

An Assessment of Sea Turtle, Marine Mammal and Seabird Bycatch in the Wider

Caribbean Region

by

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Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor of Philosophy in the Department of
Environment in the Graduate School
of Duke University

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ABSTRACT

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Abstract

Sea turtles, marine mammals and sea birds are vulnerable to higher mortality rates as a direct function of incidental capture (bycatch) in marine fisheries. Their migratory behavior exposes them to multiple fishing gear types and fishing practices and efforts to understand the rates of interaction between these taxa and fishing necessarily entails analysis of data over large spatial areas (ocean-basin) and multiple types of fishing activities. The acquisition the requisite data, however, requires considerable resources and many regions in the world are data-poor with respect to bycatch, including the Wider Caribbean Region (WCR) in the west central Atlantic Ocean basin. This dissertation presents the results of multiple strategies used to assess sea turtle, marine mammal and seabird bycatch in the WCR, with a particular focus on sea turtle bycatch. The research incorporated a synthetic review of the literature, expert consultation, statistical techniques, and geospatial analyses to assess the bycatch seascape for the region. I conclude that sea turtle bycatch in the WCR is significantly linked to turtle rookeries, especially those on the continental land mass and in the southern section of the Caribbean basin, in large part because of the near shore artisanal nature of the fisheries and the importance of these habitats for foraging and reproduction. The limited information on marine mammal bycatch does not permit robust inferences, but it clearly identifies threats to at least one vulnerable marine

mammal species, the tucuxi (*Sotalia fluviatilis*). Information on seabird bycatch was even more limited; the most vulnerable seabird populations occur in the higher latitudes (temperate zones) while the seabird populations in the WCR face significant threats from habitat loss and over-exploitation. This dissertation proposes specific recommendations for improving and advancing the information base for a regional, ecosystem-level management and mitigation of bycatch.

Dedication

To my parent, Jim and Hyacinth Kerr and to my husband Ronald.

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1. Overview

Fishing is a vital human activity, a source of food and revenue for millions.

Capture fisheries contribute an estimated \$225-\$250 billion dollars annually to the world economy (sensu Dyck & Sumaila 2010) and ensuring the sustainability of marine fisheries is therefore essential to global food security and stability. Fishing gear is not perfectly selective, and the removal of large quantities of unwanted or unusable catch (bycatch) hinders the sustainability of marine capture fisheries. The ecological, economic and social costs of bycatch in fishing activity are increasingly untenable to governments, fishing interests, marine scientists and ocean activists, and of course the fishers and seafood consumers, many of whom face shortfalls and increasing prices. The concern and efforts to mitigate discards and reduce the mortality of non-target catch arise from an increased understanding of the potential and realized impacts of fisheries on marine ecosystems (Crowder & Murawski 1998; Soykan *et al.* 2008). Addressing the issue of bycatch is fundamental to maintaining marine biodiversity.

My dissertation research has its genesis in Project GloBAL, the Global Bycatch Assessment of Long-lived Species. Project GloBAL undertook the first global multi-taxa (sea turtle, marine mammal and seabirds), multi-gear assessment of fisheries bycatch. It became evident the quantity and type of information available varied considerably between the ocean basins that were the regional units of the global analysis. Among the

12 Project Global regions the west Central Atlantic (wider Caribbean region) had limited published data on sea turtle, marine mammal and seabird bycatch. In undertaking the analysis of the wider Caribbean, I combined my interest in developing tools and methods for assessment for data-poor systems with the goal of advancing the state of knowledge of bycatch of air breathing vertebrates in that region.

The chapters in my dissertation demonstrate the multiple methodologies and approaches that were used to categorize the wider Caribbean region. In chapter 2, information synthesis, expert consultation and the use of rapid bycatch assessment methods (Moore *et al.* 2010) summarized the state of bycatch knowledge of the region. In Chapters 3 and 4 I report on the use of regression techniques to develop predictive models for fishery and leatherback turtle (*Dermochelys coriacea*) interactions. I offer recommendations in chapter 5 for actions that can improve the information base for managing and mitigating bycatch in the Caribbean.

The management and conservation of the world's oceans require synthesis of spatial data on the cumulative impacts of human activities on marine ecosystems. Sections of the marine environment in the wider Caribbean have some of the highest estimated impacts (Halpern *et al.* 2008). Integrating my research with the assessments from that study will facilitate an ecosystem-based approach to the ecosystem management in the Caribbean.

At the core of coastal and marine ecosystem management in the Caribbean is the management of small scale fisheries. The importance of the nearshore environment for bycatch in coastal fisheries suggests that targeted spatiotemporal management in these areas should be considered. This would fit with developing marine spatial planning (MSP) in the region. Given the diversity and geopolitical complexity of the region, efforts to implement (MSP) would perhaps be most feasible at the ecoregional (*sensu* Spalding *et al.* 2007) level , but Caribbean examples exists for MSP approaches at both levels (Fanning *et al.* 2007; Ogden 2010).

2. Sea turtle, marine mammal bycatch in the wider Caribbean

2.1 Introduction

Effective wildlife management must be undertaken at spatial scales comparable to the distribution of the focal species (Wiens 1989). Highly migratory marine taxa (e.g., marine mammals, seabirds, and sea turtles) regularly traverse ocean basins to forage or reproduce. Therefore managing threats to these taxa such as bycatch in fisheries requires large-scale, basin-wide assessments (Watson *et al.* 2003; Lewison *et al.* 2004b). Effective ecosystem-based wildlife management must also include a multi-taxa approach as mitigation of a threat to one species can lead to increased stress on another. Highly-migratory marine species often interact with multiple fisheries and gear types and many fisheries capture multiple species (Moore *et al.* 2009). As such, it is necessary to take a multi-taxa, multi-gear approach to assessments. Together these approaches (i.e., large-scale, multi-taxa, multi-gear) facilitate integrated assessment and mitigation by avoiding actions and policies that reduce bycatch in one habitat or for one species while creating or worsening impacts elsewhere for other species (Lewison *et al.* 2004b).

The assessment of sea turtle, marine mammal, and seabird bycatch in the wider Caribbean region (WCR) is important because the region hosts globally significant populations of these taxa, including several global and regional endemics (Encalada *et al.* 1998; Eckert & Hemphill 2005). Despite its size and diversity, the west central

Atlantic is a relatively data-poor region with respect to bycatch. Bycatch has been investigated for particular parts of the region (e.g. Trinidad and the Guiana-shield nations) and certain fisheries (e.g. industrial or semi-industrial trawls and longlines), but not others, including almost all artisanal fisheries. Regardless of the amount of available data, fishing will proceed and policies that affect fish stocks and marine ecosystems will be implemented. Thus there is immediate need for a large-scale assessment to create a foundation on which to base management, policy, and further research.

My review will provide the preliminary baseline for gauging the population impacts of bycatch on sea turtle, marine mammal populations in the WCR in the extent of the Food and Agriculture Organization's (FAO) Statistical Area 31. My review also advances predictions of bycatch in other data poor regions by examining the relationship between the extent and severity of bycatch with characteristics of the large marine ecosystems (LMEs). The west central Atlantic, encompassing four LMEs and two semi-enclosed seas (the Gulf of Mexico and the Caribbean) is a large, geographically complex area and is ideal for such an analysis (Figure 1).

The LME concept stratifies coastal and marine space on the basis of distinct bathymetry, hydrography, productivity, and trophically-dependent populations (Sherman 1991; Sherman 1993). The LME focus on productivity and oceanography is particularly useful when examining fishery-driven processes. Indeed 95% of the worlds' marine fisheries yield (by weight) is estimated to occur within the boundaries of the

LMEs (Sherman & Duda 1999). LMEs are the spatial strata adopted for mapping FAO's global fish catch database, providing an ecological complement to FAO's stratification of the oceans into 19 fishing areas for analysis of global marine fish catch (Pauly *et al.* 2000).

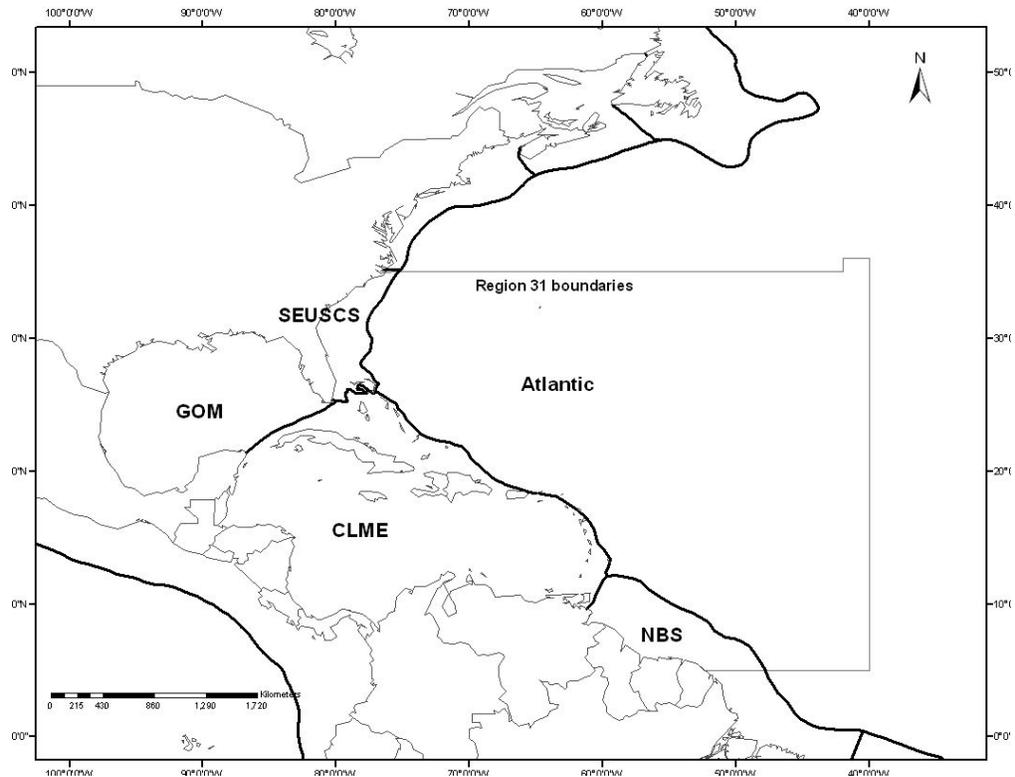


Figure 2.1: Map of the wider Caribbean region (WCR) and the associated large marine Ecosystems (LMEs) and FAO region 31 boundaries.

The LME concept has gained acceptance as an important and meaningful tool and has also been endorsed by major development agencies such as the Global Environment Facility, UNEP, and the World Bank as the framework for several international development projects (Pauly *et al.* 2000). LME level monitoring and evaluation has also been advanced as a key objective by the 8th session of the IOC-UNEP-IUCN- NOAA consultative meeting (UNESCO 2006).

2.1.1 Overview of Caribbean fisheries

The fisheries of the wider Caribbean are diverse, multi-species, and predominantly artisanal (estimated as 78 % and 94 %, of fishing effort for continental and insular territories respectively, Dunn *et al.* 2010). Inshore fisheries are fully or over-exploited and many nations have sought to increase the use of offshore pelagic resources through longline fishing and fish aggregating device technologies (Gomes *et al.* 1998). Most of the artisanal fishing fleet in the WCR, especially in the GOM and CLME employ varied hook and line gear for some portion of their fishing effort. The most valuable fisheries are the invertebrate fisheries (Theile 2001), including spiny lobster (*Panulirus* spp.), Queen Conch (*Strombus gigas*), and penaeid shrimp (*Litopenaeus*, *Farfantepenaeus*, *Xiphopenaeus* sp.) fisheries. Many of these are large, commercial operations and along with the pelagic longline fisheries for tunas and swordfish comprise the main industrial fisheries in the region. Table 2.1 provides a brief summary.

Table 2.1: Summary of major gear types in WCR fisheries.

Fishery	Target	Areas	Gear	Description
Industrial longlines	Swordfish (<i>Xiphias gladius</i>) and tunas (yellowfin (<i>Thunnus albacares</i>), Albacore(<i>T.</i>	Mainly in GOM, SEUSCS, southern CLME and the Atlantic areas	Mechanized longlines, 30-70 km in length	Multiple national fleets, including the distant water fleets (Taiwan,

Table 2.1 continued.

Fishery	Target	Areas	Gear	Description
	<i>alalunga</i>), Bigeye (<i>T. obesus</i>) and skipjack (<i>Katsuwonus</i> <i>pelamis</i>)			Korea, Japan), the US, Mexico, Cuba and Venezuela
Artisanal hook and line	Serranids (groupers) Lutjanids(snappers); Carangids(jacks), elasmobranchs, mackerels(Scombri ds), tunas and dolphinfish (<i>Coryphaena</i>), Octopus	All; reef and hard-bottom areas, muddy, soft-bottom substrates	Hand lines, pole , mechanized/ semi mechanized longlines, vertical longlines, bottom-set or anchored longlines	Highly variable. Artisanal longlines vary from 1 -30 km.
Industrial trawl fisheries	Penaeid shrimp (<i>Litopenaeus</i> , <i>Farfantepenaeus</i> , <i>Xiphopenaeus</i>)	Continental shelf of all LMEs	Mechanized; twin otter trawls	Industrial trawl fisheries operate similar gear and Turtle Excluder Devices (TEDs) are mandatory for all fisheries
	Flatfish, Gadids	SEUSCS	mid-water and bottom trawls	
Artisanal shrimp fisheries	Penaeid shrimp (<i>Litopenaeus</i> , <i>Farfantepenaeus</i> , <i>Xiphopenaeus</i>)	Continental shelf of all LMEs, some insular territories (e.g. Greater Antilles)	Non- mechanized, nets, traps, seines , pin seines (Guyana)	

Table 2.1 continued.

