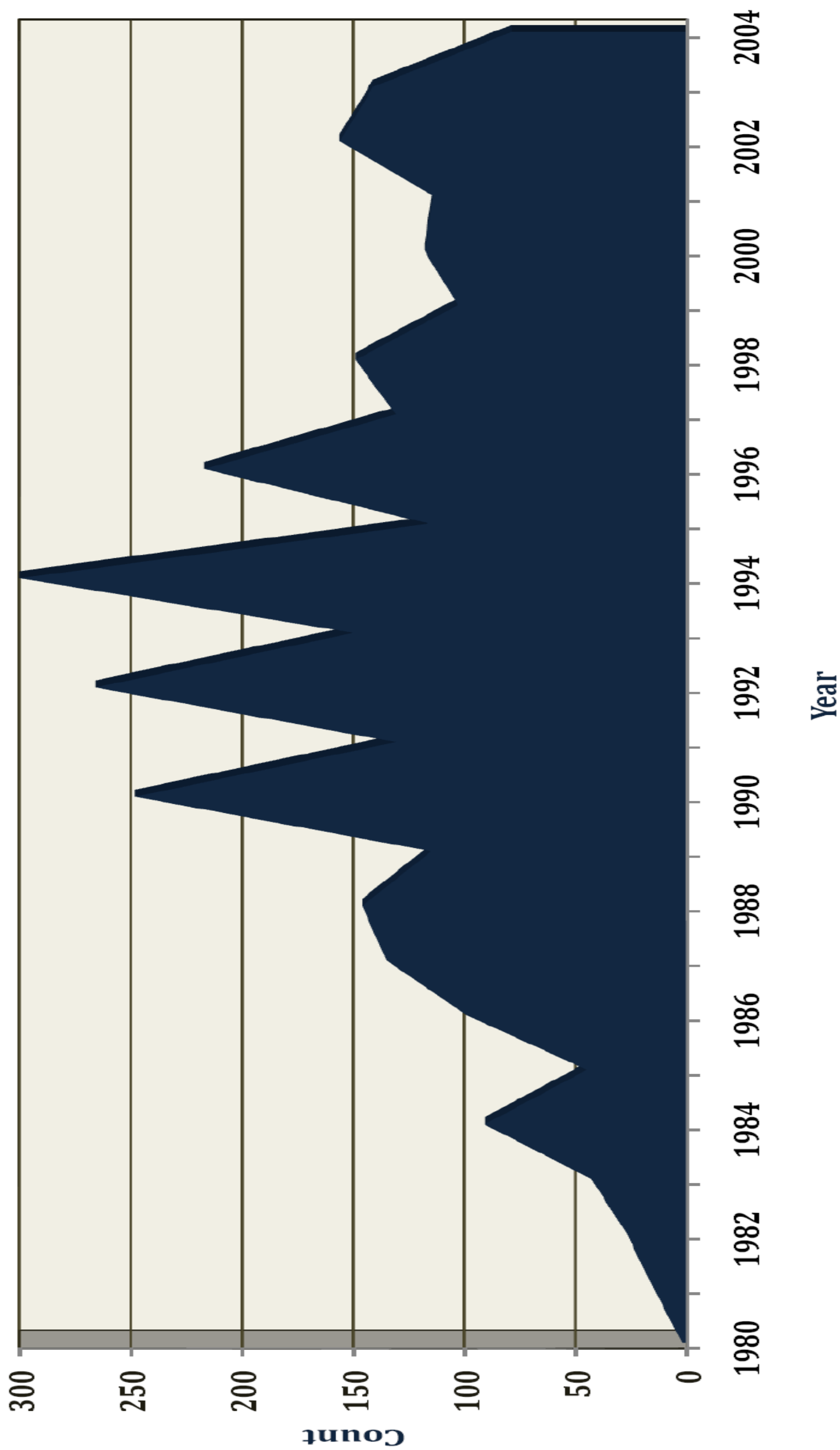

Count
300
250
200
150
100
50
0
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

Figure 5.5 Scatter Plot of TMMSN Stranding Events by Year From 1980 to 2004.

The plot shows the counts per year represented as individual points with not connecting line. A linear trend was also applied to the extent of the database and showed a poor correlation of determination (r-square value) for explaining the data variability. This weak linear trend can be in response to the cyclic variability in the mid-1990.

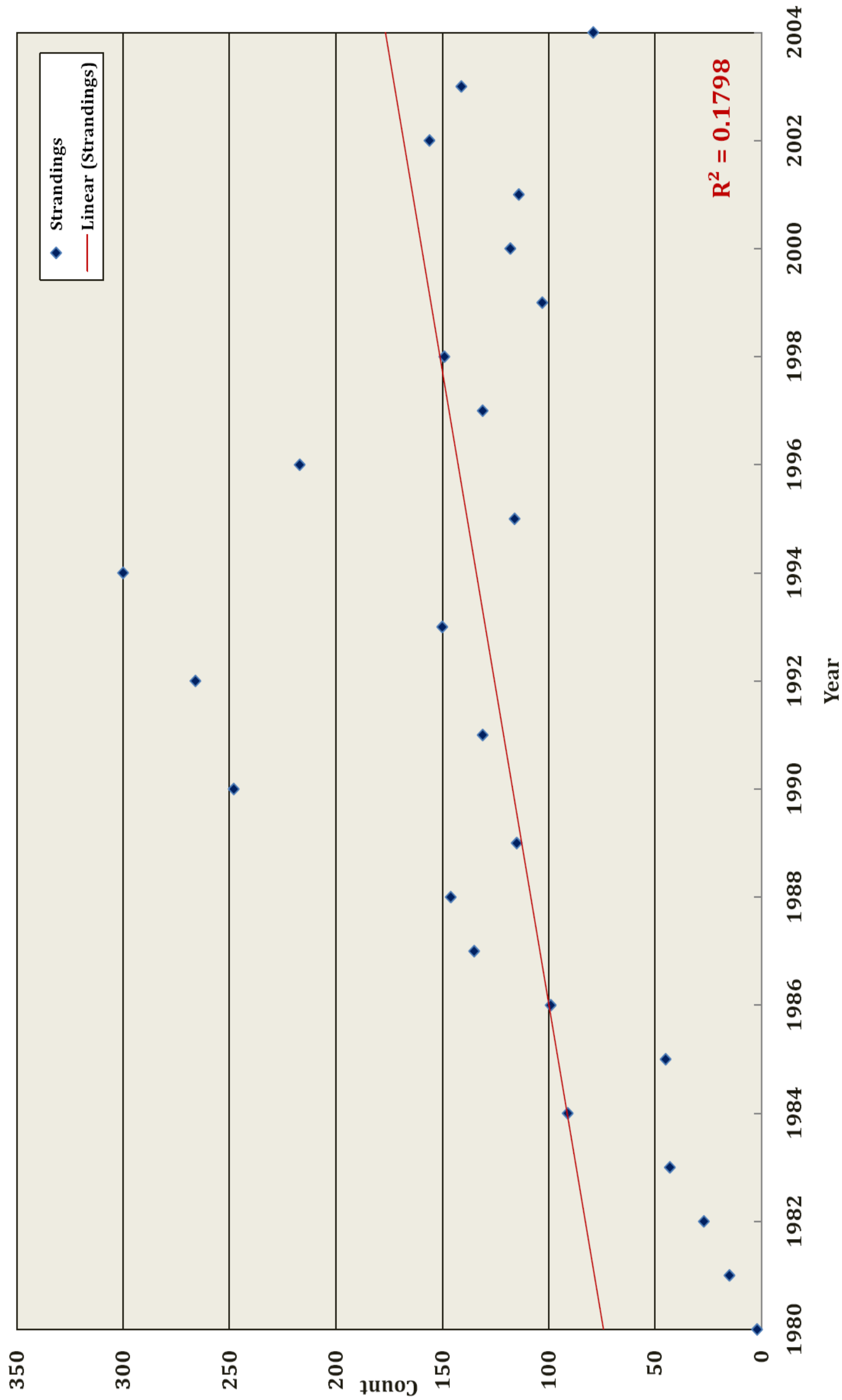
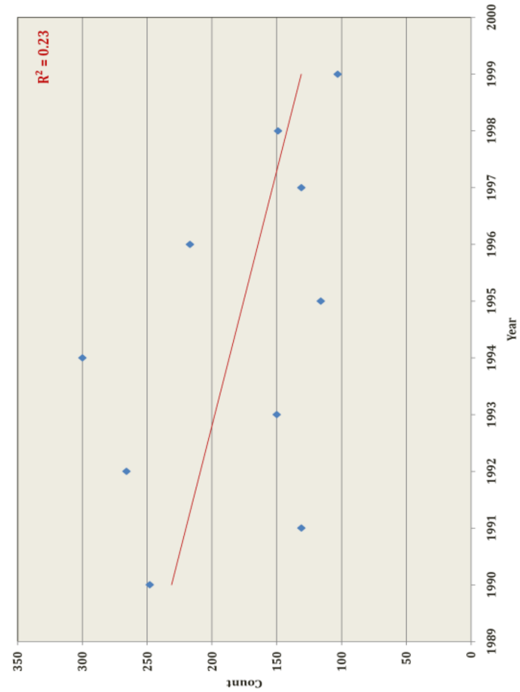
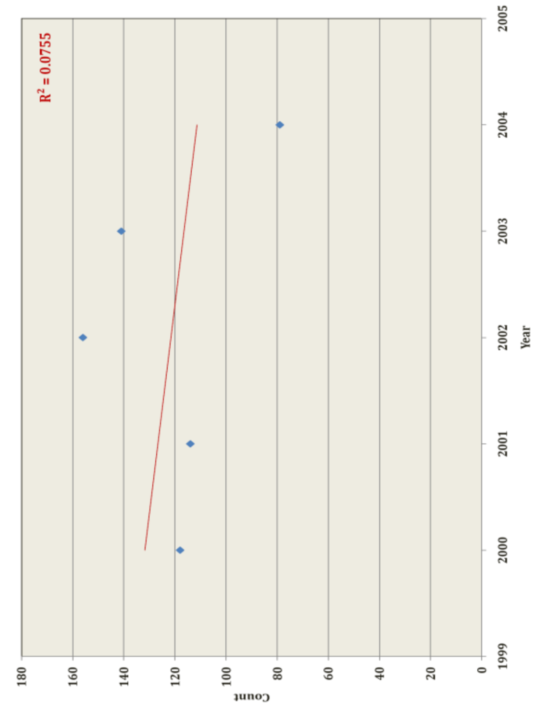
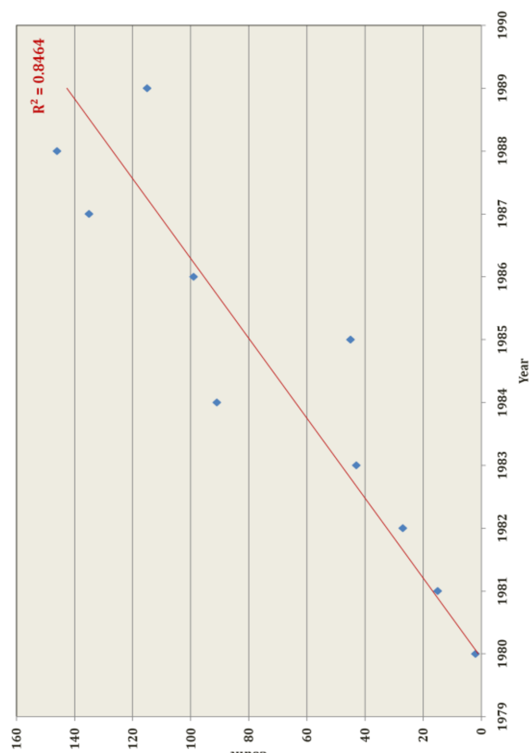

Strandings
Linear (Strandings)
R² = 0.1798
Count
Year
0
50
100
150
200
250
300
350
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

Figure 5.6 Linear Trends in TMMSN Stranding Events by Decade.

The three panels, starting from the top left, separate the stranding events by decade. The top left panel is from years 1980 to 1989, the next from years 1990 to 1999, and the bottom panel from years 2000 to 2004. The significance of the plots is to show the weak coefficients of determination, r-square values, from a linear estimate of variability. No separation of events by decade explained more than 23% of the variability in the plots.


$R^2 = 0.23$
Count
Year
0
50
100
150
200
250
300
350
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


$R^2 = 0.0755$
Count
Year
0
20
40
60
80
100
120
140
160
180
1999
2000
2001
2002
2003
2004
2005


$R^2 = 0.8464$
Count
Year
0
20
40
60
80
100
120
140
160
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990

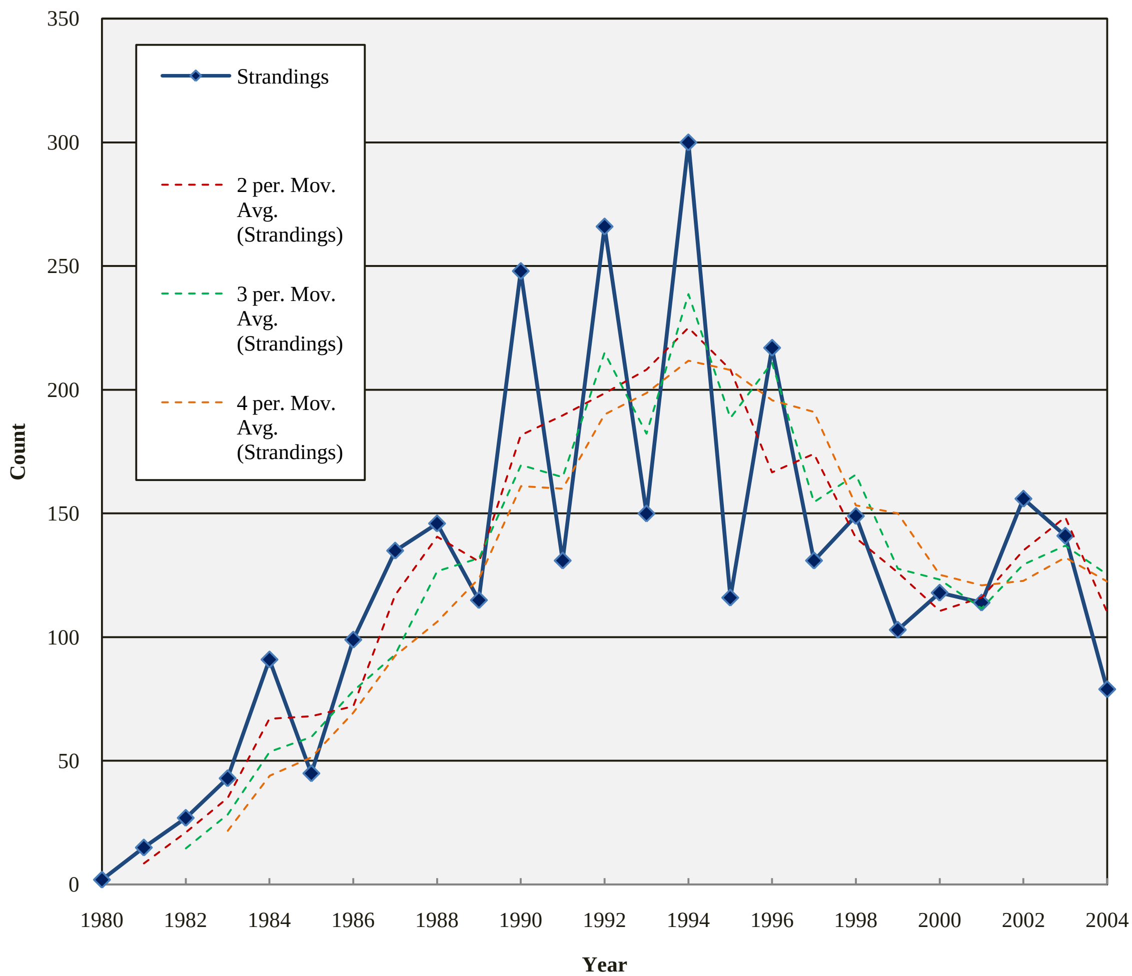


Figure 5.7 Smoothing Attempts for TMMSN Stranding Events Applying a Running Average Technique.

Running averages with periods ranging from two to four were applied to the TMMSN stranding data and the resulting curves were plotted above. The period of two provided the best smoothing for the variability from years 1992 to 1996 and maintained the overall curve shape from years 1980 to 2004. A period of three did not smooth the variability, but did follow the original curve from years 1980 to 2004. The last attempt with a period of four smoothed the 1990's variability, but did not maintain the original data curve integrity.