Fishery	Target	Areas	Gear	Description
Gillnet fisheries	Variable; coastal pelagics (Scombrids, <i>Centropomus</i> Sciaenids(weakfish), catfish, sea turtles, lobsters(<i>Panulirus</i> spp.)	All	monofilament or multifilament nylon mesh, from 5 -17 cm territories	Artisanal, nearshore operations. Three-panel gillnet (or trammel net) has been banned in some territories, but is still used in many areas
Traps	Reef finfish (Scarids, Haemulids), lobster(<i>Panulirus</i> spp.)	All	Antillean " Z" , "S" or "arrowhead" wire mesh traps	The most prevalent gear type, especially un the insular territories
	Blue crab (<i>Callinectes sapidus</i>)	SEUSCS, GOM	Wire mesh crab pot	The blue crab fishery is centered in the mid Atlantic and South Atlantic Bight.

2.1.2 Overview of sea turtles, marine mammals, and seabirds in the Caribbean

Six of the seven sea turtle species occur in the wider Caribbean and the distribution of one, the Kemp's ridley (*Lepidochelys kempii*), rests entirely within the western Atlantic and the second largest aggregation of nesting largest leatherback (*Dermochelys coriacea*) rookeries are in the WCR (Dow *et al.* 2007). The continental

rookeries host the largest nesting numbers, although the Greater Antilles, the US Virgin Islands, and Trinidad also host important colonies for loggerheads (*Caretta caretta*) and leatherbacks and several insular territories include relatively large hawksbill (*Eretmochelys imbricata*) nesting sites. Although several populations of WCR sea turtles represent significant proportions of the species' global numbers and genetic diversity, most populations are depleted compared to historic levels (Bjorndal *et al.* 1999; Meylan & Donnelly 1999). However, rising trends have been assessed in several, mainly small and protected populations (Bräutigam & Eckert 2006). Five of the six sea turtle species in the WCR are Critically Endangered or Endangered under IUCN Red List criteria (IUCN 2006); the olive ridley (*L. olivacea*) has been down listed to the "vulnerable" category (IUCN 2009).

Information on the occurrence and spatial distribution of marine mammals in the WCR is based on limited sightings, but 34 species of extant marine mammals occur in the wider Caribbean, and include seven Mysticete (baleen) whales. A thirty-fifth, the Caribbean Monk seal (*Monachus tropicalis*), the only endemic pinniped, is now considered extinct (Mignucci-Giannoni & Odell 2001).

Very little is known about the status and ecology of most marine mammals in the wider Caribbean (Jefferson & Lynn 1994; Ward & Moscrop 1999), but the region provides highly suitable habitat for several species, including the Stenellid dolphins, (*Stenella* spp.), beaked whales (*Mesoplodon* spp.), and Risso's dolphin (*Grampus griseus*).

Important calving grounds and migratory corridors for humpbacks (*Megaptera novaeangliae*) and other cetaceans occur north of Hispaniola and the Turks and Caicos as well as the Atlantic shores of the Lesser Antillean nations (Ward & Moscrop 1999). Most of the WCR species occur in all of the LMEs, however Tucuxi (*Sotalia fluviatilis*) and the common dolphin (*Delphis capensis*) are limited to the southern basin (NBS) (Amaral *et al.* 2007). The congeneric *D. delphis* is a more temperate species whose distribution is limited to the SEUSCS, while True's beaked whale (*M. mirus*) occurs in the SEUSCS and the northern Caribbean (Jefferson & Schiro 1997; Davis *et al.* 2002).

Seven of the 34 marine mammal species are IUCN Red Listed as of Critically Endangered, Endangered or Vulnerable, but 8 are data deficient (IUCN 2006). Eighteen of the marine mammal species that occur in the wider Caribbean have been recorded as interacting with fishing gear (IUCN 2006). Table 2.2 summarizes the IUCN Red List status of sea turtle, marine mammals, and seabird species of the WCR, by taxa. Appendix I identifies the Red List status for all species of marine mammals, sea turtles and seabirds found in the WCR.

Table 2.2: Summary of IUCN status of WCR sea turtles, marine mammals and seabirds.

IUCN status	Sea turtle	Marine mammal	Seabird	Total
Critically endangered	3		1	4
Endangered	2	4	2	8
Least concern			23	23
Lower risk/conservation dependent		5		5
Lower risk/least concern		6	2	8
Lower risk/not threatened		1		1
Vulnerable	1	3		4
Data deficient		15		15
Total	6	34	27	67

2.2 Methods

2.2.1 Study area

Productivity measures for the LME's demonstrate considerable variability. The productivity of the CLME (<150gC/m²/yr, NOAA 2003) is lower than the other systems, but upwelling along the northern coast of Venezuela and nutrient inputs from the Orinoco and Amazon rivers contribute to relatively high productivity in the southern portions of the Caribbean, influencing the CLME and the highly productive NBS (Table 2.3).

Table 2.3: LMEs of the wider Caribbean Region. LME boundaries are based on Sherman and Duda (1999). Shelf area estimates are based FAO Marine Fishery Resource Report (<http://firms.fao.org/resources/11842>, accessed 4/5/2009). All other estimates are based on the Sea Around Us (2009).

LME	AREA (‘000 km ²)	Shelf area (km ²)	Production (mgC·m ⁻² ·day ⁻¹)	Global coral reefs(%)	Global sea mounts (%)	Shelf area (% of total area)
CLME	3,274.1	630,000	456	7.64	1.4	19.2
GOM	1,536.2	600,000	537	0.44	0.44	39
SEUCS	294.9	110,000	740	0.19	0	37.2
NBS	1,058.5	200,000	1095	0.01	0.067	18.9

The GOM is the second semi-enclosed basin and the western boundary of the North Atlantic. The system is heavily influenced by the upwelling associated with the Loop current, warm core eddies, and the freshwater drainage from an extensive area in Mexico and the US (Tupper *et al.* 2010). The GOM is a class II moderately productive system (<300gC/m²/yr, (Heileman & Rabalais 2009). Only two countries (the US and Mexico) have EEZs within the GOM

The SEUSCS, a moderately productive ecosystem (150-300gC/m²/yr (Aquarone 2009), contains many bays and the second largest estuary in the US (the Albemarle-Pamlico estuary). Here the LME productivity is influenced by upwellings along the Gulf Stream front and intrusions from the Gulf Stream.

2.2.2 Synthesis of existing literature

I conducted a comprehensive survey of extant literature, including peer-reviewed journal articles, grey literature from national and international fisheries

agencies, United Nation Food and Agriculture Organization (FAO) documents, and NGO reports. I also used recent historical information contained in the National Reports presented to the Western Atlantic Turtle Symposia (WATS) in 1983 and 1987 and the national sea turtle recovery action plans (STRAPs) prepared by the Wider Caribbean Sea Turtle Conservation Network (WIDECAST), a volunteer network of sea turtle scientists, managers, and conservationists. I incorporated the WATS national reports into this review as pre-1990 bycatch information as these provide important context for more current data. No equivalent country reports and or region-wide network exists for marine mammals, but I examined reviews of marine mammal bycatch in US fisheries, United Nations Environment Program's (UNEP) Marine Mammal Action Plan Caribbean, and the International Whaling Commission (IWC) reports. From this extensive literature survey I prepared territory by territory synopses, summarizing information on the major fisheries and sea turtles, marine mammal, and sea bird occurrence and bycatch in a standardized format.

I compared bycatch rates of the major gear types across LMEs by compiling all available bycatch rates from 1990-2008. I did not estimate species-specific rates, because of the limited coverage and small bycatch numbers reported by many studies. Gear configuration for industrial trawl fisheries was similar throughout the region, and I standardized bycatch rates for shrimp trawl fisheries as individuals per trawl hour respectively (for standardized 20m head rope). I did not transform the numerous

reported gillnet effort metrics into a common unit, but see Wallace *et al.* (2010) for a global comparison of sea turtle bycatch with standardized effort units.

2.2.3 Consultation/ interviews

I collaborated with regional fisheries biologists, taxon experts, and conservationists to review and improve the accuracy and completeness my synopses of fisheries and my focal taxa. To this end I interviewed and consulted 14 fisheries biologists and managers from 12 member territories of the Caribbean Regional Fisheries Mechanism (CRFM) and with members of WIDECAST.

I supplemented written documentation with new information collected during site visits and with 150 interview-based surveys (Appendix B). These surveys were collected with the assistance of fisheries officers (Jamaica) and protected area staff (Mexico) and sea turtle conservation biologists (Guadeloupe and Trinidad) include interviews in several territories with fishers, fisheries managers, and biologists. The territories (Mexico, Guadeloupe, Jamaica, and Trinidad) provided information on both insular and continental fisheries in the LMEs of the wider Caribbean states.

2.2.4 Longline fisheries catch rates

The US and Venezuelan industrial longline fleets fish across all four LMEs and oceanic areas (hereafter referred to as the “Atlantic”, Figure 1). I therefore conducted a more detailed analysis of industrial longline fisheries observer data. For the US fisheries, I used observer data from the National Marine Fisheries Southeast Fisheries Science

Center's Pelagic Observer Program (POP). Data on the Venezuelan fleet (1991-2006) were extracted from the Venezuelan Pelagic Observer Program (VPLOP) database maintained by the Instituto Oceanográfico de Venezuela, Universidad de Oriente. My analysis included only records within the boundaries of my study region. I analyzed years 1992-2005 for the US fisheries (4801 fishing sets, approx. 3% of the entire fishing effort) and from 1991-2006 for the Venezuelan fisheries (5279 sets, approximately 13% of the fleet's effort). The Venezuelan program did not record marine mammal or seabird interactions. Sea turtle bycatch reporting is not mandatory for the Venezuelan fleet, but observers noted sea turtle interactions and these were added when the database was updated in 2007.

I calculated the mean and variances of bycatch rates (BPUE) for both fleets by area stratum using the delta lognormal method. The delta lognormal estimator is more appropriate than a simple mean because bycatch rates are generally lognormally distributed and bycatch (positive) sets are rare (Garrison 2007). The delta mean bycatch rate for each analytical stratum t , (four LMEs and the Atlantic) is calculated as:

$$C_t = \frac{m_t}{n_t} e^{L_t G(SL_t^2)}$$

Where:

m_t is the number of sets with positive bycatch,

n_t is the total number of observed sets,

L_t is the mean of the log transformed number of animals taken per 1000 hooks when bycatch occurred,

SL_t^2 is the observed sample variance of the log transformed bycatch rate and

G is the cumulative probability function from the Poisson distribution.

Garrison (2007) provides additional details on calculations for G and the variance and 95% confidence intervals of G_t .

I estimated total bycatch with 95% confidence intervals for the US fisheries by multiplying the estimated lognormal rate by the estimated total effort obtained from self-reported vessel logbook data (Southeast Fisheries Science Center 2006). Estimates of total effort for the Venezuelan fishery have not been reported beyond 2000 (Marcano *et al.* 2004a) and I therefore calculated fleet-wide sea turtle bycatch by the Venezuelan fisheries as a simple estimate of the proportion of the fleet observed (approximately 13%, Arocha 2007).

The relative rarity and variability in bycatch events can generate highly skewed bycatch estimates when observer coverage is very low (Sims *et al.* 2008). I therefore applied a weighting based on the median proportion of observer effort that the BPUE estimate represents. In an approach similar to Wallace *et al.* (2010), I computed a weighted median BPUE for sea turtles and marine mammals. A median bycatch rate was calculated based on annual take (individuals taken per 1000 hooks) observed for each fleet-stratum combination. This rate was weighted against the median proportion

of total observer coverage that the area received. There were no recorded observations of marine mammals by the Venezuela program, and the observed effort for those calculations was confined to the US POP.

2.3 Results

2.3.1 Recent historical information on bycatch

There is considerably more documentation regarding sea turtle bycatch before 1990 than for marine mammals and seabirds. Latin American and Caribbean territories are fortunate to have had some of the earliest efforts at regional sea turtle research and management. This is exemplified by the two Western Atlantic Sea Turtle Symposia (WATS I and WATS II) in 1983 and 1987 respectively and the preparation of national STRAPs (Sea Turtle Recovery Action Plans) by WIDECAS. At WATS 1, 13 countries provided data on incidental capture, but bycatch estimates were provided by only 5 nations and there are indications that confusion existed with regard to the definition of bycatch (e.g. spear gun fishing being listed among bycatch gear). In 1987, 16 territories provided updates on incidental catch in their national reports to the Second Western Atlantic Turtle (WATS II) Symposium (Weber 1987). The WATS II national reports provide evidence for large annual takes by trawl fisheries on the continental margins (e.g., 700 in Belize, 1000 in Honduras). Sea turtle bycatch in gillnets, and seine nets was also widely cited. The 1987 national reports to WATS 2 demonstrate the continued difficulty in discriminating incidental capture from opportunistic take, such as hand

capture of turtles during trolling for large pelagics as reported by St. Vincent and the Grenadines.

Placing current bycatch levels for marine mammals in a historical context is more challenging. The data for marine mammal bycatch prior to 1990 is limited mainly to US and Japanese fisheries (Northridge 1991). Information from other Caribbean fisheries has previously been summarized (Van Waerebeek & Reyes 1990; Vidal *et al.* 1994; Ward & Moscrop 1999). Right whales (*Eubalaena glacialis*) or humpback whales (*Megaptera novaeangliae*) have been taken in US fisheries in the past, but no recent interactions have been recorded.

2.3.2 Bycatch information since 1990

2.3.2.1 Longline fisheries

US longline vessels range throughout the west central Atlantic, with most effort concentrated in the mid and South Atlantic Bight, extending into the north Atlantic (Figure 2.2).

The Venezuelan fleet operates primarily in the southern portion of the basin (CLME) and in the Atlantic off the continental shelf slope along the Antillean arc (CLME and NBS). The fishing zones of the two fleets overlap most in the area north of Puerto Rico. The Mexican fleet developed in the 1980s, primarily targets yellowfin tuna, *Thunnus albacares* and operates in the EEZ of Mexico, with sporadic activity in the Caribbean (Gonzalez-Ania *et al.* 1998). The Mexican vessels average 22 m in length and

trip duration 15-20 days and their fishing methods are similar that of the US, (Arenas Fuentes & Jiménez Badillo 2004)

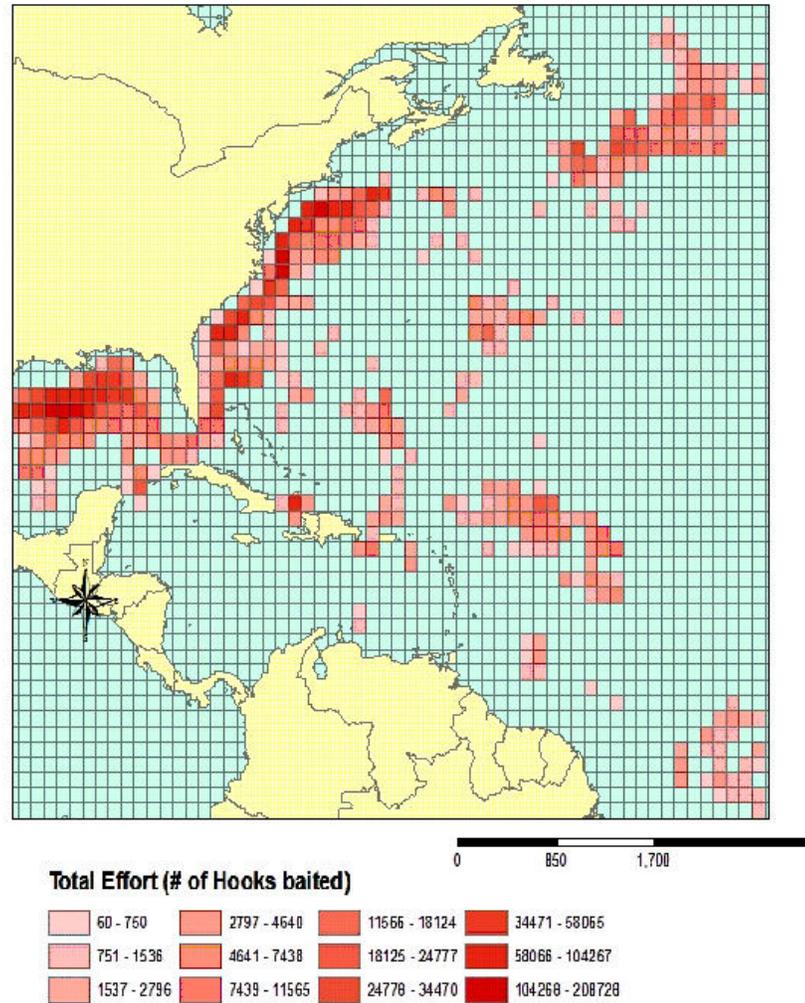


Figure 2.2: Distribution of observed fishing effort (hooks) of the US, 1992-2005. (Source: Project GloBAL).

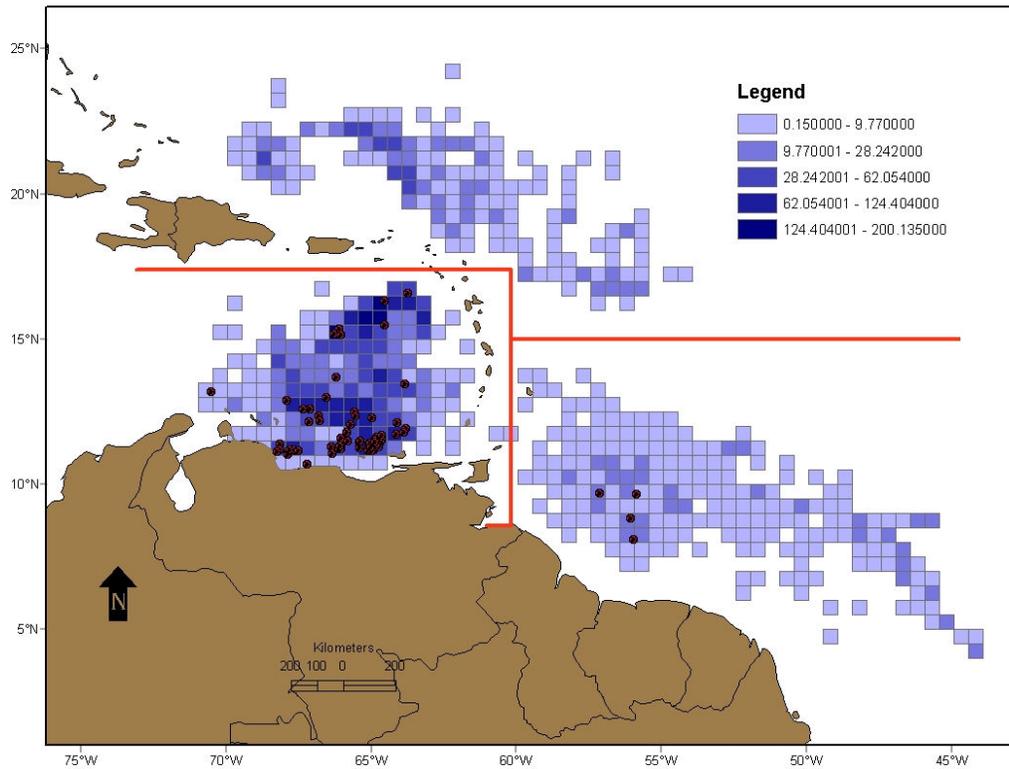


Figure 2.3: Observed fishing effort, Venezuelan Pelagic Longline Observer Program, 1991-2006. Effort measured in thousands of hooks.

All 6 species of sea turtles, at least 9 marine mammal species and 3 species of seabirds are caught incidentally by industrial pelagic longline fisheries (Table 2.4). While loggerheads and leatherback sea turtles dominate the interactions in the US vessels, greens and hawksbills are larger components of bycatch in other fleets (Figure 2.4)

Table 2.4: Summary of bycatch species and associated gear

Species	Scientific name	Industrial longlines	Other hook and line gear	Gear			Traps
				Trawls	Gillnets	Other net gear	
Loggerhead turtle	<i>Caretta caretta</i>	Y	Y	Y	Y		
Green turtle	<i>Chelonia mydas</i>	Y		Y	Y	Y	
Hawksbill turtle	<i>Eretmochelys imbricata</i>	Y	Y	Y	Y		Y
Kemp's ridley turtle	<i>Lepidochelys kempii</i>	Y		Y		Y	
Olive ridley turtle	<i>Lepidochelys olivacea</i>	Y		Y	Y		
Leatherback turtle	<i>Dermochelys coriacea</i>	Y		Y	Y		Y
Common dolphin	<i>Delphinus delphis</i>						
Long beaked common dolphin	<i>Delphinus capensis</i>						
	<i>Globicephala</i>						
Pilot whale	<i>macrorhynchus</i>	Y		Y			
Risso's dolphin	<i>Grampus griseus</i>	Y					
Pygmy sperm whale	<i>Kogia breviceps</i>	Y					
Beaked whales	<i>Mesoplodon spp.</i>	Y					
	<i>Eubalaena</i>						
Right whale	<i>glacialis</i>	Y					
Killer whale	<i>Orcinus orca</i>	Y					
Tucuxi	<i>Sotalia fluviialis</i>				Y		
Pantropical spotted dolphin	<i>Stenella attenuata</i>	Y					
Atlantic spotted dolphin	<i>Stenella frontalis</i>	Y			Y		
Spinner dolphin	<i>Stenella longirostris</i>	Y					

Table 2.4 continued.

Species	Scientific name	Industrial longlines	Other hook and line gear	Gear			Traps
				Trawls	Gillnets	Other net gear	
Stripped dolphin	<i>Stenella coeruleoalba</i>				Y		
Bottlenose dolphin	<i>Tursiops truncatus</i>	Y		Y	Y	Y	
Manatee	<i>Trichechus manatus</i>				Y		
Brown Pelican	<i>Pelecanus occidentalis</i>		Y		Y		
Fregate bird	<i>Fregata magnificens</i>						
Northern gannet	<i>Morus bassanus</i>	Y					
Laughing gull	<i>Larus atricilla</i>	Y	Y				
Herring gull	<i>Larus argentatus</i>	Y					

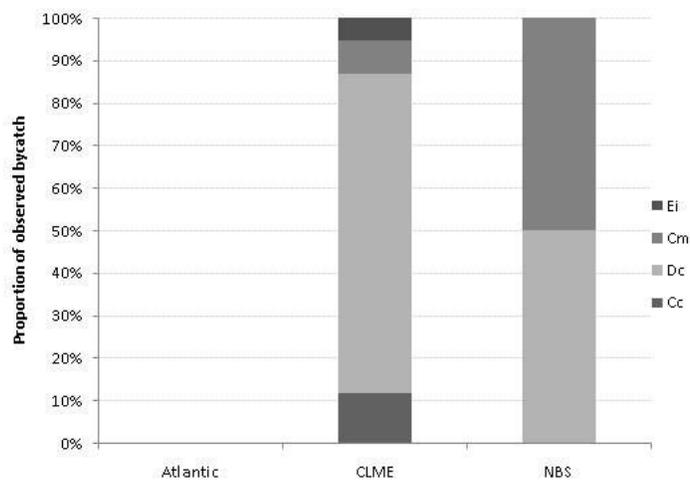
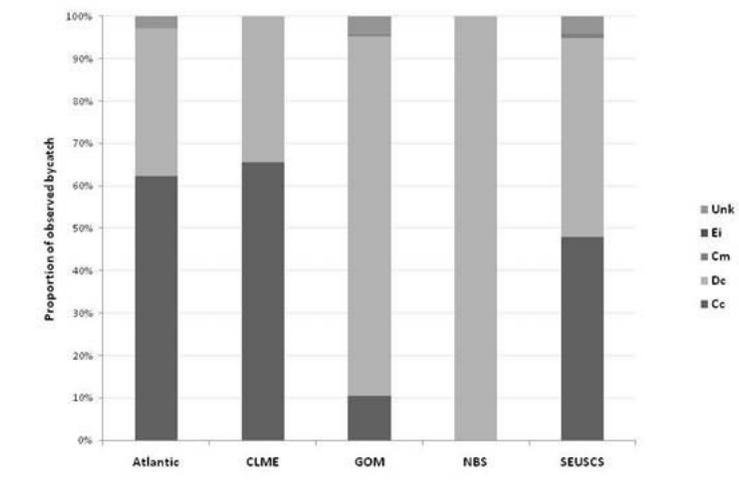


Figure 2.4: Composition of observed sea turtle bycatch in US (upper) and Venezuelan (lower) longline fleets.

Pilot whales (*G. macrorhynchus*), Risso's dolphin (*G. griseus*), beaked whales (*Kogia spp.*) and bottlenose dolphins (*T. truncatus*) were the most frequently taken marine mammal species. The Venezuelan program did not record marine mammal or seabird bycatch, but seabird bycatch was noted as being "occasional" and marine mammals are caught on rare occasions near the offshore Venezuelan islands (Arocha 2007). Only 19 seabirds were observed in the 13 year period in the US fishery, with very few specimens being identified. Hata (2006) estimated the average annual mortality in US Atlantic fisheries was 143 birds (mostly gulls and shearwaters), but noted that this number had been reduced by 2005 to approximately 20-37 animals per year

I calculated bycatch rates and total bycatch estimates for the US fleet based using the delta lognormal method for the five strata within the WCR (four LMEs and the Atlantic). My estimate of total bycatch in the US longline fleet for the period 1992-2005 is 11,888 sea turtles (95% confidence interval 8,554-16,523) and 708 marine mammals (565-891). Between 1991 and 2006, the Venezuelan fleet bycatch total estimate is 1,899 turtles, assuming a 13% observer coverage (Arocha 2007) and that the observer coverage in each LME reflected this proportion of the fishing effort.