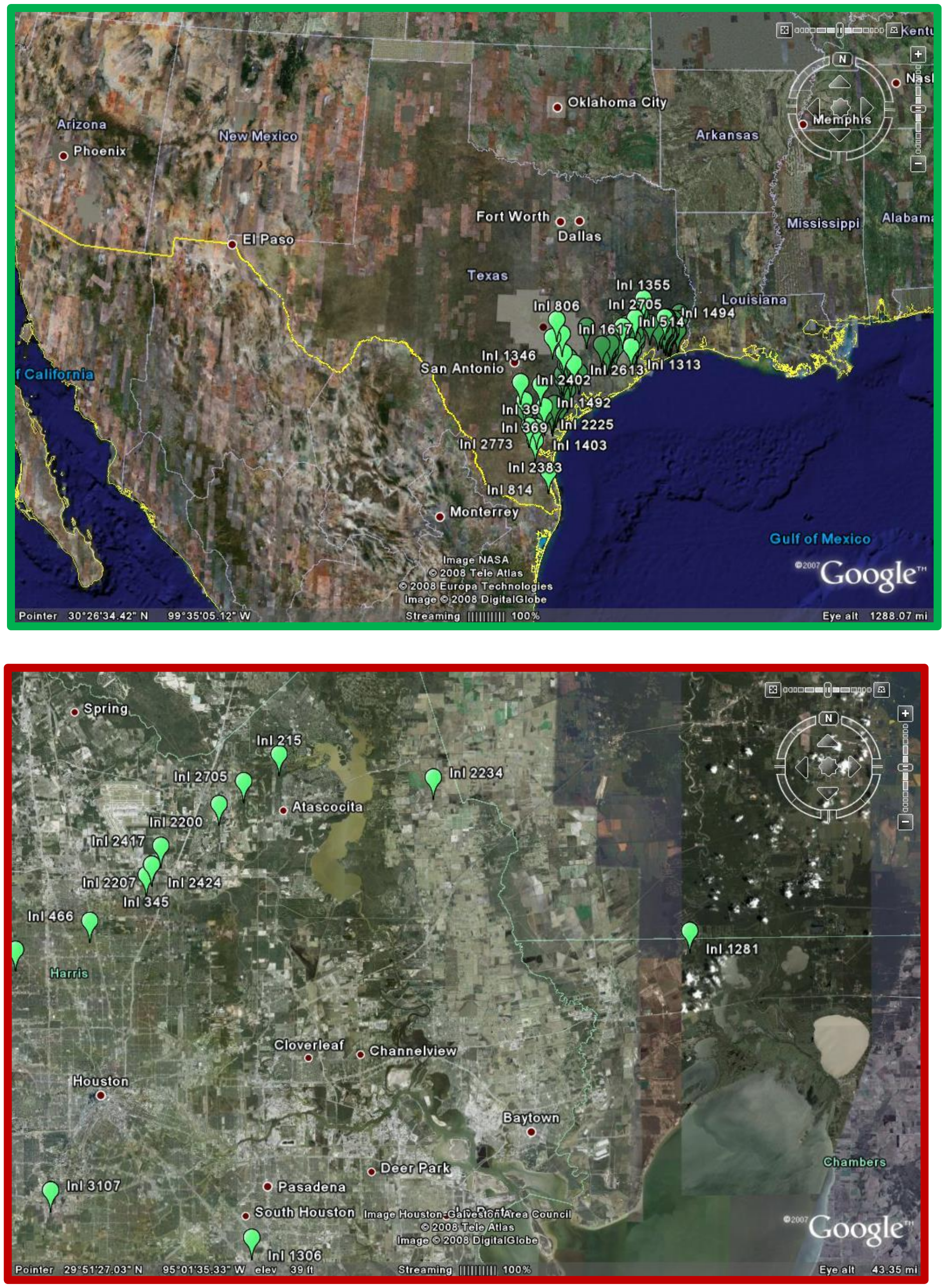
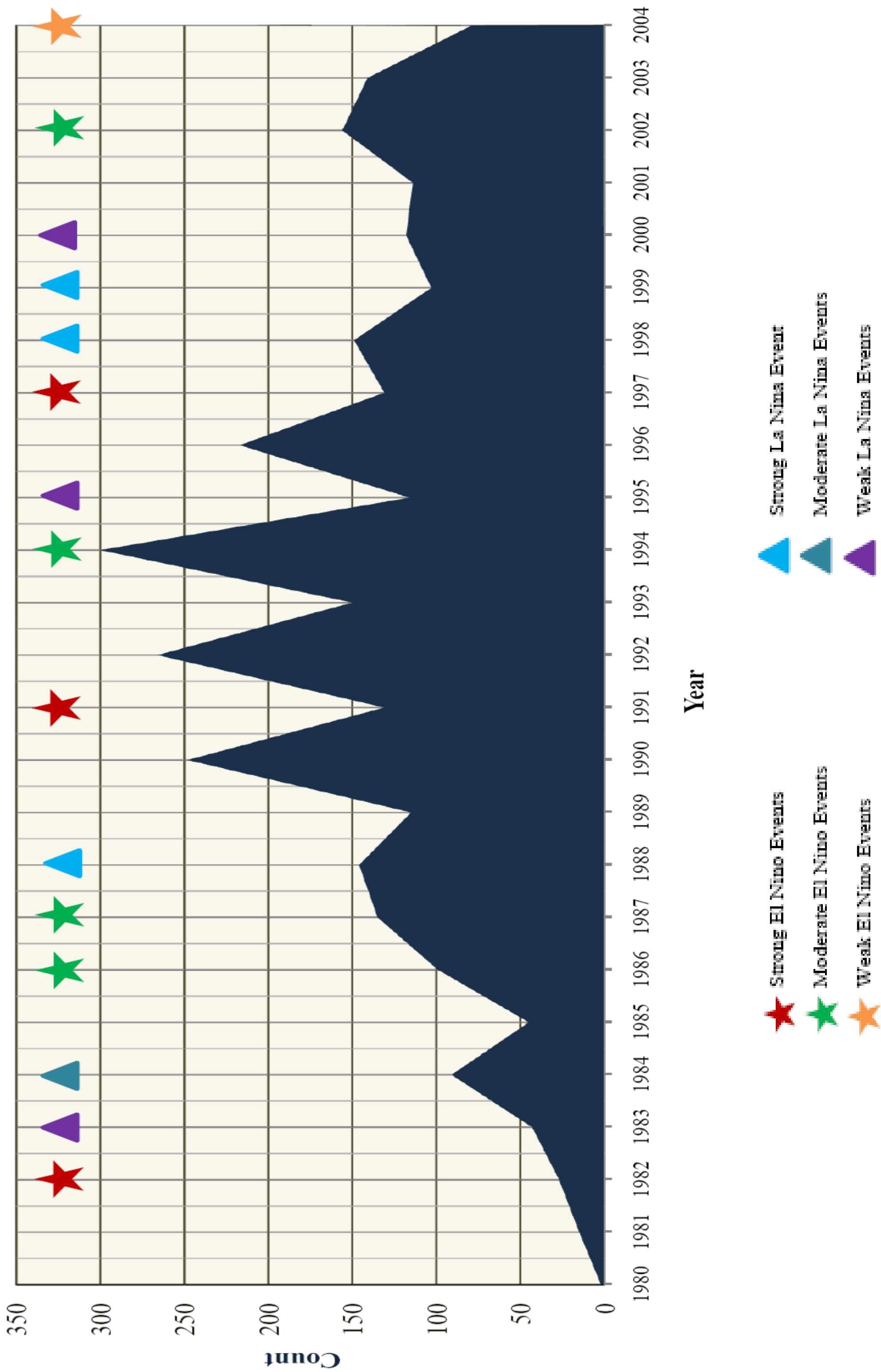


Figure 5.8 Investigating Stranding Events in Proximity to a Texas River.

The two panels are Google Earth images with the left showing Texas and the density of inland stranding events. The red box is focused on an easy identifiable river area in east Texas. The right panel is the image in the box showing a span of about 43 miles. It is evident that stranding events can occur near inland water, such as Inl 215.

Figure 5.9 TMMSN Stranding Events from 1980 to 2004 with the Presence of El Nino and La Nina Events.

This graph combines the total stranding event counts with the presence of ENSO events as determined by NOAA. The colored symbols distinguish between El Nino and La Nina events and the intensity of the ENSO events. There is no relationship with the occurrence of either ENSO event with stranding event variability, as in that either high or low counts events occur regardless of the ENSO presence


Count
0
50
100
150
200
250
300
350
Year
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Strong El Nino Events
Moderate El Nino Events
Weak El Nino Events
Strong La Nina Event
Moderate La Nina Events
Weak La Nina Events

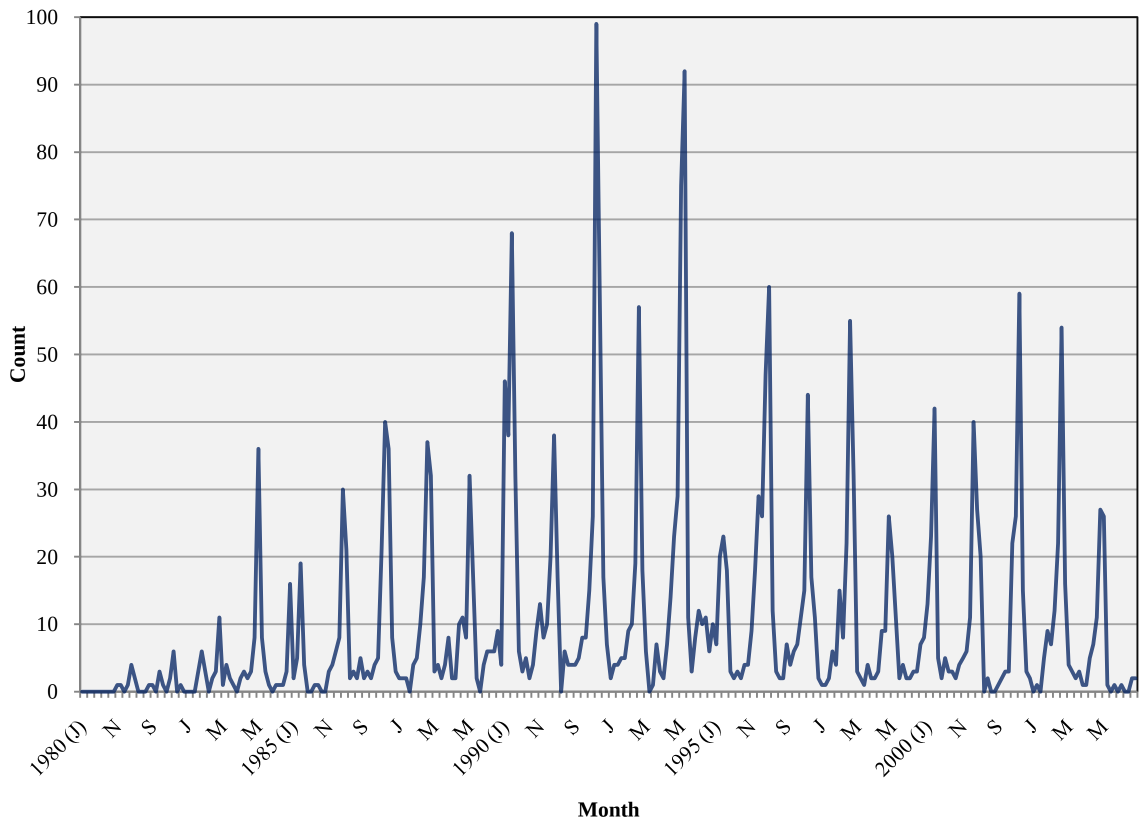


Figure 5.10 TMMSN Stranding Events by Month from 1980 to 2004.

The stranding event counts are plotted by month for each year in the database. The months labeled on the x-axis are January (J), November (N), March (M), May (M), and September (S). The monthly events are small in the beginning of the years, due primarily the personnel size of the TMMSN, and begin to increase in the mid 1980's. The variability in the 1990's is evident, as well as a shift in events between spring months (February to May) from the rest of the month counts.

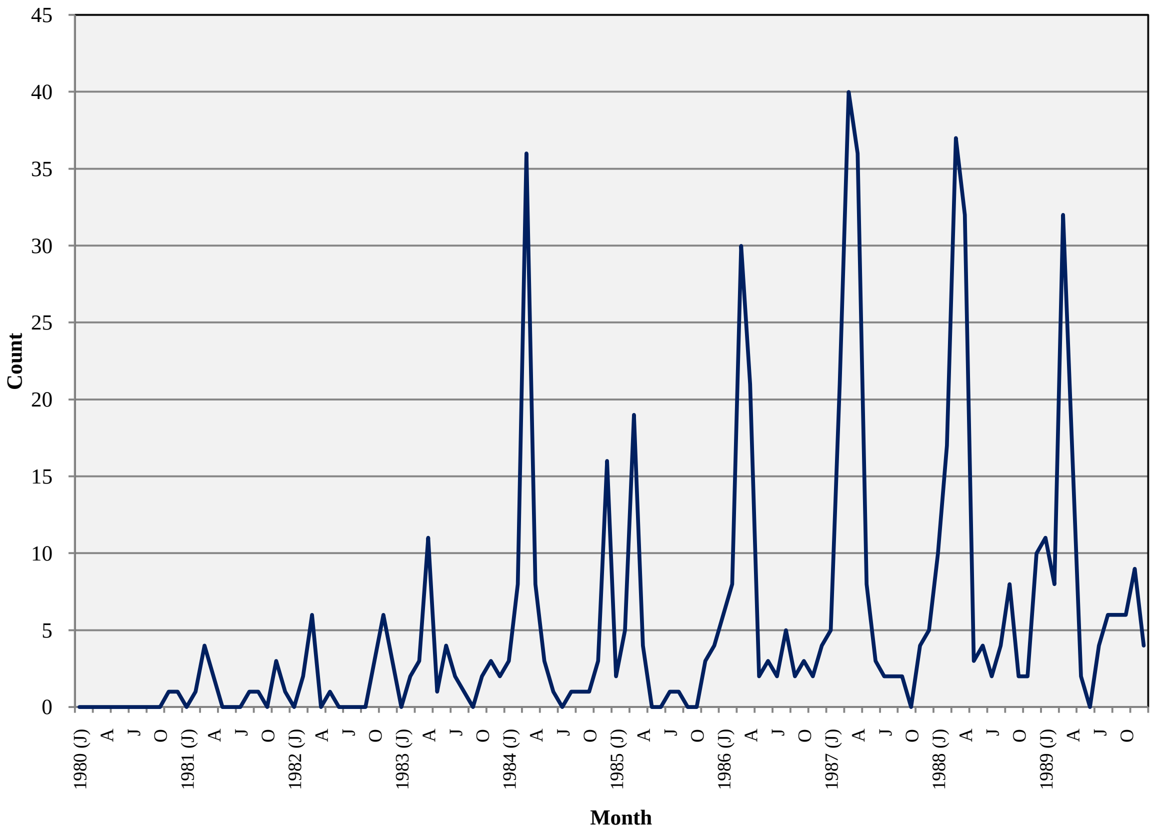


Figure 5.11 TMMSN Stranding Events from 1980 to 1989 by Month.

These events plotted are by month for the 1980 decade. The months labeled are January (J), April (A), July (J), and October (O). The stranding event counts are low starting at 1980 and do not increase until year 1984 in response to organizational building efforts by the TMMSN. The seasonal fluctuation occurs from late February to early May for most years.

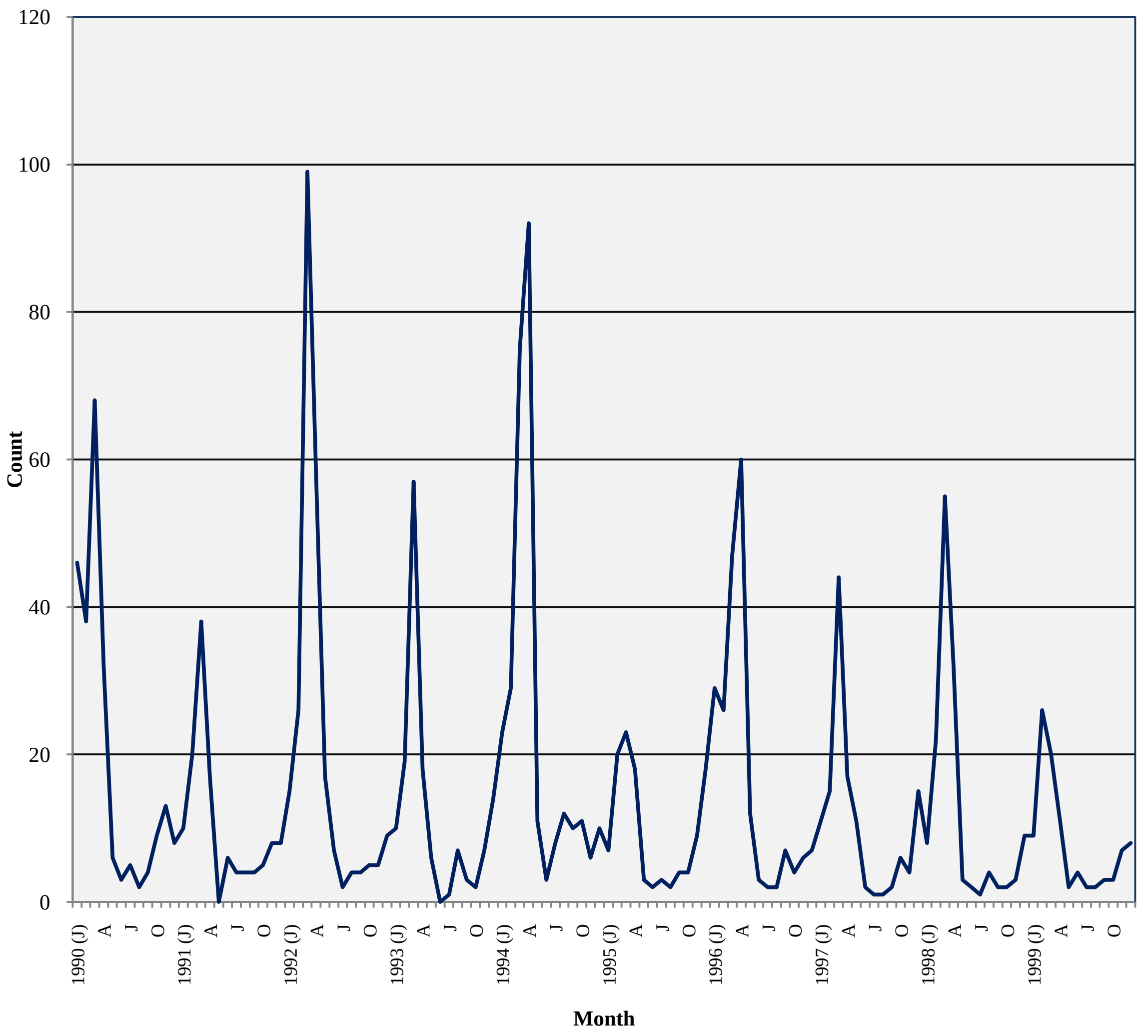


Figure 5.12 TMMSN Stranding Events from 1990 to 1999 by Month.

These events plotted are by month for the 1990 decade. The months labeled are January (J), April (A), July (J), and October (O). The two highest year counts, 1992 and 1994, are reflected in this decade plot, with a large component of the yearly events occurring in the spring months. This plot also reveals a bimodal increase in stranding events, with increases both in the spring and late fall-early winter months. The greatest seasonal fluctuation occurs from late February to early May for most years.