Table 2.5 summarizes those estimates and the sea turtle bycatch rates identified in other longline fisheries in the WCR.

Table 2.5 continued.

Fleet	Period	Area	Observed effort ('000 hooks)	Total effort by fishery	Observed bycatch (turtles)	Count (by species)	BPUÉ	Total estimated bycatch	Source
	1992-1995	SEUSCS	569.13	14,737.22	9	47 46 1 4	0.18	2652.7	<i>C. caretta</i> <i>D. coriacea</i> <i>C. mydas</i> <i>Unknown</i>
	1991-2006	Atlantic	1952.79		0	0	0	0	2
		CLME	4875.65		76	9 57 6 4	0.04	1500	<i>C. caretta</i> <i>D. coriacea</i> <i>C. mydas</i> <i>E. imbricata</i>
		NBS	431.74		4	2 2	0.12	399	<i>D. coriacea</i> <i>C. mydas</i>
Mexico	1992-1994	GOM	2156.4			2	0.0097	Total: 1899	3
Anguilla	1997	CLME	53.47		2	2	0.037		<i>D. coriacea</i> 4

Venezuela
27

Table 2.5 continued.

Fleet	Period	Area	Observed effort ('000 hooks)	Total effort by fishery	Observed bycatch (turtles)	Count (by species)	BPUE	Total estimated bycatch	Source
Bermuda	2007	Atlantic			4	4 <i>C. caretta</i>			5

The highest bycatch rates for sea turtles and marine mammals occurred in the Atlantic and CLME respectively. The relative ranking of the LME's was the same for sea turtles alone and all taxa combined, indicating the estimates are driven by the more common sea turtle bycatch.. However, when the estimates were weighted by the median proportion of observer effort they represent, then a different pattern occurs. Bycatch rates are highest for the GOM and SEUSCS for both sea turtles and marine mammals (Figure 2.5).

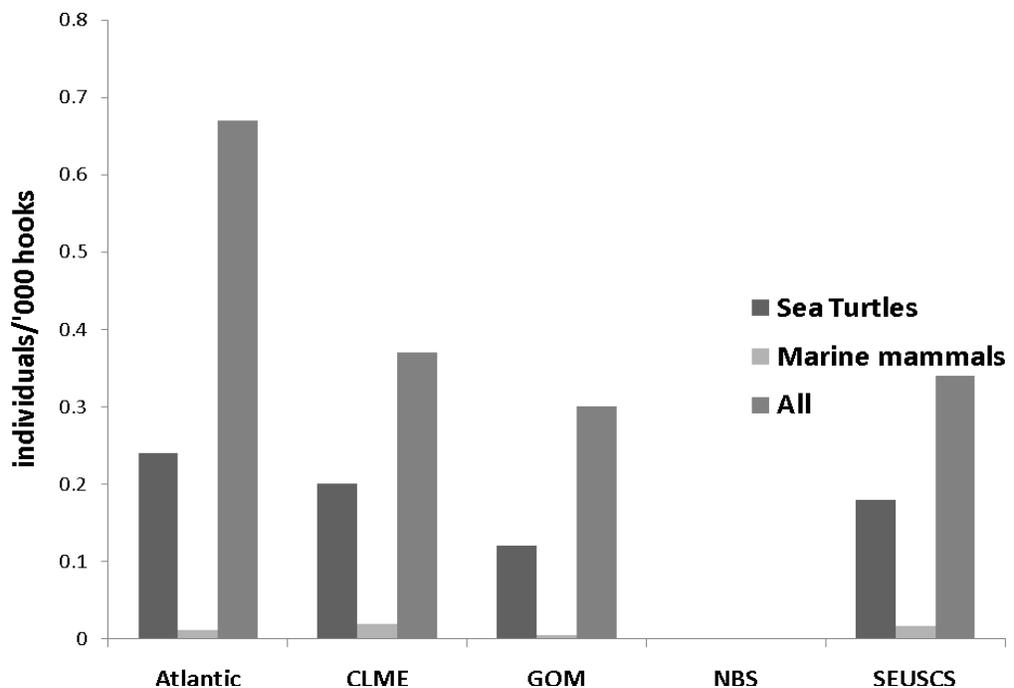


Figure 2.5: Observed US longline bycatch rates (delta lognormal estimates) for sea turtles, marine mammals and all three taxa combined, 1992-2005. Seabird bycatch did not occur in several LMEs in multiple years and was not estimated separately.

In a similar vein, average bycatch rates in the US fleet in the CLME are an order of magnitude higher than those observed in the Venezuelan fishery; however applying a weighted median to adjust for the relatively greater coverage of the CLME by the Venezuelan program suggests that these rates are actually comparable (Figure 2.6).

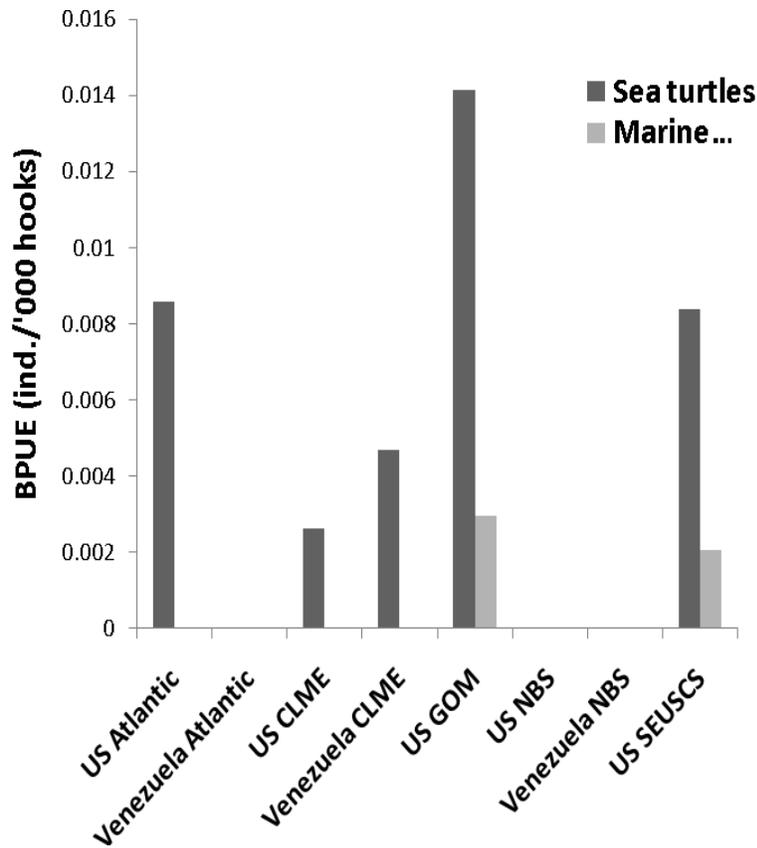


Figure 2.6: Median bycatch rates (1992-2005) for sea turtles and marine mammals, weighted by the proportion of observer coverage for the Fleet-strata combination. The weighted median annual bycatch rates (BPUE) for sea turtles were calculated by multiplying the median proportion of total annual observer coverage in the fleet-strata by the median annual BPUE. The median proportions for marine mammals were calculated using US observer coverage only, as marine mammals were

not recorded for the Venezuelan fleet. Weighted sea turtle bycatch rates are highest in the GOM and estimated as 0 for the NBS. Non-zero marine mammal rates were obtained in the GOM and SEUSCS.

It should be noted however that there are areas in the Atlantic outside of the LME boundaries that have significant sea turtle and marine mammal bycatch in US fisheries (Figure 2.7). The small number of seabird interactions in the US longline fishery occurred mainly in the SEUSCS and beyond the LMEs in the Atlantic.

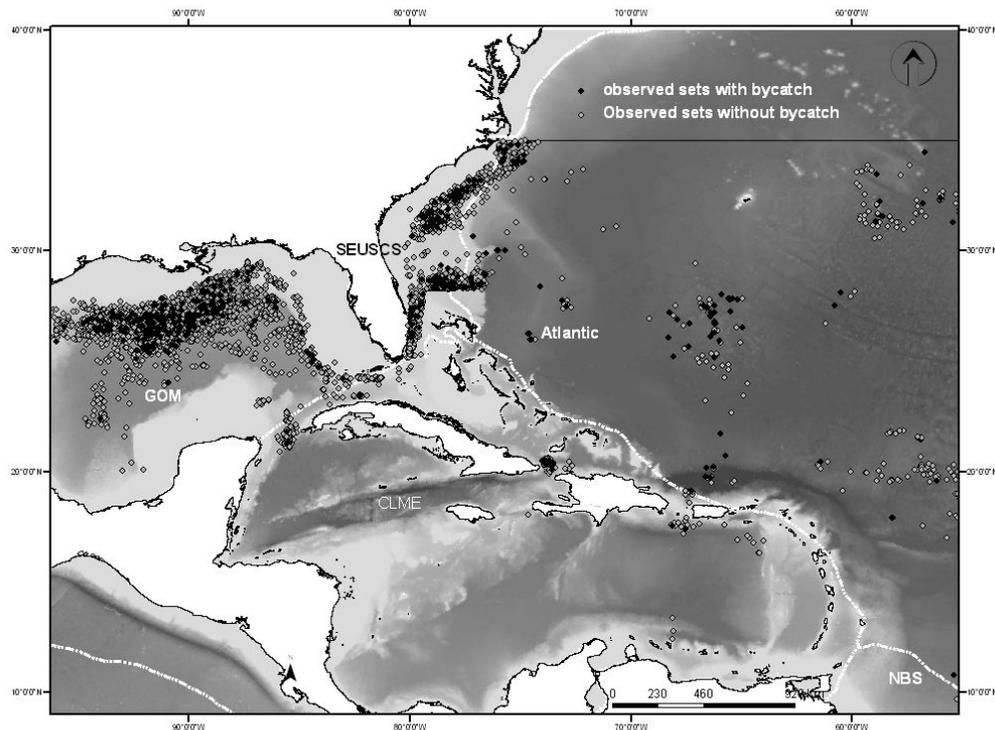


Figure 2.7: Distribution of observed bycatch and zero bycatch sets of marine mammals, seabird and sea turtles in the US pelagic longline fleet, 1992-2005.

There is evidence for higher bycatch and mortality rates in bottom-set longlines targeting demersal resources compared to pelagic or vertical longlines (Richards 2007;

National Marine Fisheries Service Southeast Fisheries Science Center 2008; Wildermann *et al.* 2009). For example, no sea turtles were observed as bycatch in vertical longlines in US fisheries (National Marine Fisheries Service Southeast Fisheries Science Center 2008). Most of the artisanal fishing fleet in the WCR, especially in the GOM and CLME deploy hook and line gear for some portion of the year. However information on artisanal hook and line fisheries is available for a limited number of territories (Table 2.6)

Table 2.6: Information o artisanal longlines in the WCR.

Territory	LME	Bycatch species	Comments	Source
Bonaire	CLME	<i>D. coriacea</i>	Entanglement in float lines	M. Nava (Sea Turtle Conservation Bonaire) pers. com.
Cayman Island	CLME	Not specified	50% commercial fishers reported catching 1-2 turtles /year	
Jamaica	CLME	Not specified	9% of fishers interviewed in 2006 reported sea turtles in hook and line fisheries. A second survey identified <i>L. kempii</i> among the species caught in trolling operations.	(Bjorkland <i>et al.</i> 2008)
Mexico	GOM	Not specified	90% of fishers interviewed reported sea turtle bycatch. High bycatch levels (>10 individuals/year) were reported by 15% of the survey sample.)	(Guzman <i>et al.</i> 2009)

2.3.2.2 Trawl fisheries

All 6 sea turtle species and 4 marine mammal species are taken in trawl fisheries. Sea turtle bycatch assemblages show sub-regional patterns. While data for many trawling nations were not available, those assessed in the late 1990s had an estimated total of 900,000 shrimp trawl fisheries-sea turtle interactions annually, with more than 98% of these occurring in the GOM and the SEUSCS (Table 2.7). The most intense effort occurs in these regions; this effort was estimated to be 6.1 million hours in 2001 (Epperly *et al.* 2002) .

Bycatch rate estimates are higher for the eastern GOM than the western GOM and summer bycatch rates for loggerheads in the Atlantic are the highest reported in the region (Table 2.7). Sea turtle bycatch rates and numbers in shrimp trawl fisheries on the continental margins of the CLME are among the lowest reported. These BPUE's are also 60% lower than those estimates based on extrapolating US Atlantic and GOM rates to trawl fisheries in Central and South America (Henwood *et al.* 1992). Kuruvilla (2001) suggested that low rates may in Trinidad be related to limited spatio-temporal overlap of fisheries and sea turtle migratory corridors. I identified annual estimates, but no catch rates for; Nicaragua (194, Arauz 1996), Cuba (635, Moncada Gavilan *et al.* 2003), Central America ((514, Arauz 1996), Guyana (1300, Tambiah 1994) and Suriname (3200, Tambiah 1994).