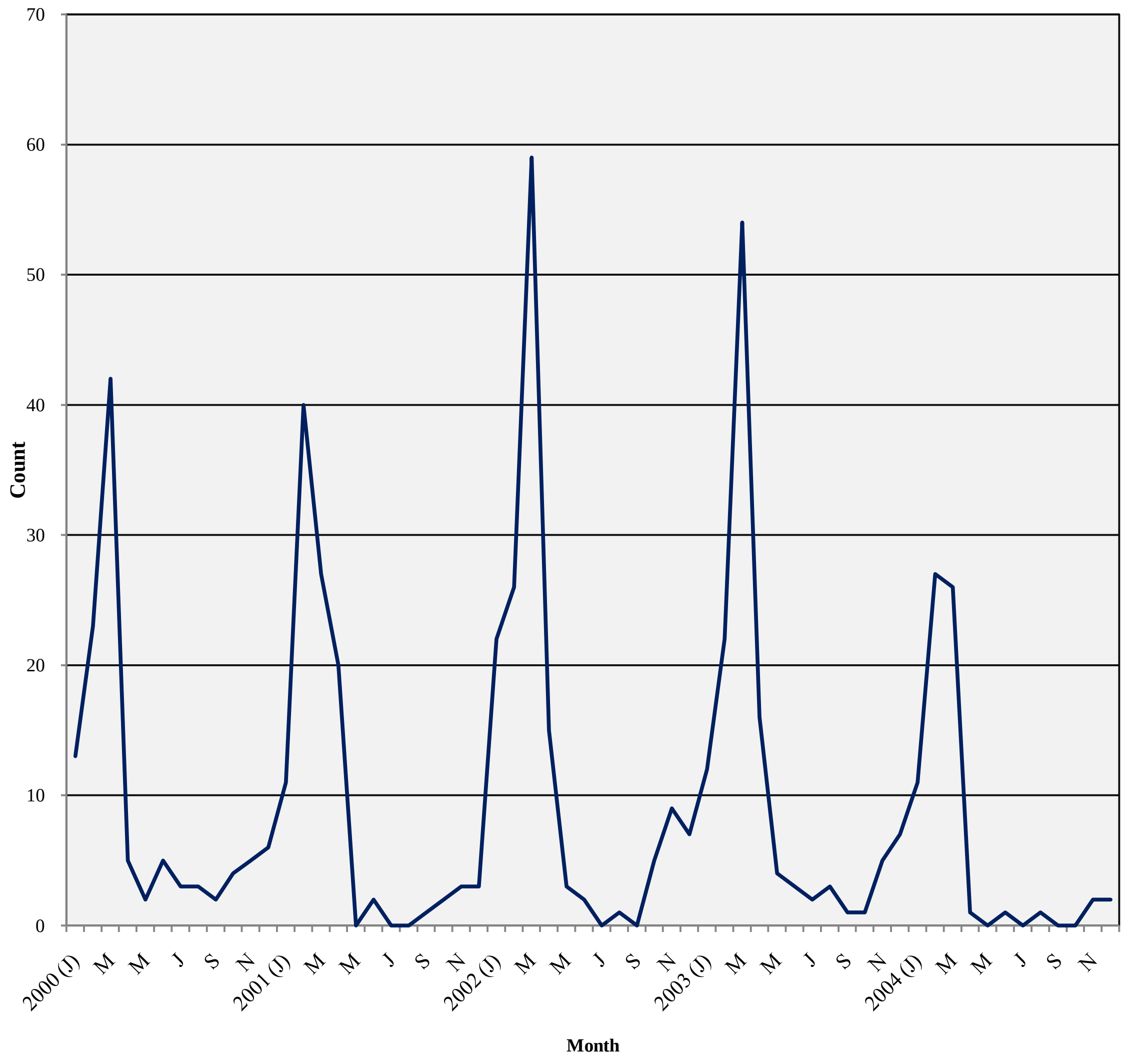


Figure 5.13 TMMSN Stranding Events from 2000 to 2004 by Month.

These events plotted are by month for the 2000 decade, which only extends to year 2004. The months labeled are January (J), March (M), May (M), July (J), September (S), and November (N). The magnitude of counts is significantly lower than the 1990 decade. This plot also shows a stretching in the area of the seasonal curve trend and with only one major seasonal mode in the spring months. The greatest seasonal fluctuation occurs from late February to early May for most years.

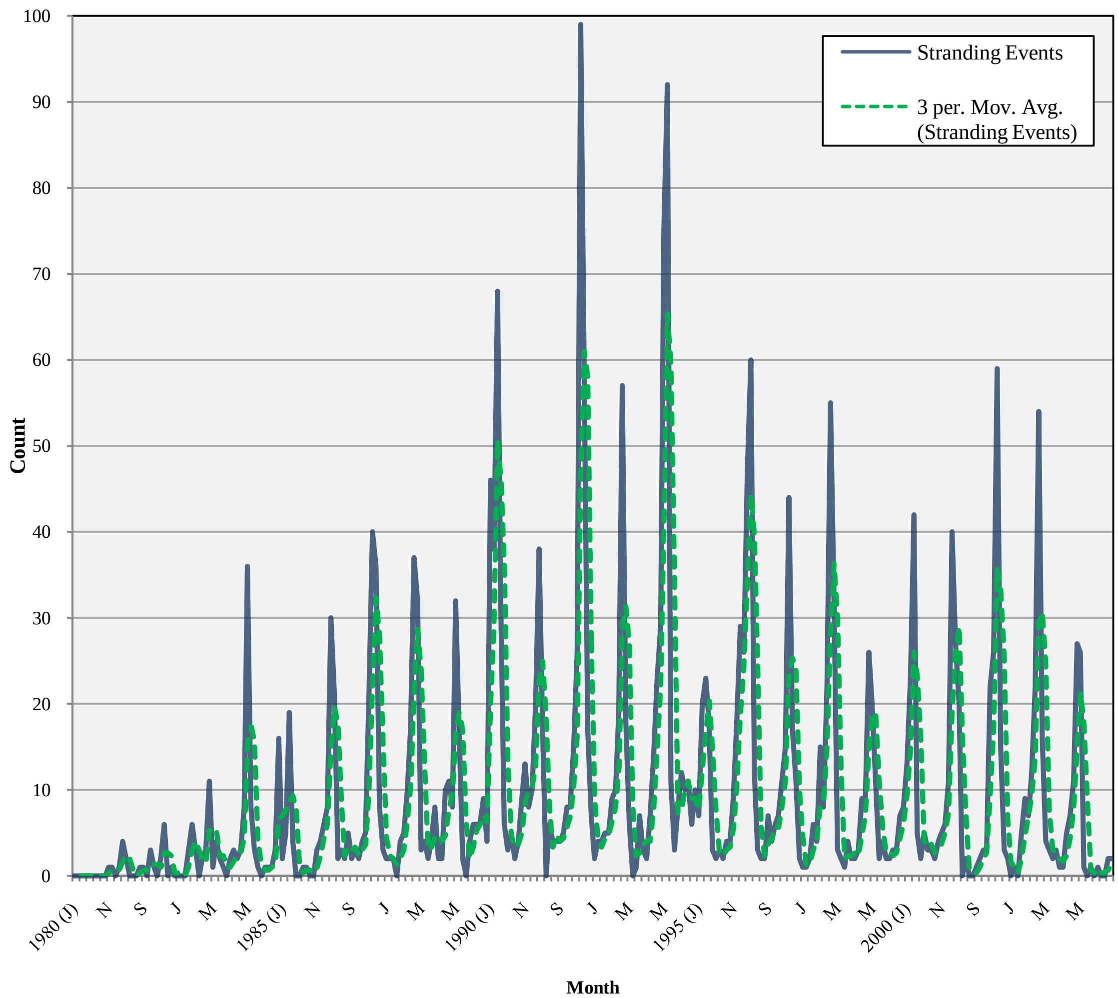


Figure 5.14 TMMSN Stranding Events by Months from 1980 to 2004.

The stranding event counts are plotted by month for each year in the database with a trend line added. The months labeled on the x-axis are January (J), November (N), September (S), March (M), and May (M). The trend applied to reduce monthly variability was a three period running average. The period selected corresponded to a seasonal average for stranding events by average three months together in a year equally four seasonal designations. The original curve integrity is maintained since the highest event amplitudes occur in the spring months for both the original and fitted data. However, the does reduce the bimodal variability appearing the 1990 decade.

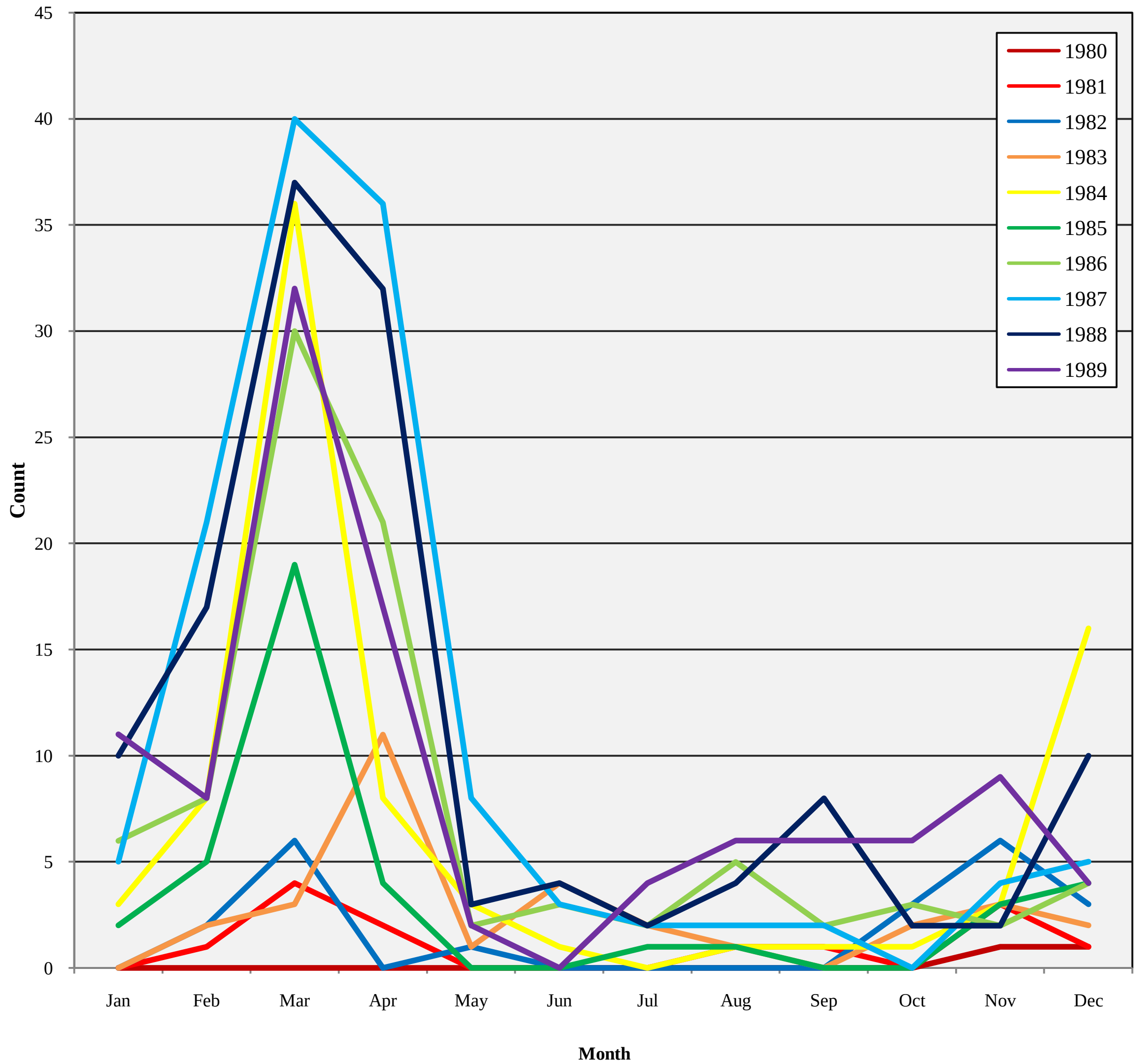


Figure 5.15 TMMSN Stranding Events Versus Month from 1980 to 1989.

Each month stranding event count was plotted by years for the 1980 decade. The years are represented by a different colored line and the curves exhibit the intense spring seasonal trend for each of the ten years represented. A second, though significantly reduced, increase is seen in the later part of the year, from December to February for years 1984 and 1998. However, the other years decrease in December and increase in late February.

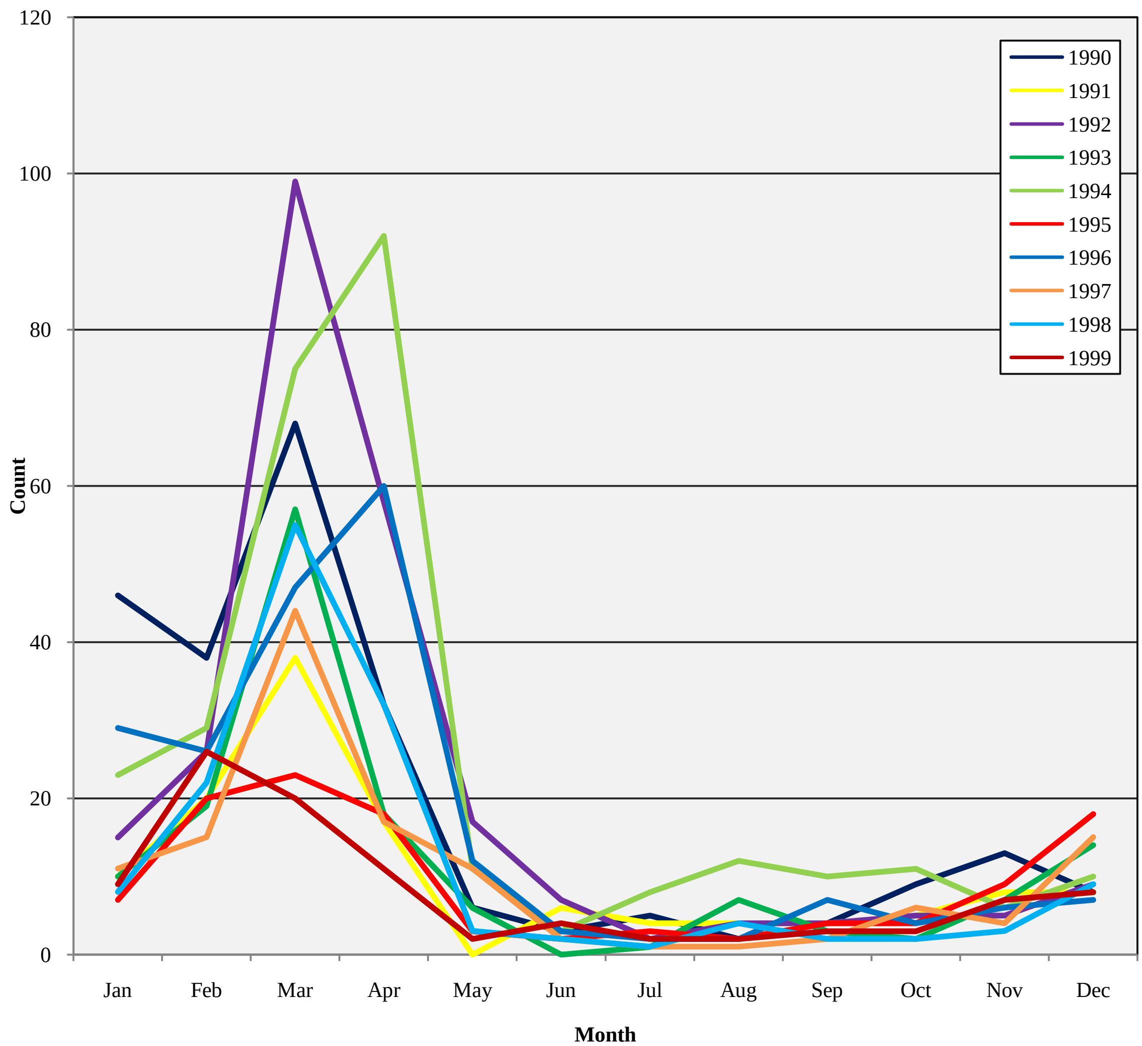


Figure 5.16 TMMSN Stranding Events Versus Month from 1990 to 1999.

Each month stranding event count was plotted by years for the 1990 decade. The years are represented by a different colored line and the curves exhibit the intense spring seasonal trend for each of the ten years represented. A second, though significantly reduced, increase is seen in the later part of the year, from December to February for all years. For years 1994 and 1996, the spring increase is low in March and higher in April. The large peak in 1992 is a result of an unusual mortality event published by Colbert et al. in 1999.

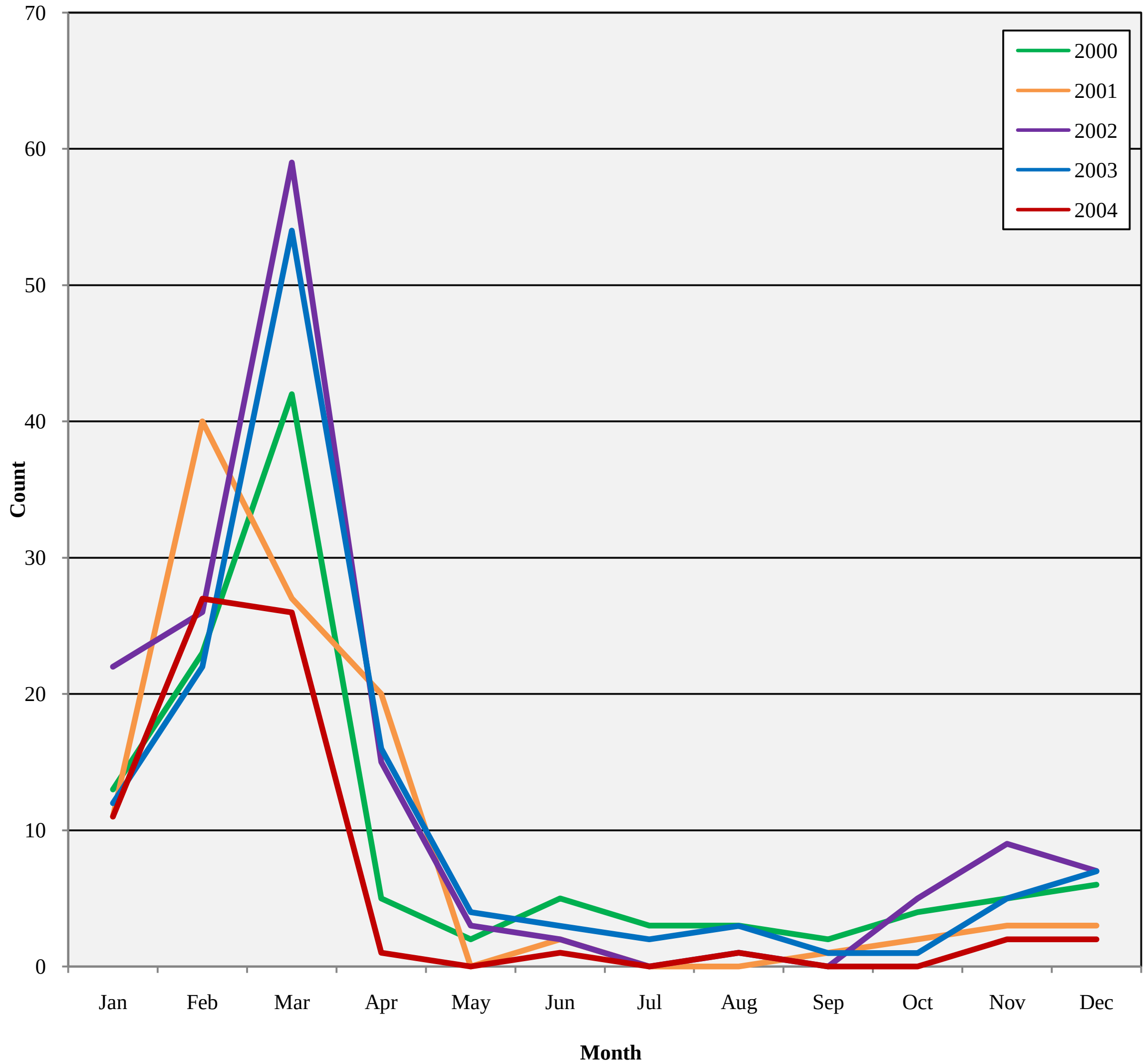


Figure 5.17 TMMSN Stranding Events versus Month from 2000 to 2004.

Each month stranding event count was plotted by years 2000 to 2004. The years are represented by a different colored line and the curves exhibit the intense spring seasonal trend for each of the ten years represented. A second, though significantly reduced, increase is seen in the later part of the year, from December to February for all years thus far. Most years peak in March, except for year 2001, which peaks in February, and year 2004, which is relatively even in stranding counts from February to March.

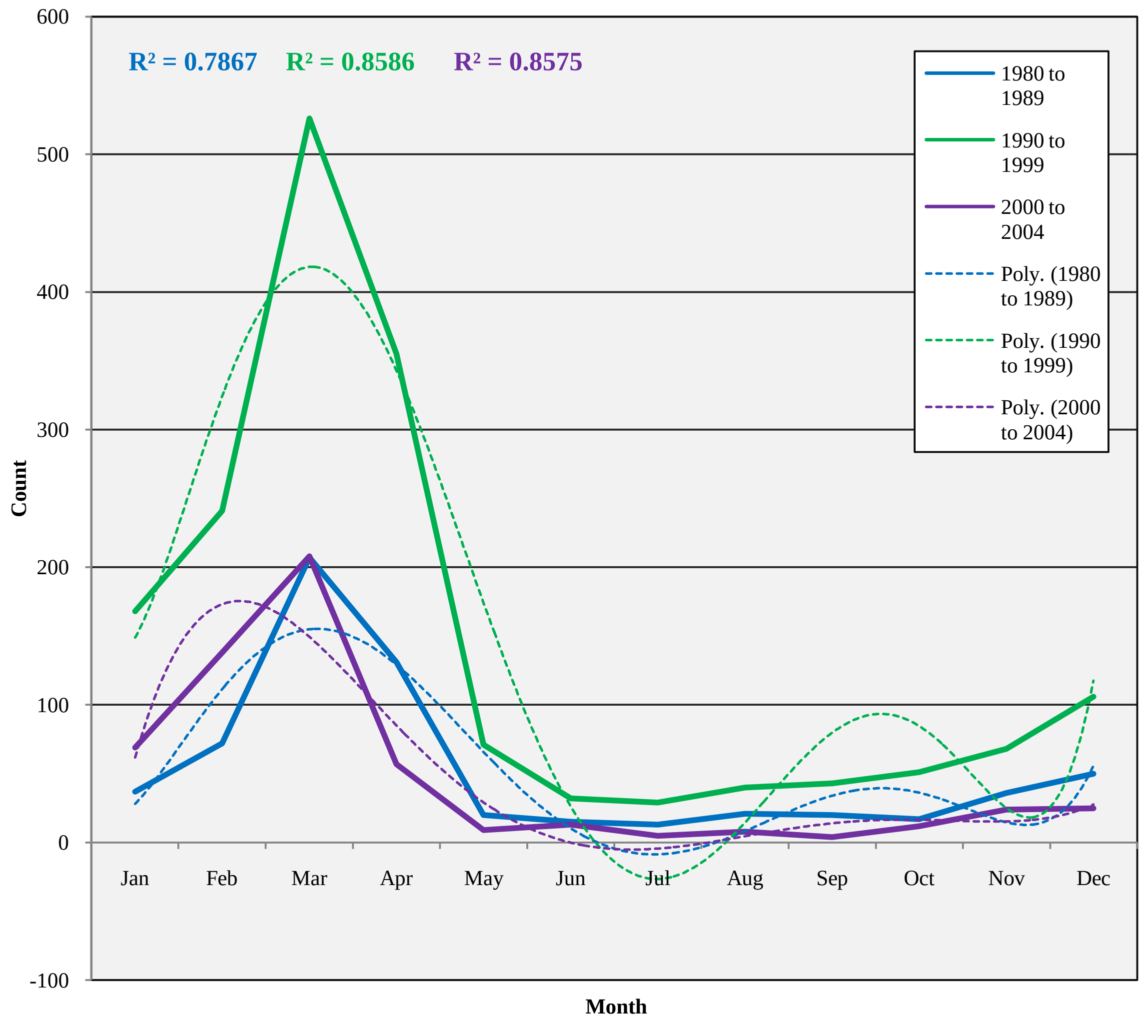
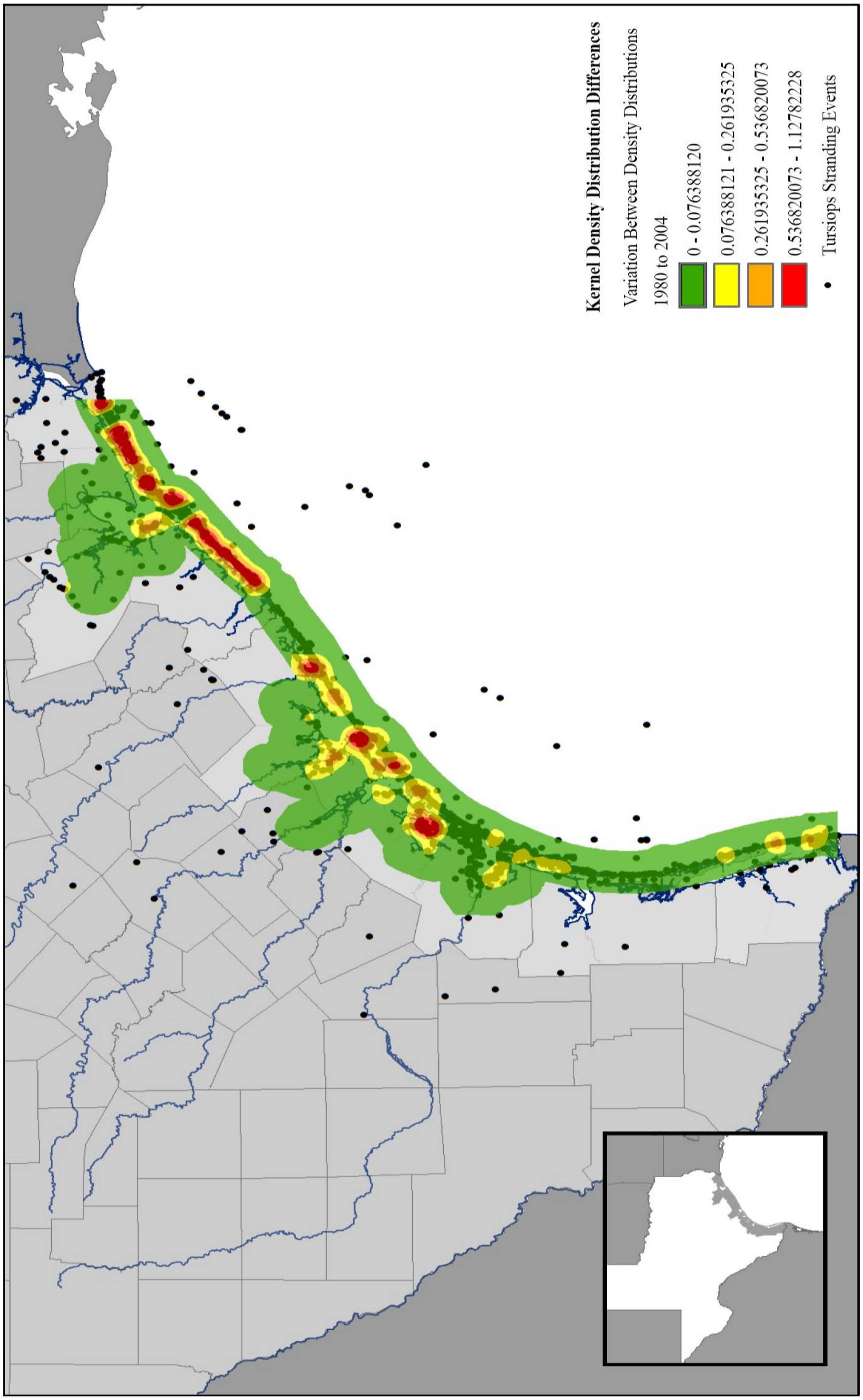


Figure 5.18 Total Decade Stranding Events Plotted by Month.

All the stranding events were counted for each year and plotted by month for the three decades studied. The coefficients of determination values are also included on this graph and correspond to the decade color. Sixth degree polynomial curves were fitted to each of the decade lines and explain from approximately 79% to 86% of the data variability. The curve fittings isolate both the spring seasonality and the increase in events from December to January. Yet, the curve fits create a region below zero events in July and a slight increase from September to October, which is both not supported by the original data and realistic to assume.

Figure 5.19 Density Distribution Variations of *Tursiops truncatus* from Years 1980 to 2004.

The map shows the results produced from performing a kernel density spatial distribution as outlined in Section 5.2. The scale indicates stranding event per quarter mile, with red showing approximately one-half to one event. Dark green represents no events per quarter mile. The map was developed by subtracting the differences between stranding event density for all three major decades. The highest density changes over the time are seen primarily along the Galveston-Brazoria counties' coastal boundaries and in Port Aransas Bay. Areas with yellow or green show little to no change in density between decades in stranding distributions.


Kernel Density Distribution Differences
Variation Between Density Distributions
1980 to 2004
0 - 0.076388120
0.076388121 - 0.261935325
0.261935325 - 0.536820073
0.536820073 - 1.12782228
Tursiops Stranding Events

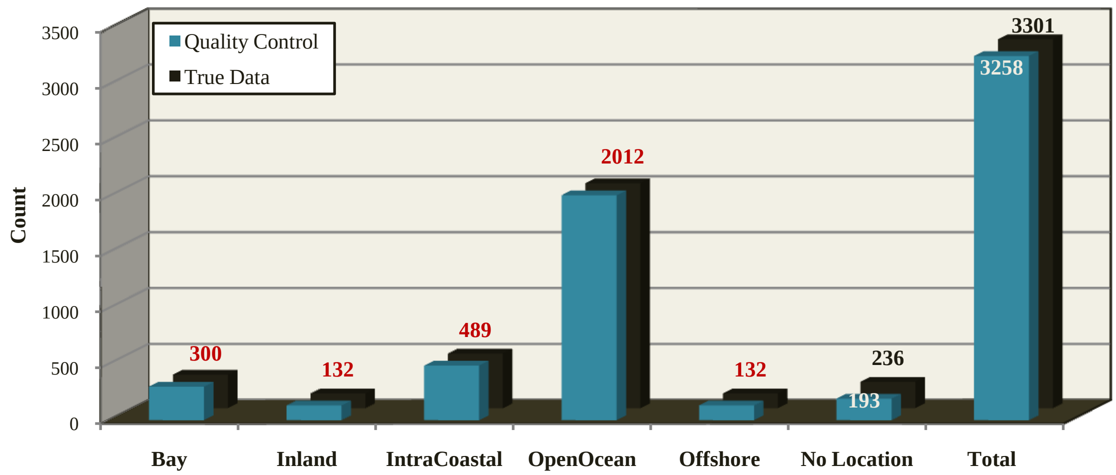


Figure 6.1 Quality Control for TMMSN Stranding Events.

This graph plots the stranding events in the TMMSN database and shows the quantity of points removed from analysis (shown in white). Data point removal were events missing a stranding year, a valid geographical location, or the species was not a cetacean. The only location with points removed before analysis was the *NoLocation* designation.

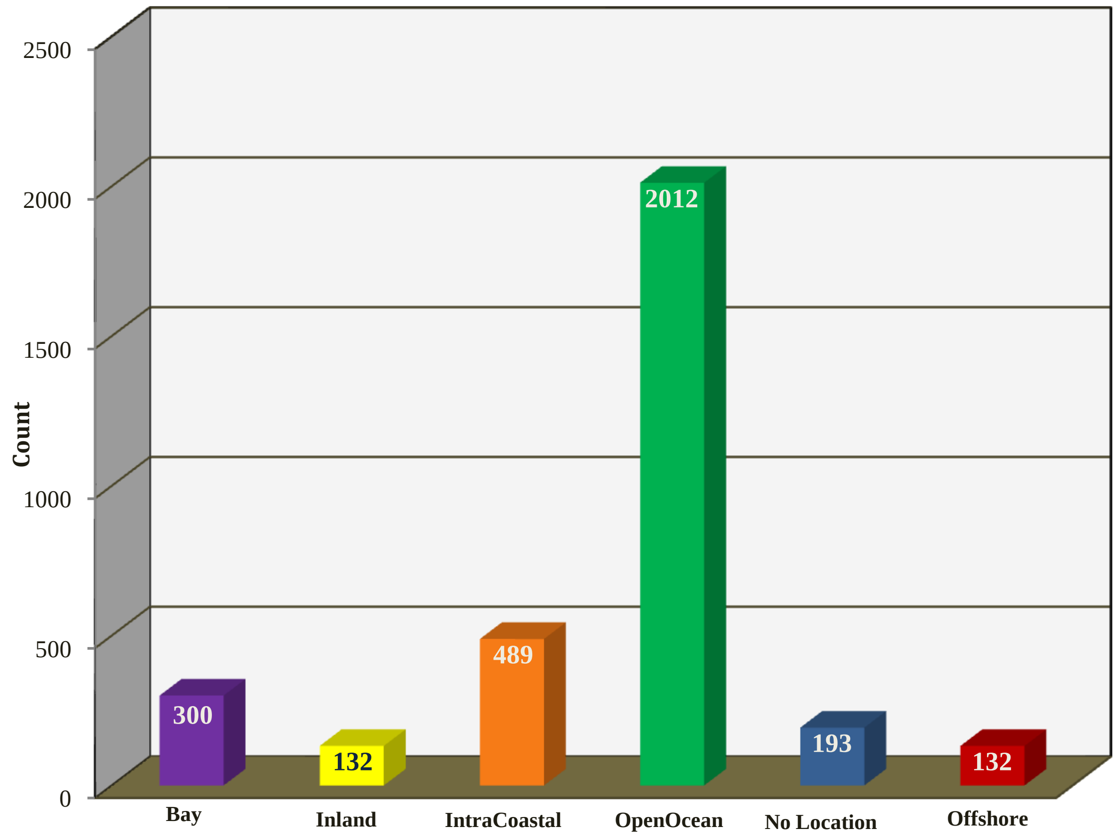


Figure 6.2 TMMSN Stranding Events by *LocationValue*.

The plot shows the number of stranding events for each developed location category. The largest category is *OpenOcean* and the smallest is tied between *Offshore* and *Inland* counts. The *IntraCoastal* and *Bay* counts combined account for approximately 35% of the total stranding events, whereas the *OpenOcean* location represents approximately 60% of all location designations. For the developed location values, *OpenOcean* proportionally more significant than the other categories created.