Table 2.7: Summary of observed sea turtle bycatch rates in trawl fisheries in the wider Caribbean LMEs, 1990-2008. Rates from observer studies of shrimp trawls standardized to individuals/ trawl hour for a 20m head rope.

Territory	Period	LME	Observed effort	Count	BPUE	Bycatch species	Total estimated bycatch	Reference
French Guiana	1992-1993	NBS	136	6	0.059	<i>L. olivacea</i>	1,000	Gueguen (2000)
Venezuela	1991-2000	CLME /NBS	55,992	64	0.0011	<i>E. imbricata</i>	330	Alio et al. (<i>In Review</i>)
						<i>C. mydas</i>		
						<i>C. caretta</i>		
						<i>D. coriacea</i>		
US	1997-1998	GOM	5,018	26	0.0052	<i>C. caretta</i>	836,481	Epperly et al. (2002)
						<i>L. kempii</i>		
						<i>C. mydas</i> and		
						<i>D. coriacea</i> .		
US	1997-1998	SEUSCS	596.5	274	0.4593	<i>C. Caretta</i>	94,439	Epperly et al. (2002)
						<i>L. kempii</i> ,		
						<i>C. mydas</i> ,		
						<i>D. coriacea</i> .		
US		SEUSCS					800	Epperly et al. (1995)

Table 2.7 continued.

Territory	Period	LME	Observed effort	Count	BPUE	Bycatch species	Total estimated bycatch	Reference
Belize	1990	CLME	-	6	0.0057	4 <i>C. caretta</i>	87	Arauz (1996)
						2 <i>C. mydas</i>		
Honduras	1992-1994	CLME	1,534.50	1	0.0007	1 <i>C. mydas</i>		Arauz (1996)
	2000-2001	CLME	-	-	-	-	619	(Moncada <i>et al.</i> 2003)
Cuba						Mainly <i>Chelonia</i> in shrimp trawls . Unspecified composition in finfish trawls		
Guyana	1994					Mainly <i>L. olivacea</i>	1,300	Tambiah (1994)
Suriname	1998					Mainly <i>L. olivacea</i>	3,200	Tambiah (1994)
Nicaragua	1994					- <i>Unspecified</i>	140	Arauz (1996)

Table 2.7 continued.

Territory	Period	LME	Observed effort	Count	BPUE	Bycatch species	Total estimated bycatch	Reference
Central America	1994		-	-	-	- <i>Unspecified</i>	514	Arauz (1996)

Sea turtle bycatch has also been assessed for the finfish trawl fisheries (Epperly *et al.* 1995) in the South Atlantic and Mid-Atlantic regions. More than a 1000 animals is the annual bycatch estimate for this fishery, with 89-181 of these assessed as lethal takes in 1991 and 1992. Approximately 80% of the observed bycatch occurred south of Cape Hatteras, on the northern edge of the SEUSCS.

Trawl fisheries in Venezuela, Suriname, and French Guiana (Ridoux & Van Canneyt 2006) capture bottlenose dolphins as bycatch. These are the only Caribbean territories where reports exist for marine mammal interactions with the trawl fishery. There are no reports of incidental mortality or injury to marine mammals associated with the US shrimp trawl activity in the northern GOM (Waring *et al.* 2009). I found no other information on marine mammal bycatch in any other GOM trawl fisheries. In the SEUSCS, the entire US Atlantic trawl fisheries captured an estimated 74 pilot whales, 146 common dolphins (*D. delphis*) and 326 Atlantic white sided dolphins (*Lagenorhynchus acutus*) between 2001 and 2005. For the trawl fisheries that operate in the SEUSCS, such as mid-Atlantic trawl fisheries, bottlenose dolphin interactions have been documented (Moore *et al.* 2009; Waring *et al.* 2009).

2.3.2..3 Gillnet fisheries

Existing data indicate that five of the six wider Caribbean sea turtle species are regularly taken in gillnet fisheries. Bycatch has been widely reported by various territories in the WCR and estimates of total bycatch in non-US territories (n=7) total

more than 16,000 sea turtles. This is not surprising as large mesh gillnets and trammel nets were and still are the gear of choice for directed turtle fisheries, an indication of their efficiency in capturing this taxon. In many cases, moratoria or other management measures to restrict turtle fisheries did not decrease the use of the gear, but shifted its deployment to new targets, particularly sharks, rays, lobster and conch. These nets continue to fish turtles, albeit incidentally.

Perhaps more than most other fishing gear, the relative non-selectivity of gillnets produces a bycatch then tends to reflect the relative abundance of the species in the fishing area. Bottom-set gillnets for demersal finfish species, lobster, and conch are more likely to entangle hawksbills and green sea turtles which are more likely to occur in those habitats than other sea turtle species (Aucoin & Leon 2007; Cuevas *et al.* 2009).

In a similar vein, gillnets set in nearshore waters with extensive spatial and temporal overlap with nesting habitat will capture the species that use that area. Trinidad and the Guianas have the largest leatherback nesting population globally and *Dermochelys* dominates the gillnet bycatch in that region. Several thousand animals are caught annually in the drift gillnet fisheries in this area (Chevalier 2001; Hiltermann & Goverse 2004; Delamare 2005; Lee Lum 2006; Livingstone & Downie 2006; Madarie 2006). Historically high rates of egg collection and fishing mortality on olive ridleys have resulted in 90% declines in nesting populations, leave few animals available for capture today. This decline may also explain the disparity between Tambiah's 1994

bycatch estimates of 21,000 turtles (mostly olive ridleys) and more recent estimates of 1200 (e.g. Madarie 2006).

In a study of 8 artisanal fisheries operating out of Campeche (Cuevas *et al.* 2009), large mesh gillnets (exceeding 10 cm) set for rays have the highest bycatch per unit effort. An estimated 20% of sea turtle bycatch occurs in the larger *robalera* gillnet fishery for snook (*Centropomis*) and other finfish. Bycatch is also common in gillnets set for corvina (*Cynoscion* spp.). In the Yucatán, the corvina fishery has the highest proportion of bycatch, followed by *sierra* (*Scomberomorus*) and *lisera* (*Mugil*) fisheries (Cuevas *et al.* 2009). Annual capture in gillnet fisheries in Campeche is estimated to be between 557-1651 hawksbills and catch rates in gillnets were considered higher than trawl fishery rates. The research in the Yucatan peninsula is significant and uncommon because it offers a comparative assessment of bycatch rates and impact within the different gillnet-deploying fisheries, as well as between gillnets, longline and trawl gear.

Sea turtle bycatch occurs in the southeastern US drift gillnet fisheries for sharks, particularly Blacktip (*Carcharhinus limbatus*), *Scomberomorus* (*S. Cavalla* and *S. maculatus*), and barracuda (*Sphyraena barracuda*). This fishery has 100 % observer coverage between November and March because of the spatial overlap with northern right whales (*Eubalaena glacialis*) calving habitat. Table 2.8 summarizes gillnet bycatch rates and takes between 1990 and 2008.

Table 2.8: Sea turtle bycatch estimates in gillnet fisheries in the WCR, 1990-2008.

Territory	Study period	LME	Sample effort	Total effort for the fishery	Bycatch Number	BPUE	Bycatch metric	Bycatch numbers by species	Estimated fishery-wide total (annual)
US	2005-2006	SEUSCS	368 sets	10	0.0271	ind/set	<i>C. caretta</i>		
Trinidad		CLME	126 individual crews	217	6996	30.13	ind/boat/year	<i>D. coriacea</i>	6996
French Guiana	2004	NBS	39 individual crews	147	428	10.97	ind/boat/year	<i>D. coriacea</i>	1604
	2005	NBS	39 individual crews	159	473	12.1	ind/boat/year	50 <i>Cheloniidae</i> 60 Unspecified 387 <i>D. coriacea</i>	1144
Guadeloupe	2002	CLME	NR	NR	1 to 3	ind/net/year	16 <i>Cheloniidae</i>		
	2002	CLME	NR	NR	1 to 2	ind/net/2-3 months	70 Unspecified		500
	2002	CLME	NR	NR	1 to 3	ind/net/year	NR		
	2002	CLME	NR	NR	3 to 6	ind/net/year	NR		

Table 2.8 continued.

Territory	Study period	LME	Sample effort	Total effort for the fishery	Bycatch Number	BPUE	Bycatch metric	Bycatch numbers by species	Estimated fishery-wide total (annual)
	2002	CLME	NR	NR	1 to 3	ind/5-6 nets/6 months	NR		
Trinidad	2005	CLME	NR	NR				<i>D. coriacea</i>	5250
US	2001	SEUSCS	83 trips	244	16	0.1928	ind/trip	14 1 1 3 1 1	<i>D. coriacea</i> <i>C. caretta</i> <i>E. imbricata</i> <i>D. coriacea</i> <i>C. caretta</i> <i>C. caretta</i>
US	2002	SEUSCS	54 trips	221	4	0.0741	ind/trip		
US	1993-1995	SEUSCS	48 trips	334	2	4.16	ind/100 trips		0
Suriname	2006	NBS	1225 vessels/6 months	2322	1160	0.947	ind/boat	<i>D. coriacea</i>	
French Guiana	2000	NBS	94.9 km net hours	NR	13	0.137	ind/km net hour	<i>C. mydas</i> <i>L. olivacea</i> <i>D. coriacea</i>	
	2000	NBS	252.7 km net hours	NR	19	0.0752	ind/km net hour	18 1	<i>D. coriacea</i> <i>C. mydas</i>

Table 2.8 continued.

Territory	Study period	LME	Sample effort	Total effort for the fishery	Bycatch Number	BPUE	Bycatch metric	Bycatch numbers by species	Estimated fishery-wide total (annual)
US		GOM	1428.2 set-hours	1428.2	16	0.0112	ind/set-hour	11 <i>D. coriacea</i>	
US		SEUSCS	196		4	0.0204	catch per set	5 <i>C. mydas</i>	
Martinique	2006	CLME		153,802				<i>C. caretta</i>	600-1500
		CLME	124.8 net km hours	NR	1	0.008	ind/km net hour	<i>E. imbricata</i>	152
Trinidad	1998	CLME	NR			1-2	ind/fishing trip	<i>D. coriacea</i>	1000
Dominican Republic	2006	CLME	61.4 km net hours	NR	4	0.065	ind/km net hour	<i>E. imbricata</i>	
Mexico	2007-2008	GOM	28 trips	NR	1	0.012	ind/trip	<i>E. imbricata</i>	1651

Information on marine mammal interactions is available for very few territories (Table 2.9) and no rates or take estimates were identified. Four, possibly five species including manatees (*Trichechus manatus*) encounter drift gillnets and trammel nets (Carr & Bonde 2000; Chevalier 2001; Bjorkland *et al.* 2008). Gillnets appear to be major threat to at least one species, the tucuxi (*Sotalia fluviatilis*). Chevalier (2001) described the incidental capture of *Sotalia* in drift gillnets in western French Guiana. *Sotalia* is the most common delphinid in the fishing area and fishers described the bycatch of *Sotalia* as infrequent but occurring from time to time. Marine mammal bycatch in the SEUSCS has been documented for mid-Atlantic gillnets fisheries. Since 2000, bottlenose dolphin bycatch has been observed in this fishery in areas south of 35N (Carlson 2001; Carlson & Bethea 2007). All *Tursiops* specimens were discarded dead, in contrast to thirty-three percent of the *S. frontalis* animals.

Table 2.9: Marine mammal bycatch in gillnet fisheries in the WCR. Sources: 1= Bjorkland *et al.* (2008); 2=Espeut (2008); 3= Carr and Bonde (2000); 4=Chevalier (2001); 5= Bouillet *et al.*(2002); 6= Carlson (2001); Carlson & Bethea (2007).

Study year	Territory	LME	Bycatch species	Findings	Reference
2006	Jamaica	CLME	<i>T. truncatus</i> <i>S. coeruleoalba</i> <i>T. manatus</i>)	4% of fishers (n=127) reported bycatch events	1
2007	Jamaica	CLME	<i>T. truncatus</i> ; <i>S. coeruleoalba</i> <i>T. manatus</i>)	4.5% of fishers (n=) report cetacean bycatch	2
1996-1998	Nicaragua	CLME	<i>S. fluviatilis</i>	Incidental capture reported by fishers	3
2000	French Guiana	NBS	<i>S. fluviatilis</i>	Observation of incidental capture in drift gillnet	4
1999-2001	French Guiana	NBS	<i>S. fluviatilis</i>	Estimated fishery related strandings to be 10-15 animals/boat/year	5
2001	USA	SEUSCS	<i>T. truncatus</i>	Highly variable, with several years of no bycatch in Florida or Georgia, and 100% mortality for <i>T. truncatus</i> ; 33% for <i>S. frontalis</i> . Annual estimated take	6, 7

2.3.2.4 Other net gear (Beach seines, purse seines, cast nets, weirs and pound nets)

Pound net fisheries in US fisheries in the GOM and SEUSCS incidentally capture Kemps, loggerhead, and green turtles (Price & Van Salisbury 2007a), however no assessment has been made regarding rates and annual sea turtle take by this fishery.