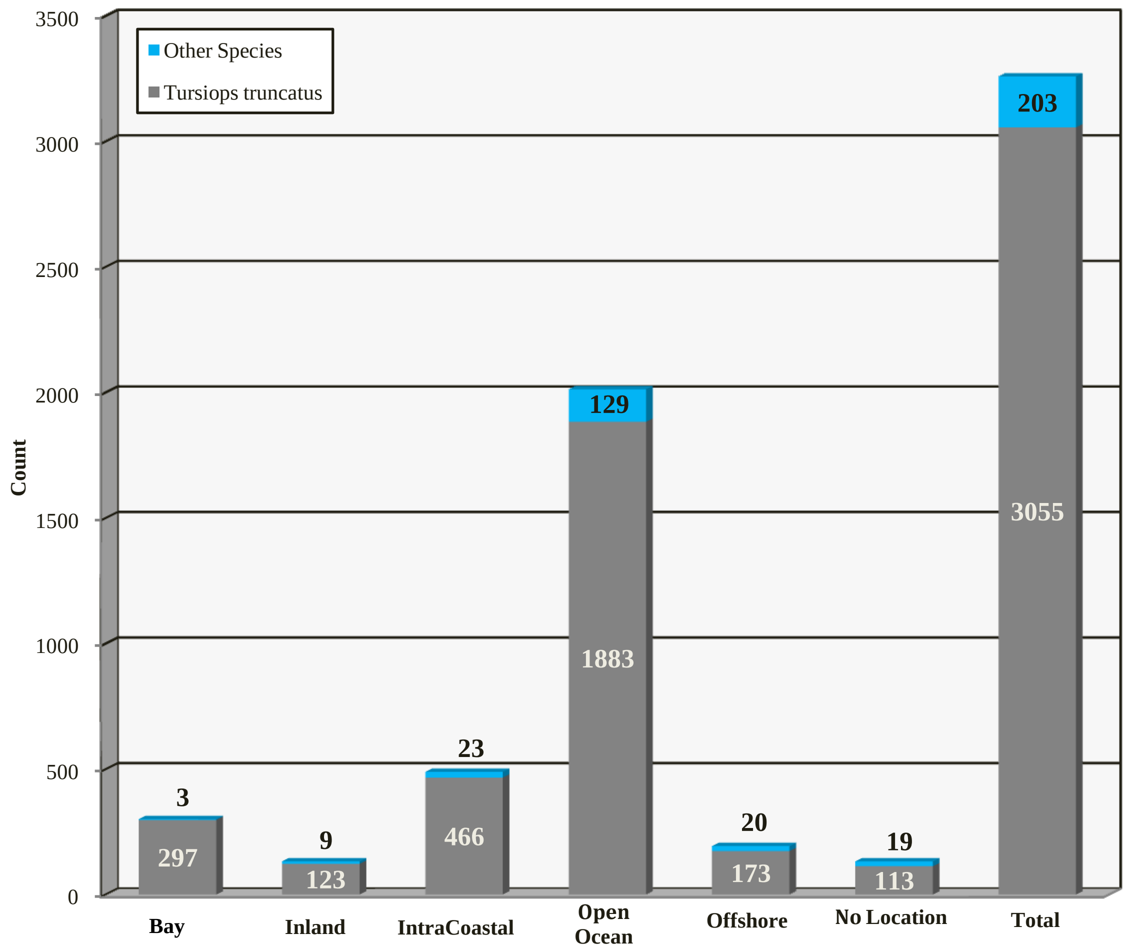


Figure 6.3 Location Distributions of *Tursiops truncatus* to Other Species in the TMMSN Database.

This figure examines the density of *Tursiops truncatus* compared to all other stranded species in the TMMSN database. The total number of stranding events is also included to represent the proportion of location distributions in comparison the total event counts. As concluded in Section 3, *Tursiops truncatus* is the dominant species in each location and almost entirely accounts for all *Bay* stranding events.

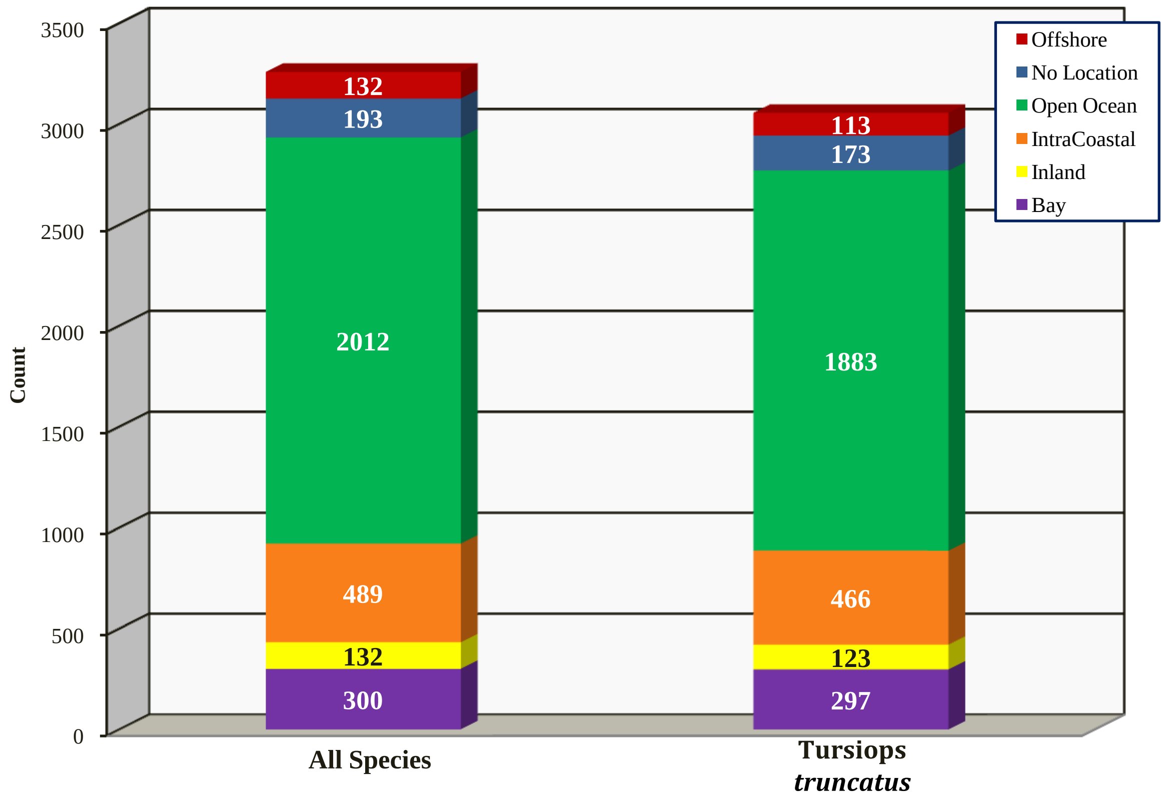


Figure 6.4 Stacked Bar Representation of TMMSN Stranding Events by Location.

This is a different type of graphical output to elaborate the dominance of *Tursiops truncatus* in the TMMSN database. The bars also represent the proportion for each species category, all versus *Tursiops truncatus*, to the developed location categories. The locations created are identified with color-coding in the legend to the right of the figure panel. The noticeable observations in this graph are the large number of events with an *OpenOcean* designation compared to the other five locations. The major difference between the entire database and *Tursiops truncatus* stranding events are in the *Offshore* and *OpenOcean* categories. *Tursiops truncatus* stranding events account for approximately 80% of all events and represent from 86% to 99% of stranding events in each location.

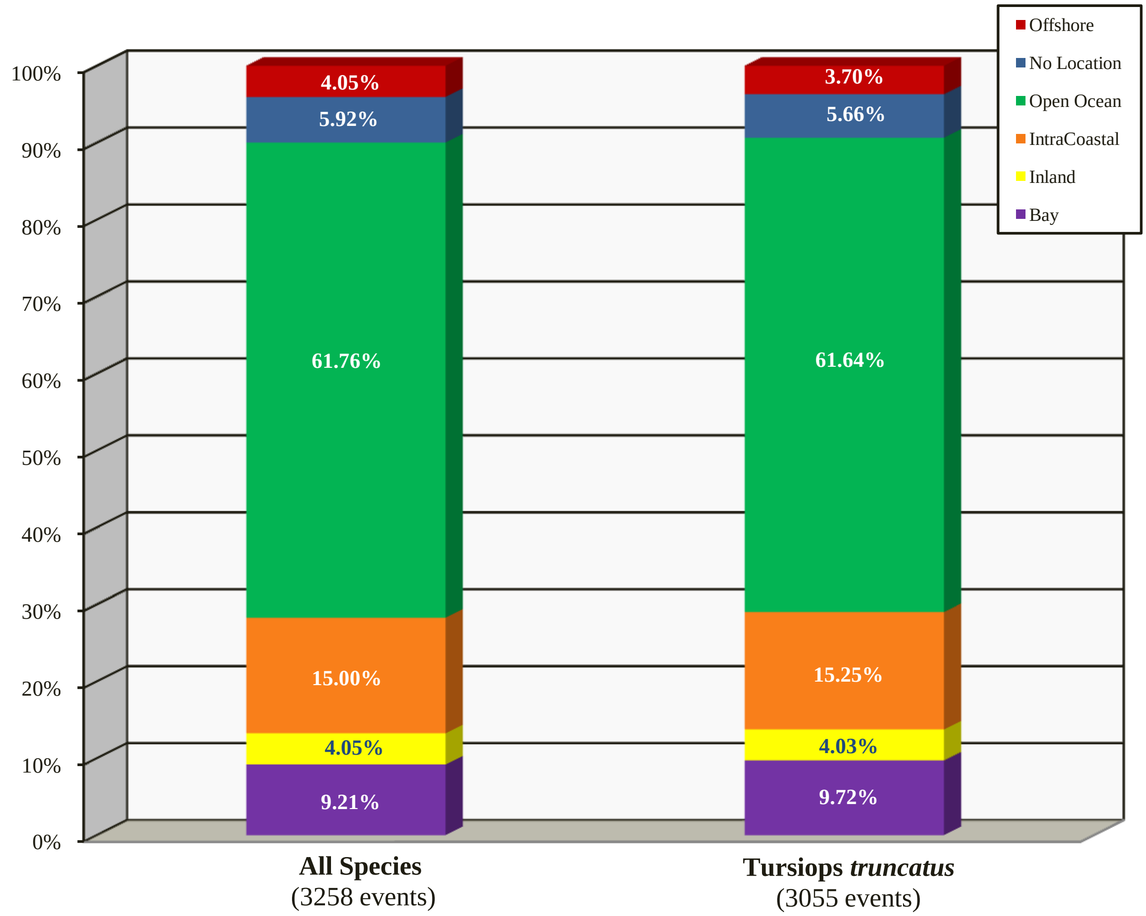


Figure 6.5 Percent Composition of TMMSN Stranding Events by Location.

The percents for stranding event counts are represented in this stacked bar chart. The overall trends with location distributions are still evident, but are significantly different when comparing all events to only *Tursiops truncatus* events.

Figure 6.6 Individual Species Distribution by Location Excluding *Tursiops truncatus*.

This bar plot resolves the stranding counts for all species except *Tursiops truncatus* by location value. The largest grouping in this graph is the *Unknown* category, which represents any animal not identified by TMMSN personnel. The five-point stars delineate whale species from dolphin species, represented by a four-point star symbol. The main conclusions are the abundance of *Offshore* and *OpenOcean* stranding for both whales and dolphin populations relating to the population distributions for species in the deep Gulf of Mexico waters as outlined in Section 3. These pelagic species are not evident in the *Bay* or *IntraCoastal* stranding locations, implying that only *Tursiops truncatus* are stranding in the inland locations.

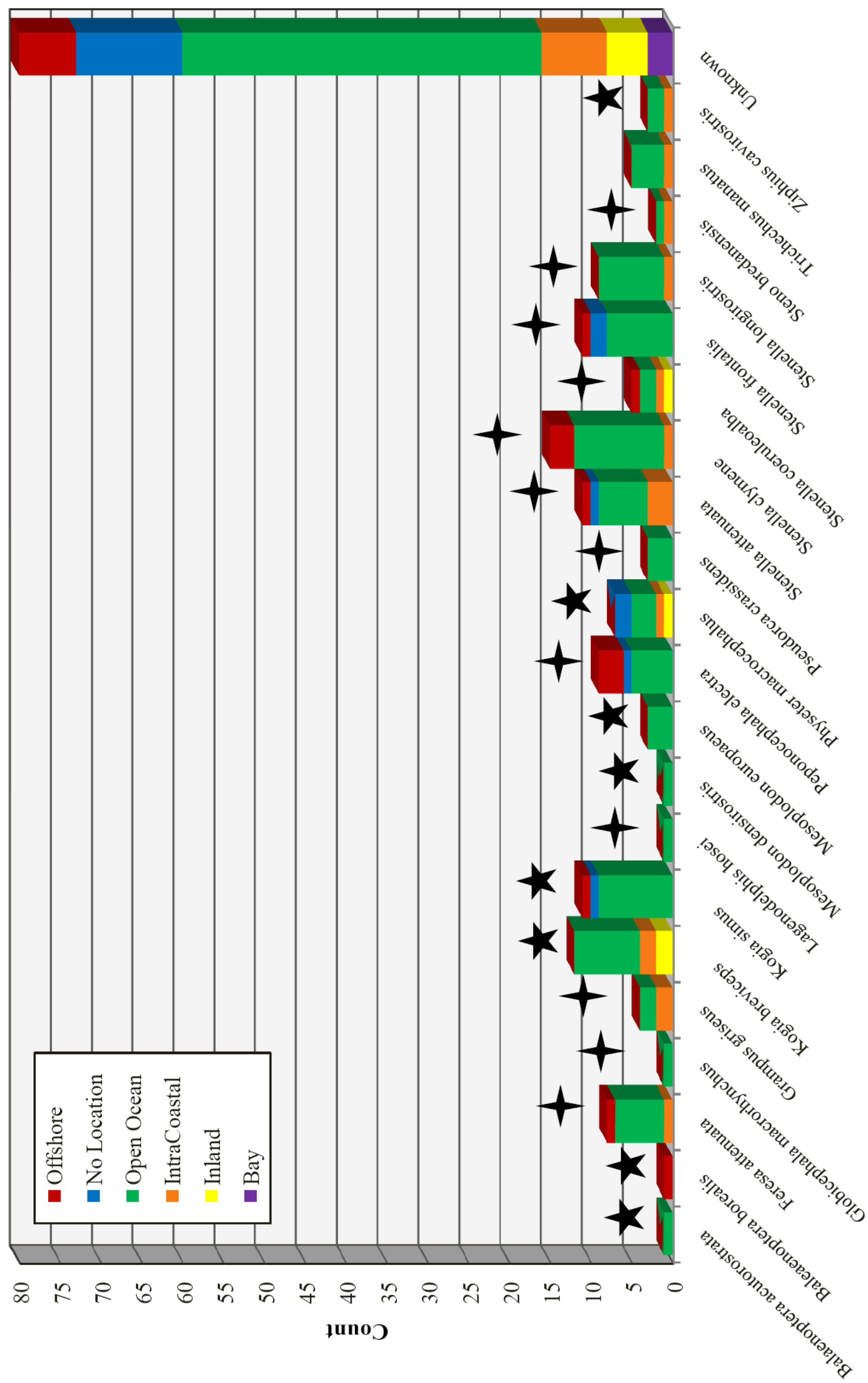
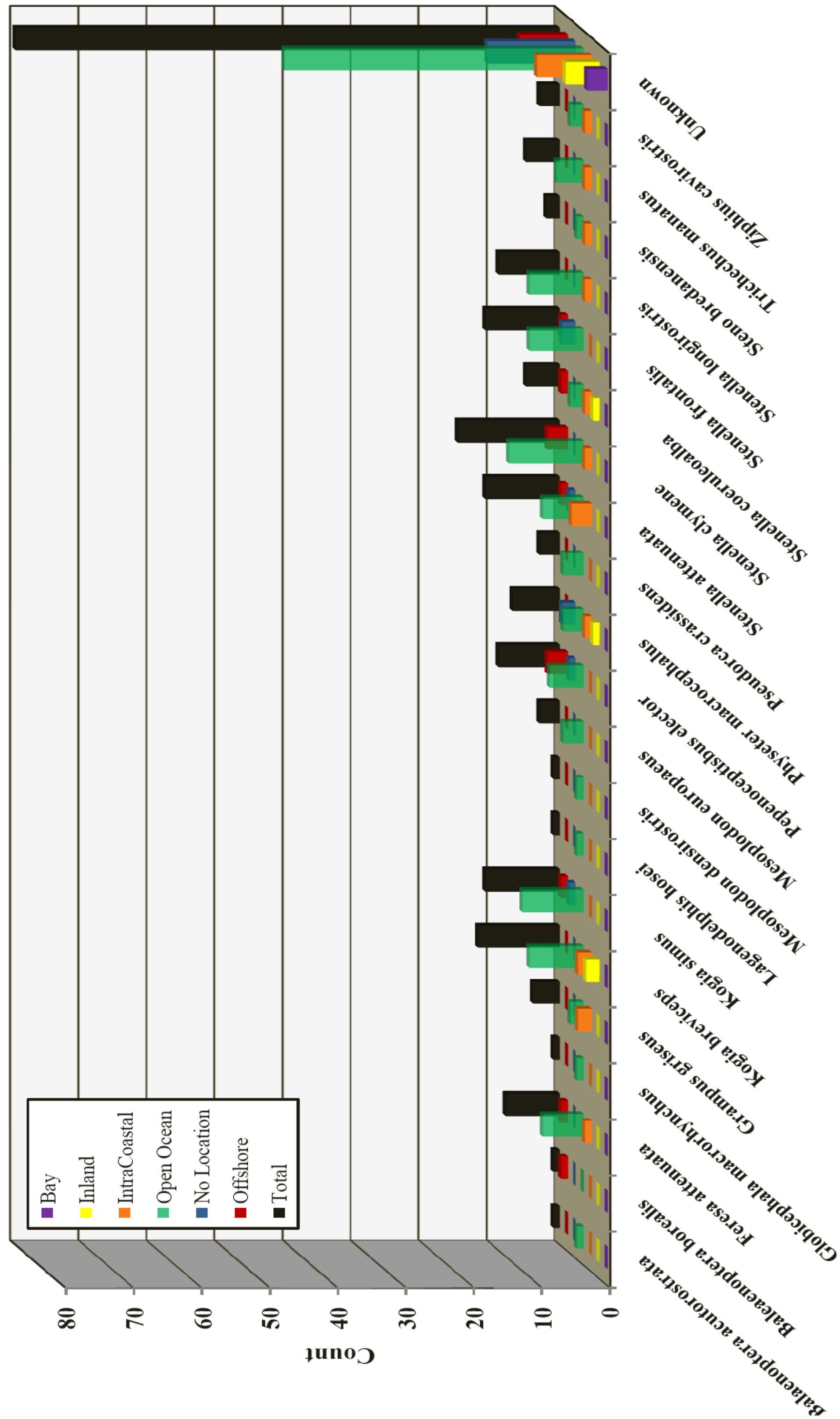

Offshore
No Location
Open Ocean
IntraCoastal
Inland
Bay
Count
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Balaenoptera acutorostrata
Balaenoptera borealis
Feresa attenuata
Globicephala macrorhynchus
Grampus griseus
Kogia breviceps
Kogia simus
Lagenodelphis hosei
Mesoplodon densirostris
Mesoplodon europaeus
Peponocephala electra
Physeter macrocephalus
Pseudorca crassidens
Stenella attenuata
Stenella clymene
Stenella coeruleoalba
Stenella frontalis
Stenella longirostris
Steno bredanensis
Trichechus manatus
Ziphius cavirostris
Unknown

Figure 6.7 Distribution of Species Stranding by Location Along the Texas Coastline.