Beach seines in the mid Atlantic (mainly North Carolina and Virginia) are essentially monofilament gillnets and bycatch species include *T. truncatus*.

2.3.2.5 Trap fisheries:

Entanglement and entrapment of hawksbills and leatherbacks were reported in 8 territories in the CLME. Leatherback bycatch in fish pot float lines maybe widespread but appear to be isolated, singular events. Small hawksbills are reportedly caught in fish traps. Such bycatch is not well described or documented. If such bycatch does occur, the long soak time for this gear will most likely produce very high mortalities.

With respect to marine mammals, bottlenose dolphins entanglement in crab pot float lines has been documented (Noke & Odell 2002). Four to five dolphins per year is the annual estimate of bycatch in crab pots between Florida's Atlantic coast and North Carolina (1994-1998). During 2003, two bottlenose were found entangled in crab pots in South Carolina (Waring *et al.* 2006).

In summary all 6 WCR sea turtle species and at least 16 species of marine mammals and 5 seabird species are documented as bycatch in artisanal and commercial fishing gear, including longlines, gillnet trawls, beach seines and traps. We identified annual estimates of sea turtle bycatch in at least one gear type for 15 territories. We estimate annual bycatch of ~ 37,000 sea turtles for the 14 non-US territories based on the available data (Table 2.10). Leatherback and loggerhead sea turtles were the most widely reported by number of Caribbean territories.

Table 2.10: Annual sea turtle bycatch estimates by WCR territory and gear type (PLL =pelagic longlines, BLL=Bottom-set longlines, TR=Trawls and GN= gillnets), 1990-2008. If an estimate but no specific gear was named, only a total estimate is entered.

Territory	Area	PLL	BLL	TR	GN	Total estimate	Date	Reference
Anguilla	CLME							
Antigua & Barbuda	CLME					100	1992	Fuller et al. (1992)
Aruba	CLME							
Bahamas	CLME							
Barbados	CLME							
Belize	CLME			87		87	1990	(Arauz 1996))
Bermuda	CLME							
Bonaire	CLME							
British Virgin Islands	CLME							
Cayman Islands	CLME					5	2006	J. Blumenthal , pers. com.
Colombia	CLME							
Costa Rica	CLME							
Cuba	CLME					1221	2000-2001	Moncada et al (2003)
Curacao	CLME							
Dominica	CLME					100	2001	(Weidner <i>et al.</i> 2001)
Dominican Republic	CLME							
French Guiana	NBS			1000	274	3748	2004 & 2005	(Delamare 2005)
Grenada	CLME							
Guadeloupe	CLME					500		
Guatemala	CLME							
Guyana	NBS			1300		1300	1994	(Tambiah 1994)

Table 2.10 continued.

Territory	Area	PLL	BLL	TR	GN	Total estimate	Date	Reference
Haiti	CLME							
Honduras	CLME							
Jamaica	CLME							
Martinique	CLME					600		
Mexico (GOM)	GOM		1000 +			>1651	2007-2008	(National Marine Fisheries Service Southeast Fisheries Science Center 2008)
Mexico (CLME)	CLME							
Montserrat	CLME							
Nicaragua	CLME			140		140	1993	Arauz (1996)
Panama	CLME							
Puerto Rico	CLME							
Saba	CLME							
St. Vincent & The Grenadines	CLME							
St. Eustatius	CLME							
St. Kitts & Nevis	CLME							
St. Lucia	CLME							
St. Martin/ St. Maarten	CLME							
Suriname	NBS				1370	1370	2006	(Madarie 2006)
Trinidad & Tobago	CLME				6996	6996	2005	(Lee Lum 2006)
Turks & Caicos	CLME					190		

Table 2.10 continued.

Territory	Area	PLL	BLL	TR	GN	Total estimate	Date	Reference
USA GOM	GOM	5827	1115	835,146		836,481	1992-2005	This assessment
USA CLME	CLME	1126				9	1992-2005	This assessment
USA SEUSCS	SEUSCS	2653		94316		94439	1997-1998	This assessment
US Atlantic	Atlanti	2282						This assessment
US Virgin Islands	CLME							
Venezuela	CLME/NBS	1899		1370	600	2640	1991-2006; 2007/2008	This assessment
Central America	CLME			514			1993	Arauz (1996)

This cross-taxa, cross-gear analysis reveals some consistent patterns across LMEs. Although the gap in information from many insular fisheries precludes definitive conclusions, shelf area as a proportion of LME area appears to correlate with sea turtle (and probably cetacean bycatch numbers as well) in WCR. Based on the available information, gear impacts appear consistent whether single taxa or multi-taxa are considered. We identified significant bycatch numbers outside of the LME boundaries, in a region that corresponds to the Bahamian Ecoregion, one of the 232 marine ecoregions developed by The Nature Conservancy and the World Wildlife Fund (Spalding *et al.* 2007). An assessment at the marine ecoregion level might therefore

useful, but the resolution and quality of the data from non-US fisheries are not of a comparable resolution.

2.4 Discussion

Information on megavertebrate bycatch is largely confined to US and/ or industrial fisheries. In many cases, the information consists of few observations or a limited spatial and temporal sample. Bycatch in some important fisheries (e.g. small scale tuna fisheries) are almost completely un-assessed. Nevertheless, the information reviewed suggests that bycatch in the WCR is widespread and highly variable. The GOM and the SEUSCS dominance in longline bycatch are congruent with LME characteristics such as greater productivity, proportionally larger shelf area relative to total area and for sea turtles, proximity to the major rookeries in the region. Several nesting populations in the Caribbean are increasing and bycatch rates might rise in coastal fisheries adjacent to nesting beaches in these areas (Lewison *et al.* 2003).

Trawl fisheries in the GOM and SEUSCS, gillnet fisheries in proximity to nesting beaches or coral reef and sea grass habitats and longlines targeting demersal resources pose the most significant risk to sea turtles in the WCR. There are however significant mitigation measures developed and required for the aforementioned gear types, with the exception of gillnets.

There are no studies of incidental capture for marine mammals outside of industrial longline fisheries (Mexico/US), US gillnet fisheries, and gillnet fisheries in

French Guiana. Of the 16 species reportedly caught in fisheries, bottlenose dolphins (all four LMEs), pilot whales (CLME, GOM, and SEUSCS), Risso's dolphins (GOM and SEUSCS), tucuxi (NBS and CLME) and beaked whales (Ziphiidae) in the CLME are the species with the most frequent interactions. While the number of marine mammal species bycaught in the NBS is the lowest of the 4 LMEs, bycatch may be contributing to observed tucuxi population declines in that region. Information on other the species is limited to isolated and rare events. While all the WCR turtles taken as bycatch are endangered (IUCN CR, E, V), only 2 of the marine mammal species are vulnerable (humpback whales and manatees). The data-deficient status of many of the other marine mammal species incidentally caught in fishing gear suggests that the full population impact of bycatch on marine mammals in the Caribbean remains unknown.

Marine ecosystems have been intensively modified by human activities and perhaps the bycatch landscape has also been altered. Olive ridleys, once caught in large numbers in trawl and gillnet fisheries off the Guianas, may be a relatively minor component of the bycatch today, due to both TED requirements and the overall decline in the nesting colonies in Suriname (Godfrey & Chevalier 2004). This "ghost of bycatch past" may also explain why 2005 estimates of sea turtle bycatch in Suriname are lower than earlier estimates. In a similar vein, Gosse's 19th century account of large numbers of porpoise bycatch in Jamaica may be a window into changes on coastal delphinid

populations. Such populations have likely already undergone major declines, leaving relatively remnant populations with very low bycatch probability today.

While my assessment elucidates important features of the bycatch landscape for the WCR, I recognize that the analysis compares rates across a broad temporal window (1990-2008). During this time frame, considerable advances have been made, implemented and made mandatory for fisheries, and important shifts in fishing effort and activity have taken place.

My challenge has been to integrate multiple data types to elucidate the bycatch landscape for the air-breathing marine taxa. Bycatch datasets are very limited for most wider Caribbean countries and the reported rates are often based on very small sampling effort. Thus there are no empirically-derived estimates of bycatch for any entire fishery in this region. Bycatch has not been assessed or reported within the context of LME spatial boundaries and my approach required assigning rates and information to the specific LMEs.

It was not possible to estimate gear or species-specific rates from many interview-based studies. Such assessments are also confounded by opportunistic take (such as by scuba divers or spear fishers), especially where directed sea turtle or cetacean fisheries operate. Additionally, the potential economic and political consequences (e.g. export embargoes of bycatch-generating fisheries) are real concerns

for some territories and data from experimental trials or observer programs are not readily available.

While observer programs with adequate vessel coverage provide the most reliable data from which to inform bycatch management (National Marine Fisheries Service Southeast Fisheries Science Center 2008), I demonstrate that a thorough review of literature, expert opinion, and data analysis can elucidate important features of the bycatch landscape.

I conclude from this review that priority areas for further assessment and action are

- invertebrate fisheries that deploy gillnets as the fishing gear
- Gillnet fishing activity in proximity major rookeries or rookeries that support distinctive genetic segments or diversity.
- Bottom-set longlines on the continental margins
- *Sotalia* bycatch in the NBS
- cetacean population assessment and habitat use.

At the 8th session of the IOC-UNEP-IUCN-NOAA consultative meeting on Large Marine Ecosystems, the CLME project identified LME-level monitoring, evaluation, and reporting as a key objective (UNESCO 2006). My research represents the first-ever analysis of bycatch at the ocean-basin scale for the wider Caribbean region.

Megavertebrate bycatch has been assessed in an LME context examined for one other

system, the Benguela LME (Petersen *et al.* 2007; Honig *et al.* 2008) and there are no comparisons between adjacent and oceanographically connected systems as undertaken in this review.

There are increasing efforts within the region to assess and manage bycatch, especially in artisanal fisheries, but greater collaboration between fisheries managers, fisheries biologists, taxon experts, and conservationists is needed to develop and sustain monitoring of air-breathing vertebrate interactions with fisheries. Given the number of legal sea turtle fisheries and the directed cetacean fisheries in the region, assessing sources of mortality for marine turtles and mammals should become a priority for sustainable management of fisheries and ocean resources.

3. The spatial overlap between breeding leatherback sea turtles (*Dermochelys coriacea*) and nearshore fisheries. Bycatch in the Trinidad drift gillnet fisheries.

3.1 Introduction

Incidental capture of non-target species (bycatch) is one of the most pressing challenges to sustainable use of marine resources (Hall *et al.* 2000; Kelleher 2005).

Fisheries bycatch has been identified as a major factor in the decline of several taxa of large vertebrates, including elasmobranchs, marine mammals, sea turtles, and seabirds (Crowder & Murawski 1998; Lewison *et al.* 2004a; Peckham *et al.* 2007). All seven species of sea turtles (families Cheloniidae and Dermochelyidae) are caught incidentally in global fisheries. Wallace *et al.* (2010) estimated that between 1990 and 2008, the number of interactions globally between sea turtles and fishing gear (hooking, entanglements, or capture) exceeded 800,000. The decline of several leatherback populations especially in the Pacific and the species' critically endangered status has been attributed in part to bycatch in fishing gear (Sarti *et al.* 1996; Spotila *et al.* 2000a; Lewison *et al.* 2004b).

Worldwide leatherback bycatch in longline gear alone was estimated to be greater than 50,000 annually (Lewison *et al.* 2004b).

Studies have demonstrated that potentially high bycatch rates occur when sea turtle high-use areas overlap with numerically large near shore fisheries and that bycatch in coastal fisheries represents an emerging threat for leatherbacks (Fossette *et al.*

2008). Because adult leatherbacks enter into tropical waters from northern foraging zones during the nesting season, increasing attention is being focused on understanding the distribution of leatherbacks in waters adjacent to rookeries in relation to environmental covariates and fisheries (Chan *et al.* 1990; Ferraroli *et al.* 2004; James *et al.* 2005a; van de Merwe *et al.* 2009; Shillinger *et al.* 2010). Integrating information on the distribution of fishing, bycatch and leatherback movement is critical in determining the role and extent of spatio-temporal solutions in mitigating the effects of bycatch.

However, information on the distribution and timing of fishing effort and bycatch events lags behind the collection and analysis of remotely-sensed movement and migration data for sea turtles. Independent observations of fishing activity are generally acknowledged as the most precise data type (Kennelly 1999), but the multi-year data required are costly to collect in the dynamic and numerous artisanal fisheries. Consequently, information on the fleet dynamics and fishing effort are unavailable for many fisheries, especially nearshore artisanal fisheries (Dunn *et al.* 2010).

In the wider Caribbean region, information on leatherback bycatch in coastal net fisheries is available from strandings data (Hiltermann & Goverse 2004), interviews of fishers (Delamare 2005; Lee Lum 2006; Madarie 2006) and short term snapshot studies (Chevalier 2001). The lack of independent observations of artisanal fisheries bycatch of leatherbacks has limited the investigation and characterization of high-use areas and bycatch risk. For example, residency time of leatherbacks tagged in the Guianas was

overlaid against broad spatial envelopes defining shrimp and snapper fisheries by depth and distance to shore (Georges *et al.* 2007). Based on this, bycatch risk was assessed relative this overlap, but not quantified because of the unavailability of fishing effort and bycatch.