Species identities as classified by the TMMSN. This graph plots all species identified by the TMMSN, excluding *Tursiops truncatus*, by number of stranding events for each location. The total number of stranding events for species is also included. The stranding counts are low for all species and the *Unknown* category from 1980 to 2004. The majority of species, whales or dolphins, strand in the *OpenOcean* locations. A few of the prominent coastal species, such as *Stenella attenuata* and *Kogia breviceps*, do strand further inland, but very infrequently from 1980 to 2004.


Bay
Inland
IntraCoastal
Open Ocean
No Location
Offshore
Total
Count
0
10
20
30
40
50
60
70
80
Balaenoptera acutorostrata
Balaenoptera borealis
Feresa attenuata
Globicephala macrorhynchus
Grampus griseus
Kogia breviceps
Kogia simus
Lagenodelphis hosei
Mesoplodon densirostris
Mesoplodon europaeus
Peponocephala electra
Physeter macrocephalus
Pseudorca crassidens
Stenella attenuata
Stenella clymene
Stenella coeruleoalba
Stenella frontalis
Stenella longirostris
Steno bredanensis
Trichechus manatus
Ziphius cavirostris
Unknown

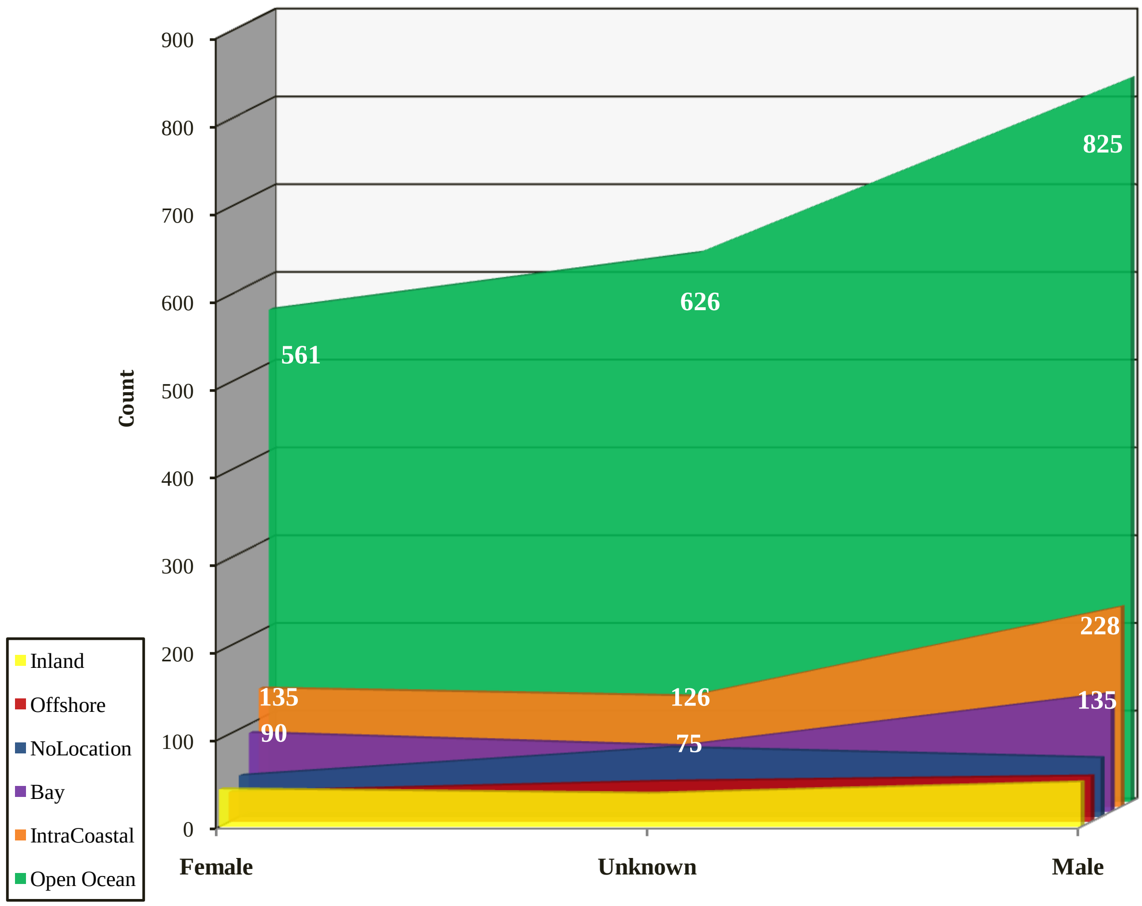


Figure 6.8 *Tursiops truncatus* Stranding Event Locations by Gender.

In this graph, the primary stranding location is the *OpenOcean*, with the second largest as *IntraCoastal* stranding events, for each gender classification. The male stranding rates are the highest for all location values, due to the structure of family groups and animal behavioral instincts (Section 4). The female stranding events are nearly equal to the abundances of unknown gender stranding events.

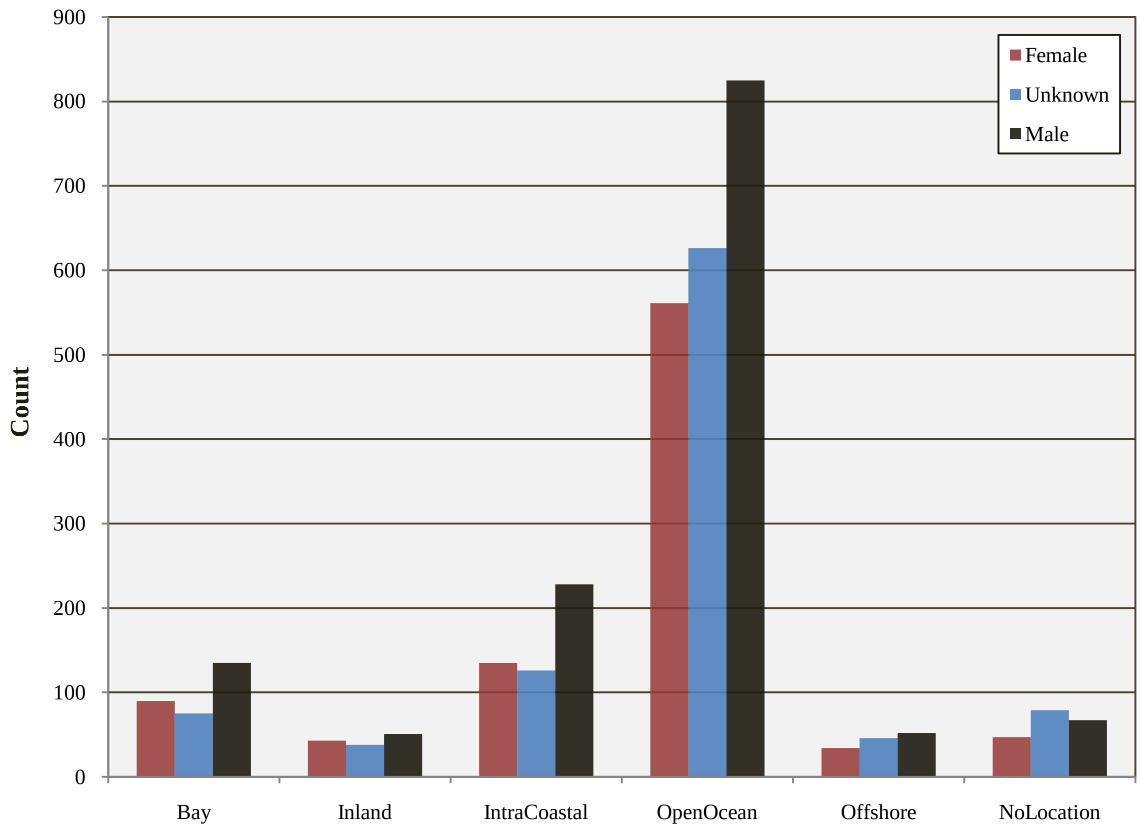


Figure 6.9 TMMSN Marine Mammal Stranding Events by *LocationValue* for Gende.

By plotting all stranding events by gender, there is a significant increase in *OpenOcean* events compared to the other five locations. Male species peak at each location, expect for the *NoLocation* category, which was not considered in any previous analysis. The *IntraCoastal* and *Bay* stranding events are similar in counts and gender. There is also a significant amount of unknown gender events affecting the proportion of the database, meaning no one gender is separable from another.

Figure 6.10 *LocationValue* Comparisons of Marine Mammal Stranding Events by year Without Total Event Counts.

This line-area plot graphs the stranding counts by year with an area representing each location category. The first noticeable category is *OpenOcean* events, which accounts for approximately 60% of the area. There is no apparent trend in stranding event increases or decreases with time. The events for each location are small in 1980 and increase as a response to the TMMSN increasing stranding response efforts. The next feature to focus on is the dominant peaks in 1992 for both *IntraCoastal* and *Bay* stranding events. These peaks are attributed to an unusual mortality event documented by Colbert et al. (1999), in which over 200 *Tursiops truncatus* stranded by no definite causes along Port Aransas and Matagorda Bays.

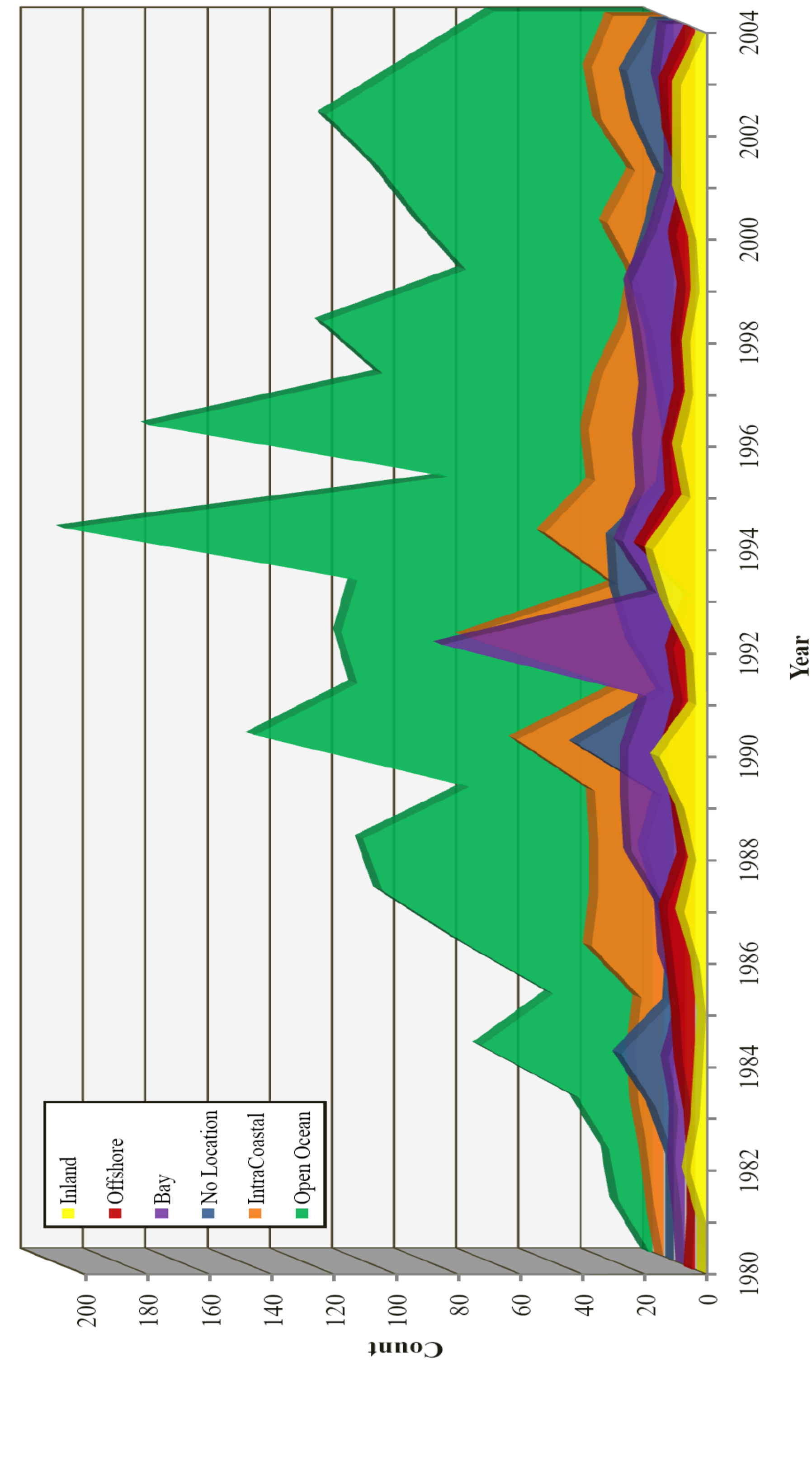

Inland
Offshore
Bay
No Location
IntraCoastal
Open Ocean
Count
0
20
40
60
80
100
120
140
160
180
200
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

Figure 6.11 *LocationValue* Comparisons of Marine Mammal Stranding Events per Year.

In this plot, the total number of stranding events is added to compare the temporal response in each location. The cyclic pattern in the mid-1990's is disrupted by unusual peaks in both *IntraCoastal* and *Bay* stranding events, resulting from an unusual mortality event in Port Aransas (Colbert et al. 1999). From 1990 to 1999, there are increases in the rates for the inshore location categories, which dissipate with time. Despite these influences, the *OpenOcean* data follow closely to the total stranding events until 2001, where rising event rates in *Inland*, *NoLocation*, and *IntraCoastal* events affect the total stranding rates.

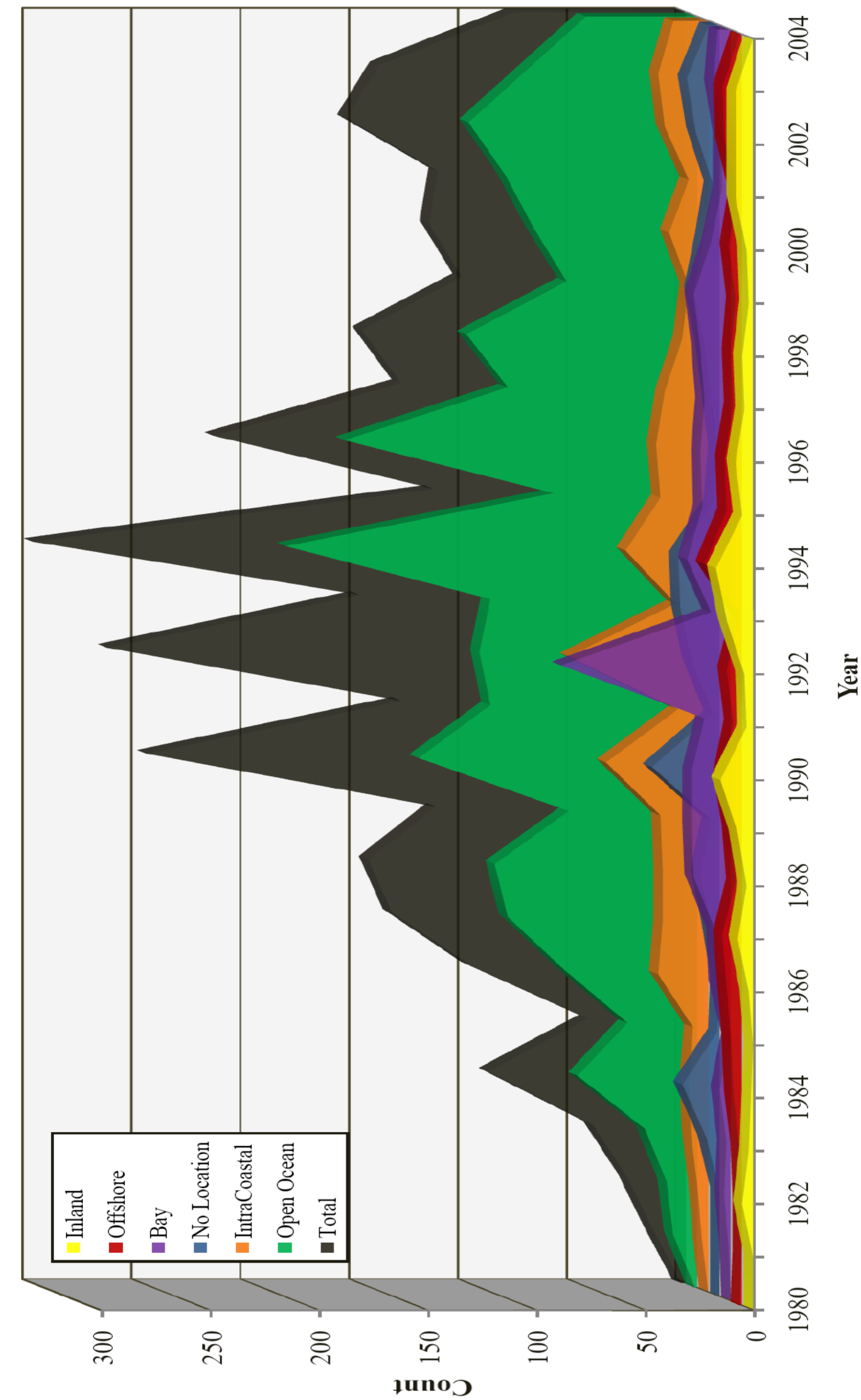
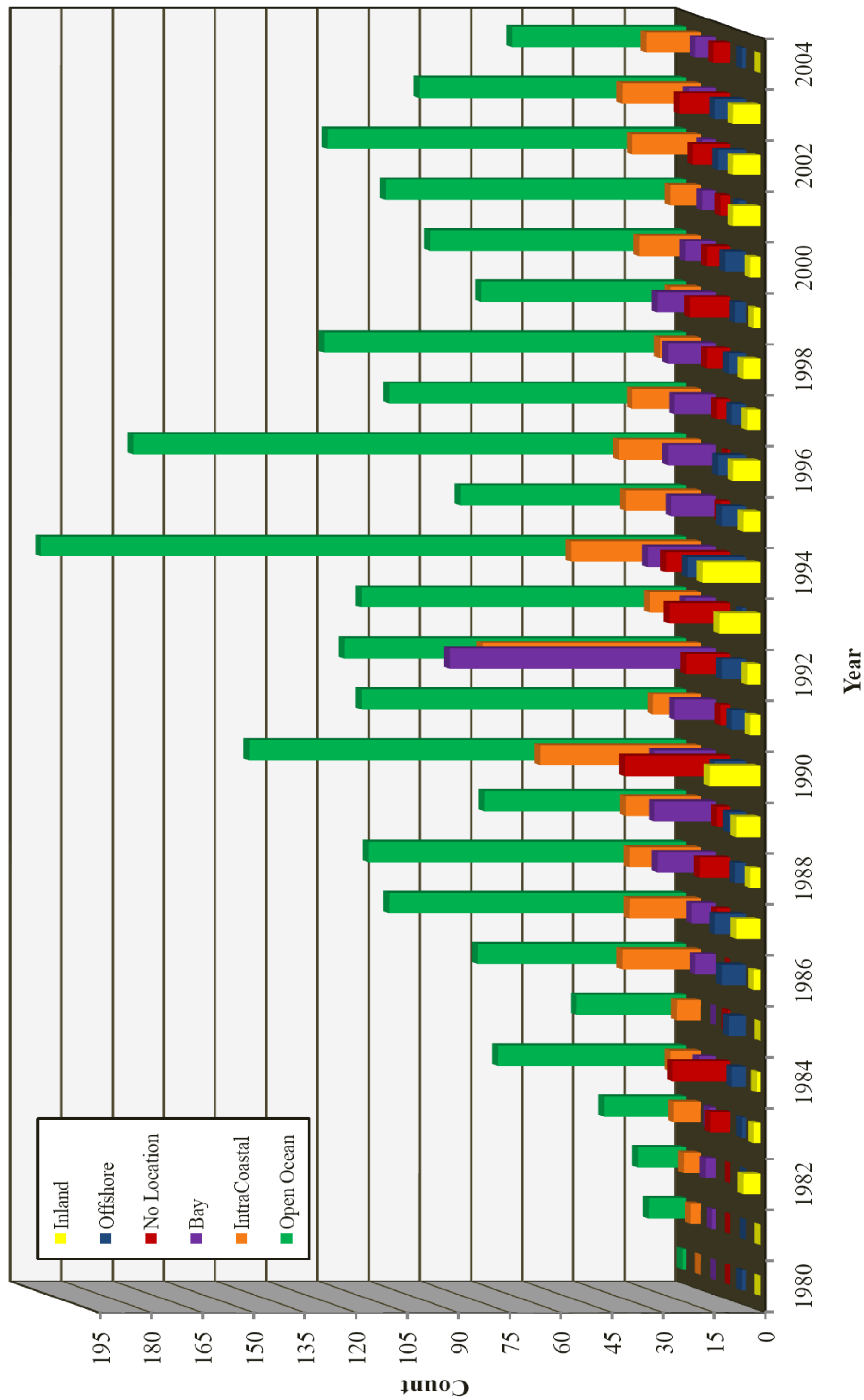

Inland
Offshore
Bay
No Location
IntraCoastal
Open Ocean
Total
Count
0
50
100
150
200
250
300
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

Figure 6.12 Comparing Total Yearly TMMSN Stranding Events by Location.

Each location is plotted by events per year from 1980 to 2004. There is no apparent linear increasing or decreasing patterns in the graph and each location appears to follow a cyclic pattern with varying amplitudes of response. The largest peaks occur in the *OpenOpean* category for all years, but there are significant increases in 1992 for both *IntraCoastal* and *Bay* stranding events, resulting from a unique mortality incidence (Colbert et al. 1999). *IntraCoastal* stranding events are prominent in 1990 and 1994, which was the highest year count, but not single incidents have been determined as the cause for the increase.



Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean
Count
0
15
30
45
60
75
90
105
120
135
150
165
180
195
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

Figure 6.14 Comparison of TMMSN Marine Mammal Stranding Event Locations from 1980 to 1989.

The events for each location are graphed from 1980 to 1989. All locations are low in the early 1980's, as result of the organization forming in 1980 and having to build personnel and equipment for response efforts. As the network's personnel expands, the stranding rates increases. The *OpenOcean* category is the largest event location and *IntraCoastal* stranding events increase in 1986, followed by an increase in *Bay* stranding in 1988. *Offshore* stranding rates appear to be influential in the mid 1980's, but the counts are all below 10 events. At the end of the decade, each location appears to either decrease or level off, except for the *Inland* category.

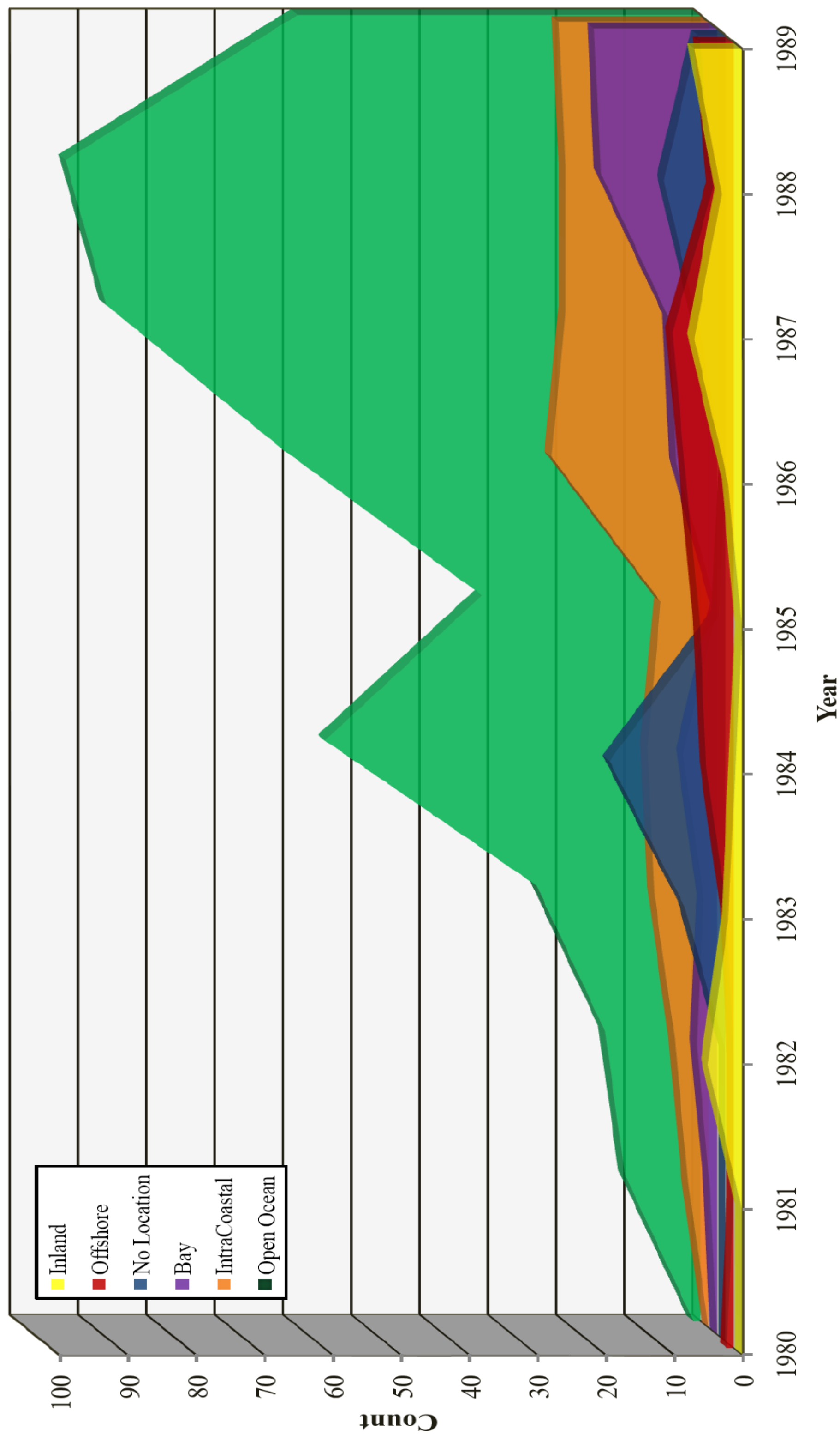

Count
100
90
80
70
60
50
40
30
20
10
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
Year
Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean

Figure 6.14 Comparison of TMMSN Marine Mammal Stranding Event locations from 1980 to 1989.

The total number of stranding events is included in this graph to identify similarities between the location values and the entire database for 1980 to 1989. The *OpenOcean* events appear to mimic the general trend of the total events, except for slight variations in 1986 and 1988. In 1986, the increase in *IntraCoastal* stranding events influence the total numbers and the combination of both *IntraCoastal* and *Bay* stranding events affect the magnitude of the total events in 1988.

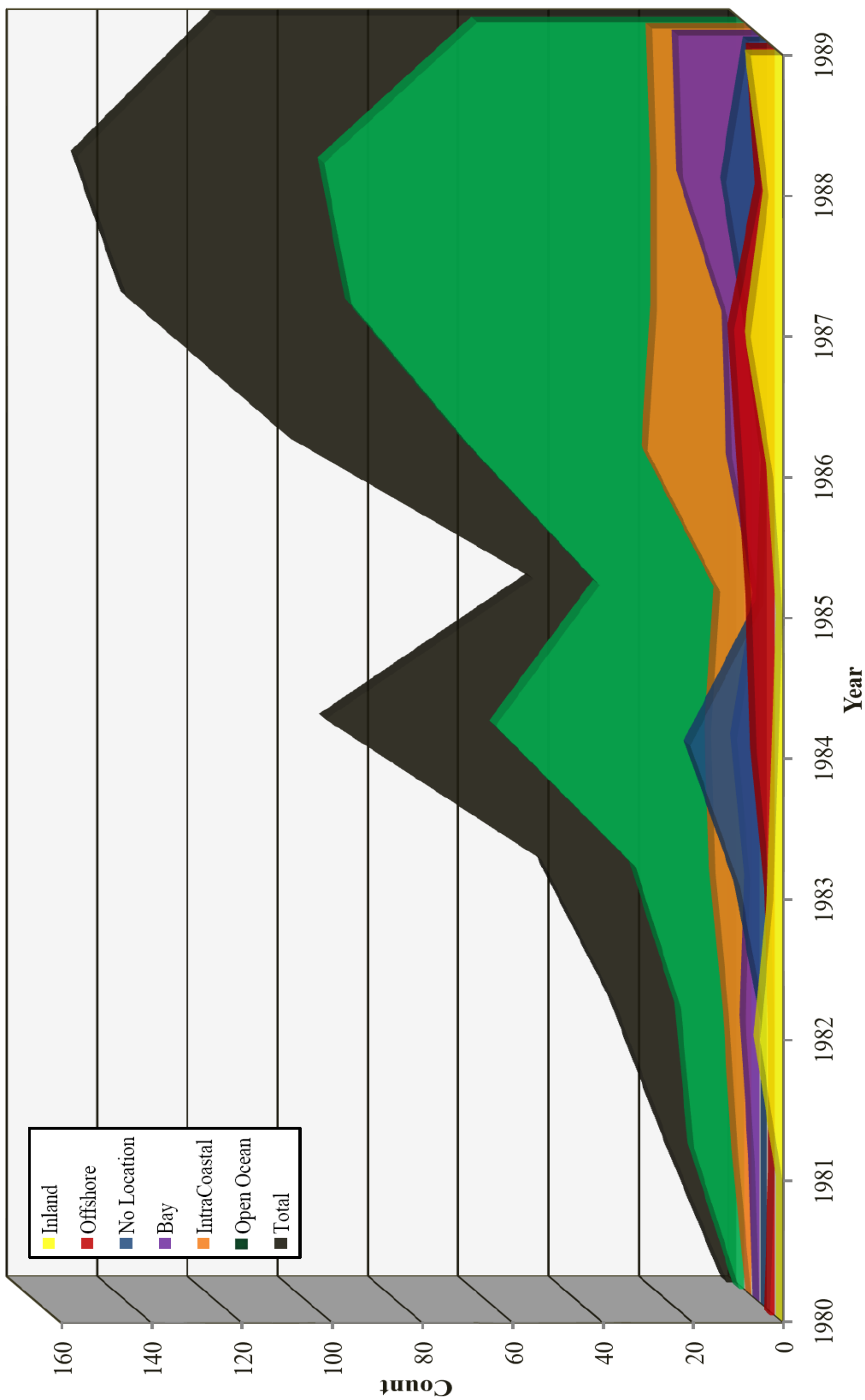

Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean
Total
Count
160
140
120
100
80
60
40
20
0
Year
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989

Figure 6.15 Comparison of TMMSN Marine Mammal Stranding Event Locations From 1990 to 1999.

Isolating stranding events by location from 1990 to 1999 reveals the impact of events in the *IntraCoastal* and *Bay* categories. Stranding rates decrease in the early years, but immediately increase in 1992 and subside for the remainder of the decade, except for the *OpenOcean* locations, which cycle from high and low rates until 1999. The peaks in 1992 result from over 200 *Tursiops truncatus* stranding the Port Aransas and Matagorda Bay ecosystems (Colbert et al. 1999).

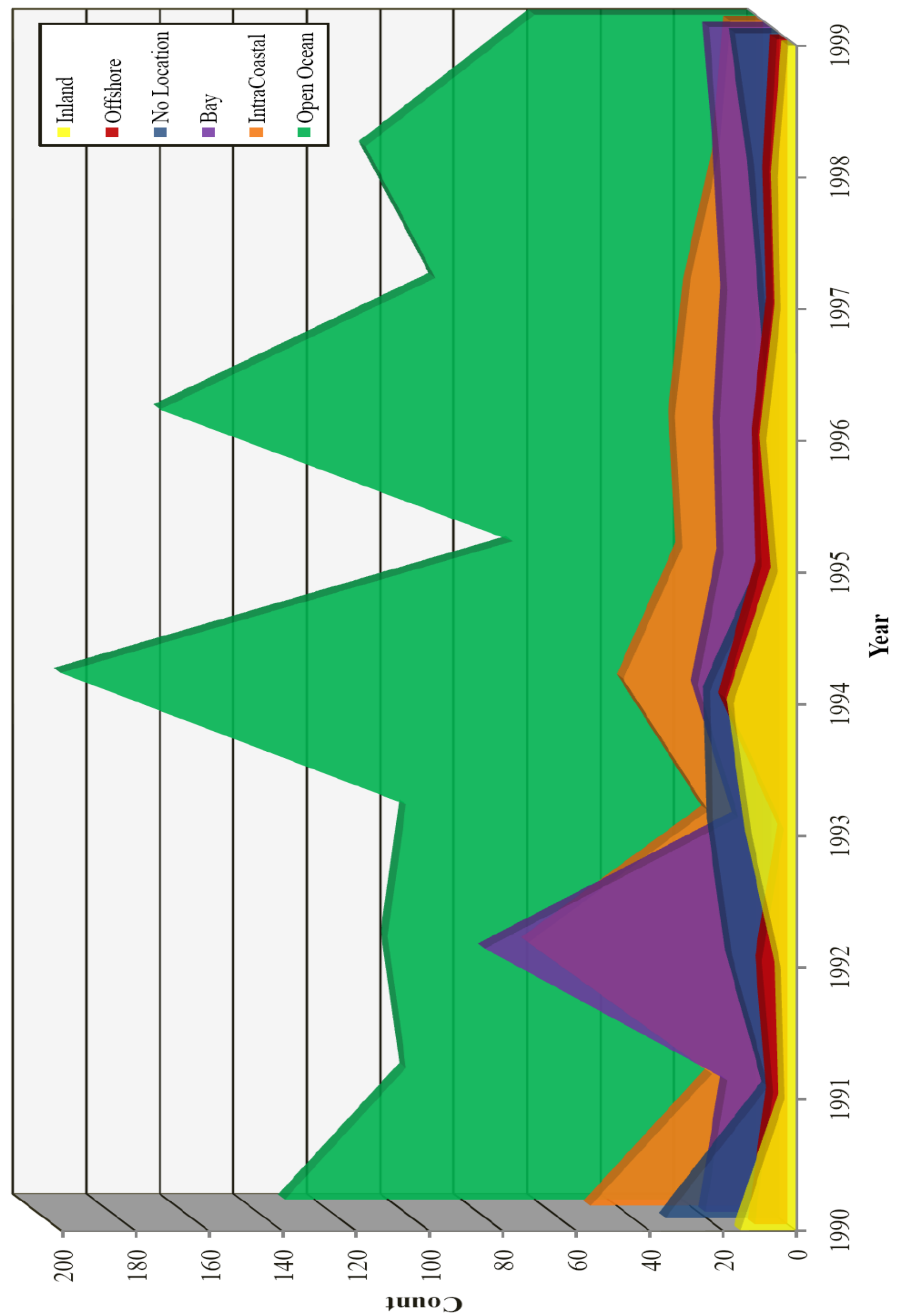

Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean
Count
0
20
40
60
80
100
120
140
160
180
200
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year

Figure 6.16 Comparison of TMMSN Marine Mammal Stranding Event Locations from 1990 to 1999 Including Total Event Counts per Year.

Adding the total events with each location values line emphasizes the validity of additional spatial information to investigate stranding events. The combination of both the *Bay* and *IntraCoastal* events significantly influences the total event response, by mitigating the dominance of the *OpenOcean* events throughout the database. Though less in magnitude, the same effect is seen in 1994, which is the highest event year in the TMMSN database.