One wider Caribbean territory and fishery with data on leatherback migration as well as observed bycatch in coastal fisheries does exist is Trinidad in the southern Caribbean (Figure 3.1).

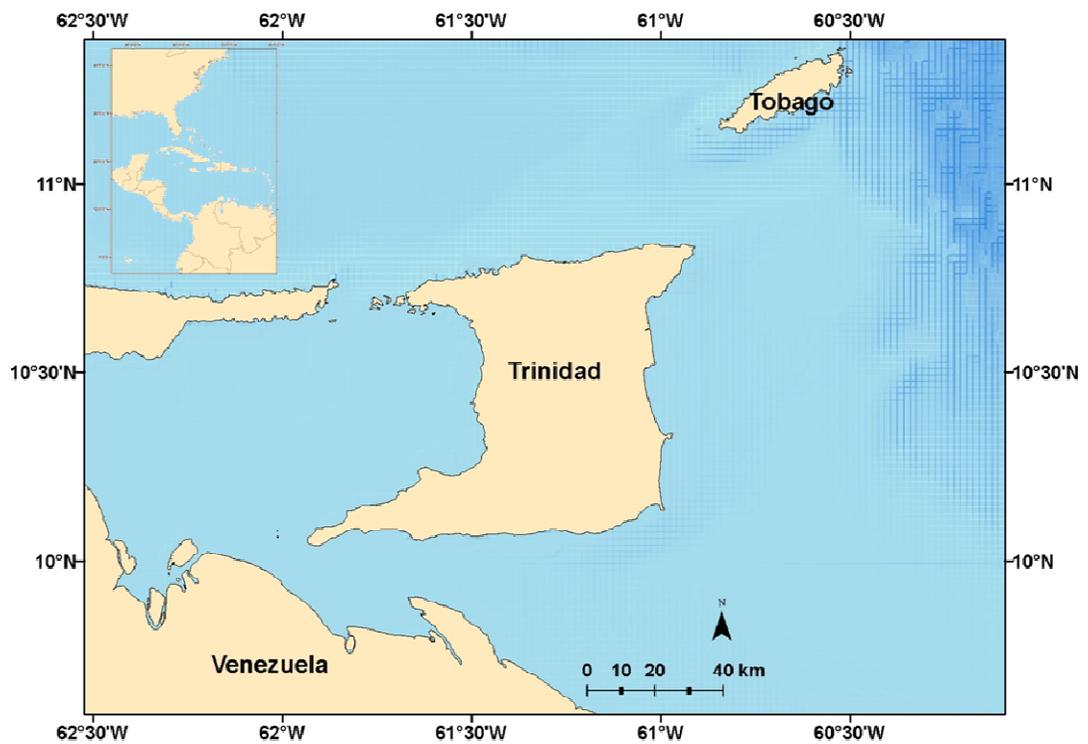


Figure 3.1: Location of Trinidad, larger island of the twin-island Republic of Trinidad and Tobago.

Leatherbacks make their reproductive migrations from high-latitude feeding grounds to coastal waters offshore nesting sites on Trinidad's northern and eastern coasts (Figure 3.2). In this nearshore environment they are vulnerable to artisanal gillnet fisheries (Eckert 2006) and annually more than 3,000 animals are taken as bycatch, with an estimated mortality rate of 30% (Lee Lum 2006). Bycatch in coastal gillnets is a significant source of mortality to reproductive adults on these breeding grounds (Eckert & Lien 1999; Gass 2006) and is considered the single greatest threat to the Trinidadian populations (Eckert 2008).

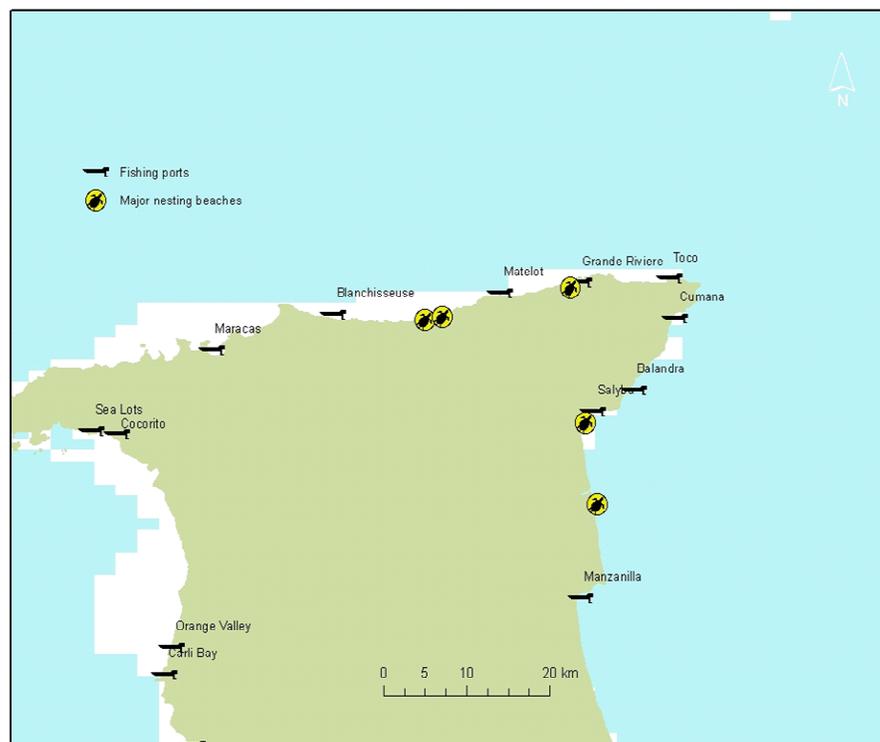


Figure 3.2: Major leatherback nesting beaches are situated in the northeastern corner of Trinidad, in close proximity to major fishing ports. *Source: (Lee Lum 2006; Dow et al. 2007).*

The combined nesting aggregations of Trinidad and the Guianas are among the largest in the wider Caribbean (Eckert 2006; Witt *et al.* 2009). Atlantic populations comprise an estimated 70% of the global leatherback population (Georges *et al.* 2007) and are considered critical to the species' long-term survival. Leatherback bycatch also threatens the financial viability of Trinidadian fisheries and negatively impacts other economic activities such as sea turtle eco-tourism. For these reasons, mitigating sea turtle bycatch is both a global conservation concern and a national priority (Eckert *et al.* 2008).

The global significance of the southern Caribbean leatherback nesting populations and significant levels of bycatch in the artisanal fisheries has catalyzed research on leatherback movement and migration and interaction with fisheries in Trinidad. Eckert (2006) pioneered research on movements around and away from Trinidad using satellite telemetry to track nine post-nesting females between 1995 and 2003 (Figure 3.3). Information on bycatch numbers was collected by direct observation during experimental gear mitigation trials led by the Wider Caribbean Sea Turtle Conservation Network (WIDECAST) researchers (Eckert 2008; Gearhart & Eckert 2009).

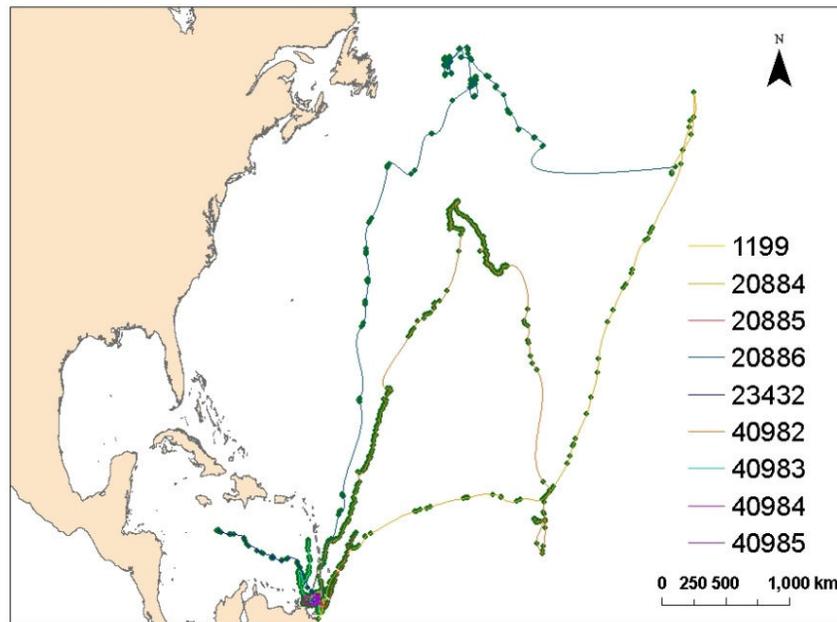


Figure 3.3: Movement of 9 post-nesting leatherbacks tagged at nesting beaches in Trinidad between 1995 and 2003. Tracks drawn from telemetry data (Eckert 2006).

While leatherback bycatch in fisheries and their movement migration away from Trinidad have been analyzed separately (see Eckert 2006; Lee Lum 2006; Eckert 2008; Gearhart & Eckert 2009), no models have been developed to link leatherback high use-areas with bycatch risk for this population. My objective, therefore, is to use the telemetry data and data from experimental gear trials to describe leatherback occurrence and bycatch with respect to eco-geographical variables and, identify and characterize the intersection of core leatherback internesting habitat and gillnet fishing effort in northeast Trinidad. Information on how bycatch rates vary with fishing pressure can assist in

determining the appropriateness of spatially directed management actions. Specifically,

I will conduct:

- i) a preliminary exploration of the frequency of a binary response (presence/ absence, and bycatch / bycatch with respect static and dynamic environmental covariates to assess possible significance as predictor
- ii) kernel density analysis to compare performance of 2 different bandwidth selection methods on kernel home range estimation and to assess the overlap of turtle occurrence and fishing activity by comparing the kernel home ranges of turtles and the fishing activities
 - compare the kernel home ranges of EC and NC turtles with respect to several environmental variables and to their relative overlap with fisheries.

The scope and extent of both the telemetry and fisheries data sets pose challenges with respect to employing common statistical methods for predictive habitat suitability assessment and bycatch modeling. Wildlife telemetry data typically violate the assumptions of regression models because they are spatially and temporally auto-correlated. They often consist of unbalanced, presence-only data assessed against cross-correlated environmental variables (Aarts *et al.* 2008). The small, two-year bycatch dataset assessed in this study was generated from experimental fishing gear trials and did not collect independent samples across the fishery. I therefore conducted kernel

density estimation to identify high use areas for both turtles and the fisheries. Kernel methods are commonly employed in the study of animal home range and habitat selection (Seaman & Powell 1996). Kernel methods employ non-parametric probabilistic density estimation approach to describe the utilization distribution (UD). The UD is the distribution of an animal's position in a plane (Worton 1989) and represents the relative frequency of the location points of an animal over a period of time (Seaman & Powell 1996). This assessment introduces kernel density estimation based on newer approaches to kernel bandwidth selection and examines the home ranges of the telemetered animals based on their location as either primarily east coast or north coast nesting females. The Caribbean Sea is the primary oceanic influence of Trinidad's northern coast, while the Atlantic Ocean is the main influence on the eastern shoreline and there appears to be limited overlap in interesting distribution between north and east coast nesters (S. A. Eckert, Director of Science, WIDECAST, *pers. com.*). These two groups may differ in the extent of their spatial overlap with fisheries and consequently may be exposed to different bycatch risks. Because the information on fisheries was limited to a small number of vessels from two ports, I did not use models of spatial overlap such as the William's spatial overlap index (Williamson 1993) which has been used to delineate fisheries and sea turtle space-use overlap (see McClellan *et al.* 2009). Instead, I extended the kernel home range concept to the behavior of the observed fishers.

To assess which variables may be associated or linked to the overlap of fisheries and leatherback occurrence, I compared the distribution of bycatch from the mitigation trial data and the distribution of leatherbacks from the telemetry data with respect to static and dynamic ecological variables. Research has indicated that both distance-related variables and those representing dynamic ocean conditions influence leatherback movement and use of interesting areas and probability of bycatch (Fossette *et al.* 2009; Shillinger *et al.* 2010). Nesting beaches act as central places during the interesting season because sea turtles make repeated forays from the coastal waters to and from the beach to lay multiple clutches of eggs (Limpus *et al.* 1992; FitzSimmons *et al.* 1997). Leatherbacks tracked during their interesting phase in Costa Rica's Las Baulas National Park in the Pacific disperse in close proximity to the coast (about 10 km) and occupy continental shelf habitats (Shillinger *et al.* 2008) and location and extent of core home ranges for those animals showed little between-year variability. In the Atlantic where animals have demonstrated movements up to hundreds of kilometers distant between nesting events, females monitored in the Guianas were found to spend 40% of their time within a 20 km radius in shallow waters and long distance movement generally involves movement across the continental shelf or to adjacent or neighboring beaches (Eckert 2006; Fossette *et al.* 2007; Georges *et al.* 2007). Thus, despite their lower philopatry, I hypothesize that models including distances from these key central places (nesting beaches, the shoreline, and shelf) may have utility in predicting leatherback occurrence.