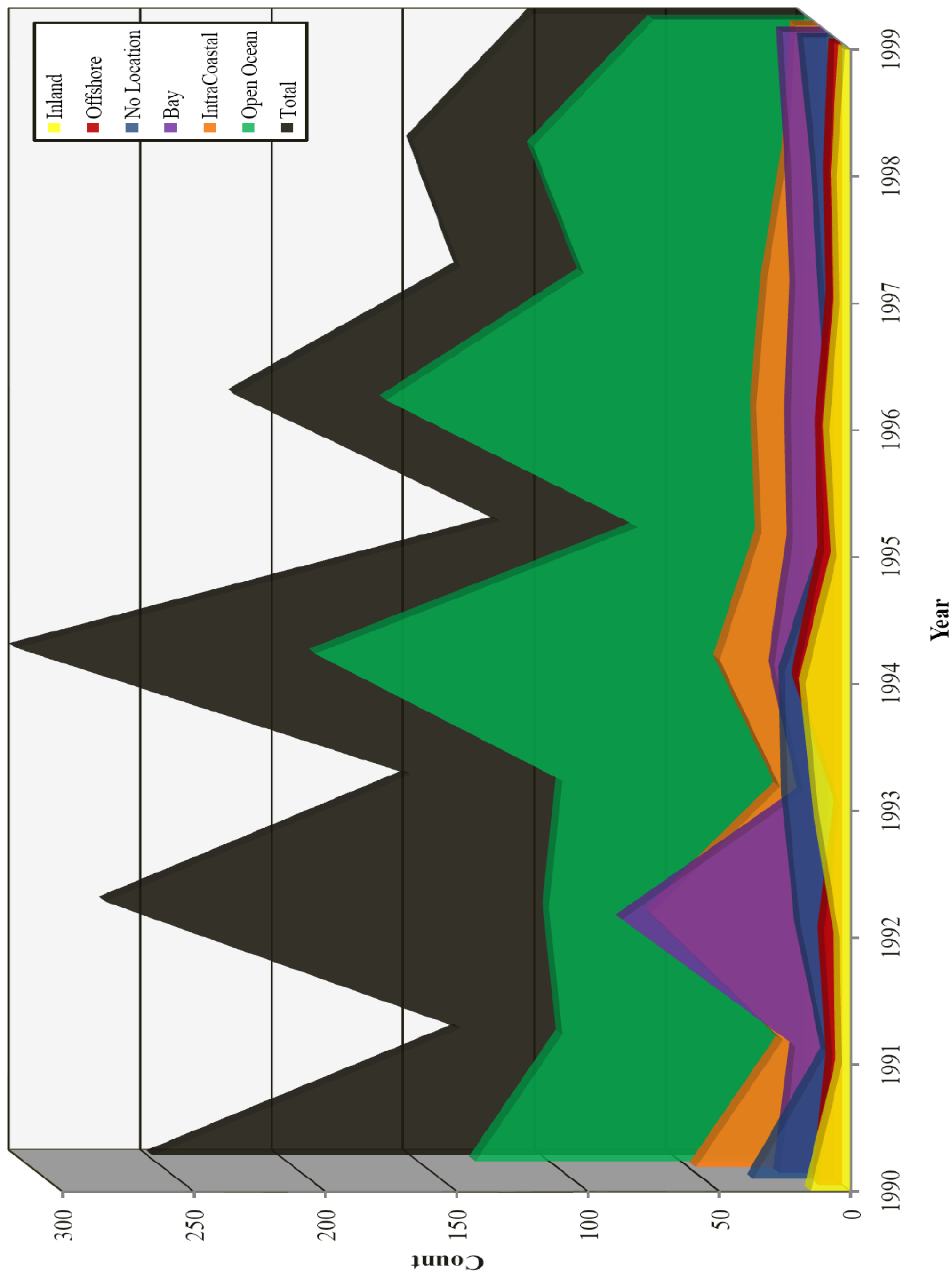

Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean
Total
Count
300
250
200
150
100
50
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year

Figure 6.17 Comparison of TMMSN marine mammal stranding event locations from 2000 to 2004.

From 2000 to 2004, the *OpenOcean* stranding events dominate all location values. Unlike the other years, the *OpenOcean* values peak in 2002 and decrease. All other locations only experience small event increases and stranding rates remain consistent over the five years.

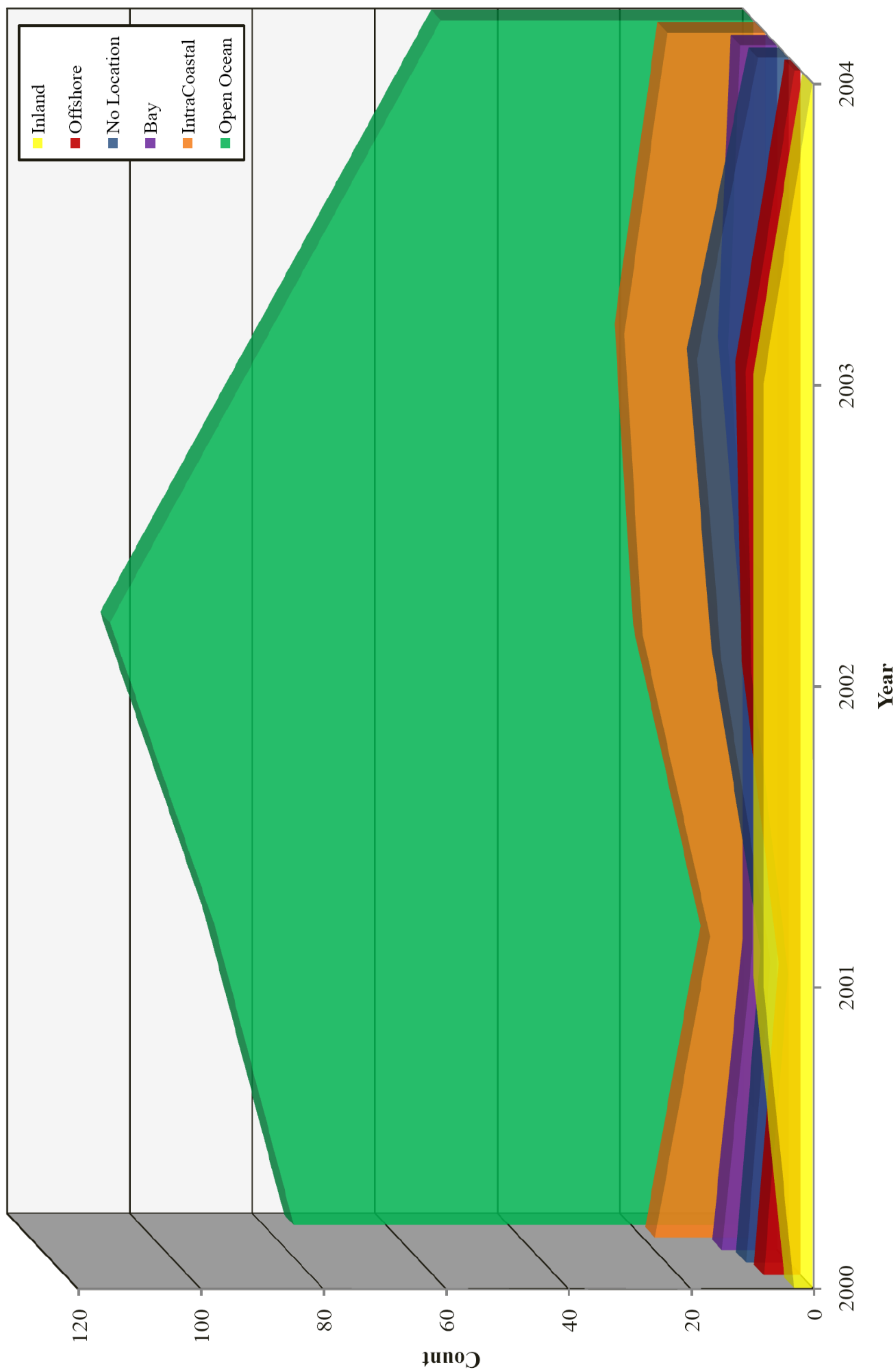
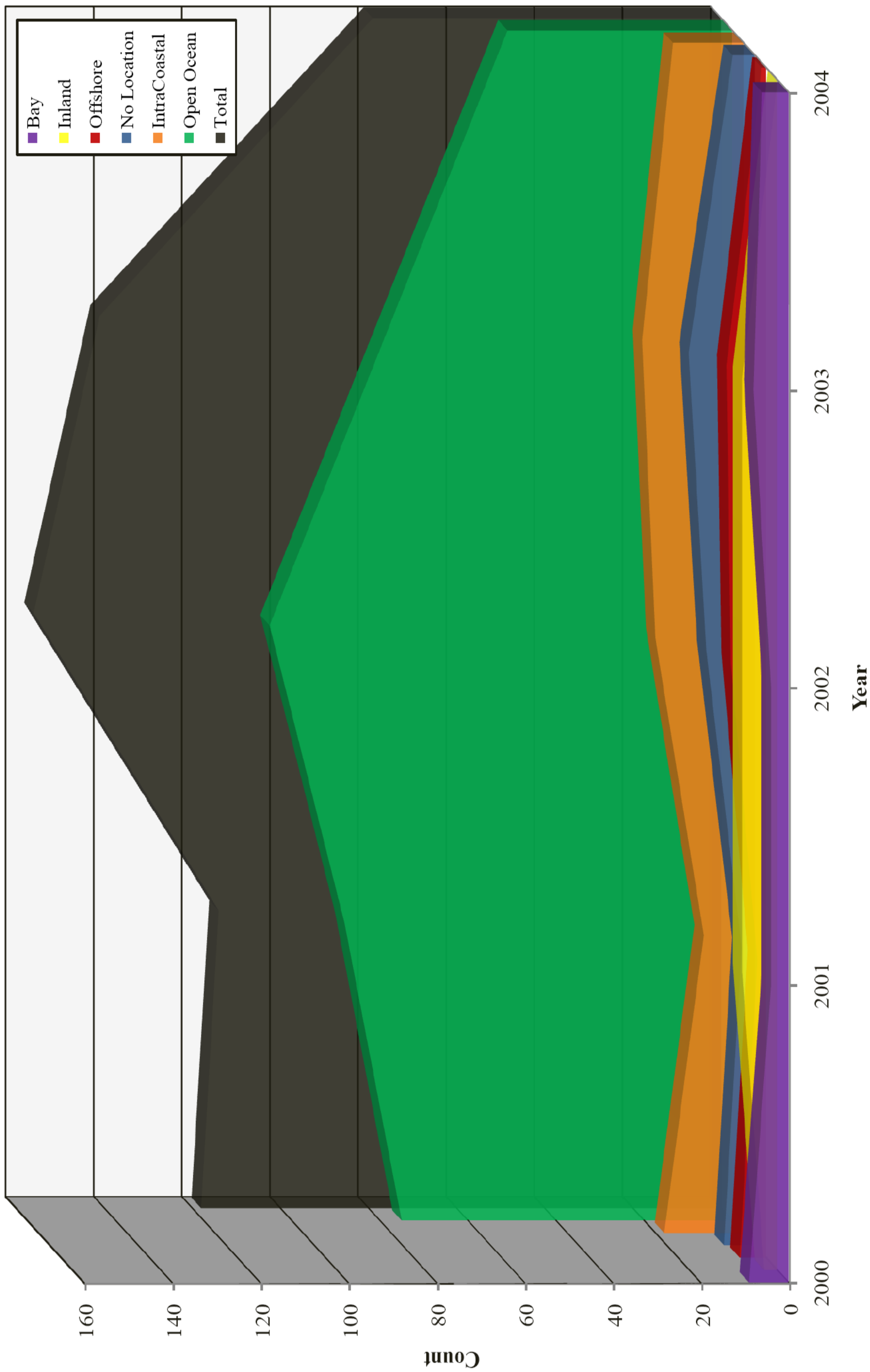

Inland
Offshore
No Location
Bay
IntraCoastal
Open Ocean
Count
0
20
40
60
80
100
120
2000
2001
2002
2003
2004
Year

Figure 6.18 Comparison of TMMSN Marine Mammal Stranding Event Locations from 2000 to 2004 Including Total Event Counts per Year.

Though all locations, except *OpenOcean*, are nominal in rate, the combination of these locations influences the total stranding event counts from 2000 to 2004. The total event shape from starting in 2002 is directly influences by the peak in *OpenOcean* events and the additive counts from the *IntraCoastal*, *Inland*, and *Bay* counts. This same effect is the cause for the large counts in 2003. This range of years is the only incidence where the *OpenOcean* events do not coincide directly with the total stranding events and cannot be attributed to an unusual mortality event as in year 1992.


Count
Year
0
20
40
60
80
100
120
140
160
2000
2001
2002
2003
2004
Bay
Inland
Offshore
No Location
IntraCoastal
Open Ocean
Total

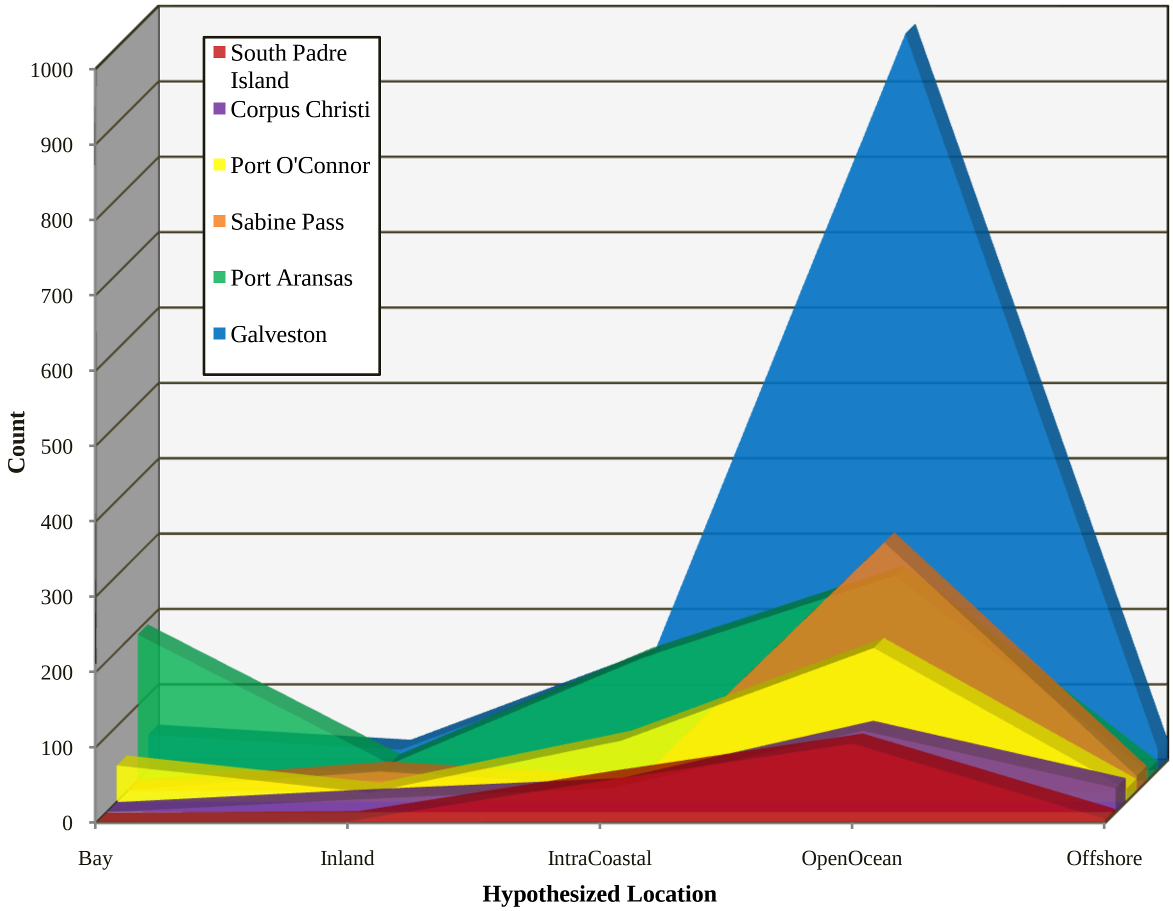


Figure 6.19 TMMSN Stranding Regions Compared to *LocationValue* Designations.

To investigate the validity for spatial locations and the benefit of these location attributes for the TMMSN, the counts for each location were graphed by TMMSN stranding region. If there was no distinction between the additional spatial information, then all regions would experience a proportional similarity in counts for all locations. However, this is not the case, and counts for each location are different for each region. The two noticeable regions are the elevated numbers of *OpenOcean* events in Galveston and the *Bay* events in Port Aransas. The difference in location events supports the notion that stranding rates are geographically influenced by multiple environmental factors, both from the marine and coastal environments.

VITA

Ruth Louise Mullins
Texas A&M University
Department of Oceanography
rmullins@ocean.tamu.edu

Education B.A. Texas A&M University, College Station, TX, 2004
Major: Biology
Minor: Biological Oceanography

Research Cruises/Fieldwork

- Methods Controlling Hypoxia: LUMCON Ship Pelican, 2006, 2007, 2008 for 4 days each: CTD rosette deployment and recovery, plankton tows, water sampling, and record-keeping

- Galapagos Cetacean Survey: Oceanographic Institute of the Ecuadorian Navy ship Rigel, May 2007: Cetacean acoustical surveys and visual behavioral observations using hydrophones and an analogue recorder

- Gulf of Mexico: R/V Gyre, Aug. 2005: Plankton sampling and sediment cores

Publications

- Richardson T.L., J.L. Pinckney, A.M. Ciotti, and R.L. Mullins. Photosynthesis and growth rates of the toxic dinoflagellate *Karenia brevis* (dinophyceae). Journal of Phycology, *In review* 2005.

Skills, Awards, Professional Societies

NSF GK-12 Fellowship, 2008 – 2009
Buck Weirus Spirit Award, 2008

Graduate Course Certificates in Geographical Information Systems (GIS) and Ocean Observing Systems

Beta Beta Beta Honor Society , Member
Graduate Student Council, Executive Vice President 2007 - 2008
Oceanography Graduate Council, President 2005 - 2009

PADI SCUBA Open Water