Variables representing static distances from central places have also been linked to bycatch probability of loggerheads in the western Mediterranean Sea. Baez *et al.* (2007) discovered that the probability of catching at least one loggerhead bycatch during a fishing operation increased significantly as the distance of the location from the coast increased.

The role of oceanographic correlates such as surface water temperature and processes affecting meso-scale features have been well studied for leatherbacks in their temperate feeding areas (James *et al.* 2005a; Houghton *et al.* 2006; Witt *et al.* 2007) and along post-nesting migration corridors (Shillinger *et al.* 2011). However knowledge of the role of these and other eco-geographical factors on movement and habitat use in the tropical interesting environment is very limited. This study will examine sea surface temperature (SST) and chlorophyll a as potentially important ecological covariates in predicting habitat use. Recent studies have concluded that SST and ocean productivity may play critical, albeit different roles in the interesting habitat of the Pacific and Atlantic leatherback turtles. Pacific leatherbacks may behaviorally thermoregulate by selecting water temperatures to optimize egg production. In contrast, Fossette *et al.* (2009) found gravid leatherbacks in the Guianas remained in the warmer waters perhaps because trophic conditions in the Atlantic may permit leatherbacks to compensate for reproductive costs by feeding between two consecutive nesting events. Thus the timing and spatial habitat use on the tropical breeding grounds may be driven by prey

searching behavior in productive waters. Chlorophyll a, as a proxy for ocean productivity may indicate conditions which favor zooplankton production. Chlorophyll a may also signal areas of enhanced productivity which may be targeted by coastal fisheries and therefore relevant to the risk of capture of turtles by nearshore fisheries.

3.1 Materials and methods

Telemetry data

Eckert (2006) deployed nine satellite transmitters on adult leatherback females emerging to nest on Trinidadian beaches between 1995 and 2003; three in 1995, four in 2003 and one each in 1999 and 2002. Three of the transmitters were placed on animals nesting on Grande Riviere beach in the north and six on nesters at Matura beach on the east coast Figure 3.4. The transmitters were the platform transmitter terminals (PTT) type and designed to work with the Argos CLS system. Eckert (2006) describes the attachment and the deployment of the equipment on the turtles.

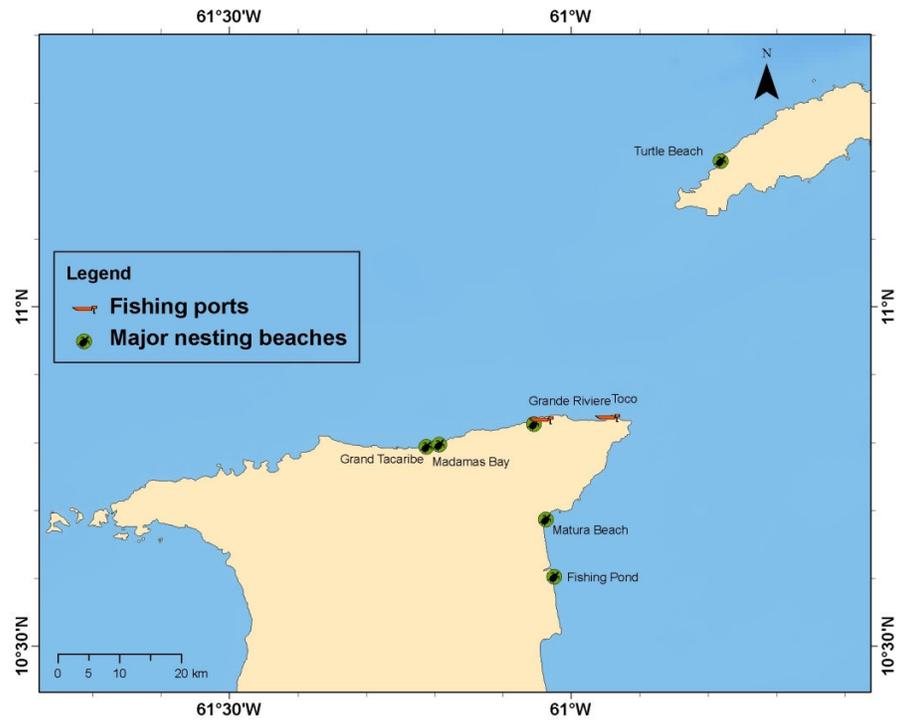


Figure 3.4: Location of main Trinidad leatherback nesting beaches, including deployment sites of satellite tags (Grande Riviere and Matura).

Data processing

The PPT tags transmit location information and other user-programmed data (e.g., leatherback dive profile) to the Argos satellites; however this analysis examines only location data. The data transmitted from the satellite classifies the locations based on the estimated accuracy of the position (location class). Location classes (LC) designated 3, 2, 1, have standard deviations of 150 m, 350 m and 1000m respectively. Positions with LC “0” are unbounded (> 1000 m), while LC “A” and “B” have no positional accuracy. Positions where the location process has failed are identified as LC

“Z” (Argos 2011). Data from the PTTs were distributed using ARGOS Automatic Distribution System via email (Eckert 2006). For this analysis the Argos ASCII-type DIAG data files were read into a data frame using the readDiag function in package Trip (Sumner 2010) in the computing software R (R Development Core Team 2009). A summary of the data by animal ID is provided in (Table 3.1).

Table 3.1: Summary of location data for satellite-tracked turtles tagged while nesting at Grande Riviere (GR) or Matura (M) beaches 1995-2003. Number represent number of location (points) summarized by turtle id and location class.

ID	Tagging Location	Location Class (LC)							TOTAL
		Z	B	A	0	1	2	3	
1199	M	5	166	70	19	25	2	5	292
23432	GR	15	56	52	73	30	7	6	239
40982	M	66	642	418	243	188	89	25	1671
40983	M	13	151	97	82	68	47	25	483
40984	GR	9	254	191	42	75	54	45	670
40985	GR	11	62	41	44	33	16	10	217
20884	M	33	91	60	24	27	7	4	246
20885	M	9	98	54	44	41	26	10	282
20886	M	33	84	72	37	63	26	17	332
TOTAL		194	1604	1055	608	550	274	147	4432

A basic step in filtering telemetry data is the removal of point locations which require unrealistic swimming speeds between successive intervals. However this process may exclude good quality locations for which high travel speeds are the result of two locations being taken very close in time (Hays 2001). Such situations may be particularly important when tracking marine taxa whose diving behavior can result in a large proportion of low quality location classes. Freitas *et al* (2008) developed an

algorithm that included both estimated swim speed and distance between successive locations in filtering telemetry data. This “sdafilter” in the R package “Argosfilter” initially removed all z class locations (location process failed) and then all locations requiring unrealistic swimming speeds between successive locations, unless they were less than five kilometers apart. This procedure allowed for the retention of high quality fixes between two locations taken close to each other in time. Swimming speed threshold was set at 4.7 km/hr (1.1 m/s) for this research, based on swim speeds estimated by Eckert (2006) and Eckert *et al.* (2006). Additionally, no turning angles were specified. The filter returns a vector with the elements "removed" (location removed by the filter), "not" (location not removed) and "end location" (location at the end of the track) for each location. Points labeled “not removed” and “end location” were retained. These retained location data points were mapped in a geographical information system (ArcGIS Version 9.3, ESRI Redlands, CA). Next, I removed improbable locations(e.g., on land, other ocean basins) based on the Global Self-consistent, Hierarchical, High-resolution Shoreline Database (GSHHS) data, Version 1.4 (Wessel & Smith 1996). The remaining dataset contained 2971 records.

I excluded satellite telemetry records outside of the interesting period for those animals (IDs 20884, 20886, 23432, 40982, 40983) tracked beyond that period (see Eckert 2006). Records that included transmissions before the reported deployment date (e.g., equipment testing) or after the reported end of transmission date (possible re-use of

satellite tag) were also removed. The filtered data for the interesting period retained 1,658 locations of the 4,432 original points (Table 3.2).

Table 3.2: Summary of location data for the interesting period. The data were filtered to remove locations where the location process had failed and those requiring unrealistic swim speeds (beyond a threshold) and points on land. For animals tracked beyond the interesting time, locations after egress from the area were also removed.

ID	Tagging							Total
	Location	B	A	0	1	2	3	
1199	M	82	42	9	18	1	3	155
20884	M	37	32	4	7	2	3	85
20885	M	46	35	23	20	17	2	143
20886	M	7	5	3	5	4	1	25
23432	GR	8	9	18	3	1	0	39
40982	M	246	181	68	68	44	8	615
40983	M	60	55	43	36	16	14	224
40984	GR	63	68	32	44	25	7	239
40985	GR	31	24	32	28	13	5	133
Total		580	451	232	229	123	43	1658

To account for spatial and temporal autocorrelation I extracted from the interesting data the single best location per day for each animal. Selection was based initially on location class (LC). A measure of transmitter signal frequency and strength (IQ) was then used to break ties between points which had the same LC. The dataset of best interesting locations (best locations per day dataset) consisted of 142 points (Table 3.3).

Table 3.3: Summary of selected best location per day for each animal. Selection based location class (LC), with ties between points broken by IQ.

ID	Beach	B	A	0	1	2	3	Total
1199	M	6	8	6	13	1	2	36
20884	M	0	1	0	3	0	3	7
20885	M	0	3	1	5	8	2	19
20886	M	0	1	0	1	1	2	5
23432	GR	0	4	8	2	1	0	15
40982	M	0	1	1	7	11	5	25
40983	M	0	0	0	0	3	12	15
40984	GR	0	0	0	0	4	7	11
40985	GR	0	0	0	0	4	5	9
Total		6	18	16	31	33	38	142

To assess the possible significance of environmental variables in predicting leatherback occurrence, I chose random points to represent locations where turtles were not present (pseudo absences). I generated 100 pseudo absences using the Spatial Analyst extension in ArcGIS 9.3. Pseudo absences were generated up to 120 km from the north and east coasts of Trinidad, a value within range of the maximum distance traveled by the turtles between nesting events, and therefore, a biologically relevant extent for investigating species occurrence and predictor variables. I appended these pseudo-absences to the best locations per day data using the ArcGIS “merge” tool. I assigned a value of “0” to the pseudo-absences in a “presence” field. To match pseudo absence points to time-series data of the remotely-accessed oceanographic variables, dates were randomly assigned to the pseudo absence points using the range of dates in the best locations per day dataset.

A summary of data processing steps and number of data points at each stage is depicted in Figure 3.5.

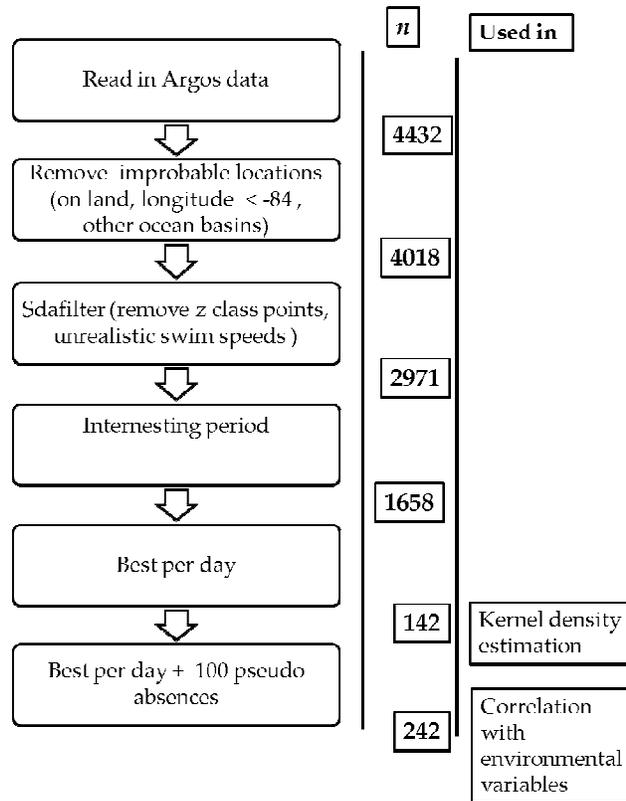


Figure 3.5: Flow chart of processing Argos telemetry data for nesting leatherbacks from Trinidad.

The “best locations per day dataset” is used to describe the probability of finding an animal using kernel density methods. The same data with the inclusion of pseudo absences is also used to assess potentially significant variables relating to leatherback occurrence.

Bycatch data

Bycatch assessment was conducted using data from experimental leatherback bycatch mitigation trials carried out in Trinidad between 2007 and 2009 (Eckert 2008, 2009; Gearhart & Eckert 2009). The experimental trials involved vessels from two northeastern Trinidad fishing ports, one each from Toco and Matelot communities. The fishing crews were paid to fish in a typical manner while onboard observers maintained a fishing log of location, effort, catch, and sea turtle bycatch. These trials were conducted between May and June in 2007-2009 and compared bycatch in the traditional surface-set drift gillnets to a modified gillnet in a matched pair experimental design (Eckert 2008). The height (10 m) of the mesh panel in control nets conforms to the typical configuration of a Trinidadian drift gillnet, while the experimental nets were modified to be half as deep (i.e., 5 m, see Figure 3.6). Panels consisted of 100 m long multifilament nylon nets, and the panels were set in single string format in alternating configuration.

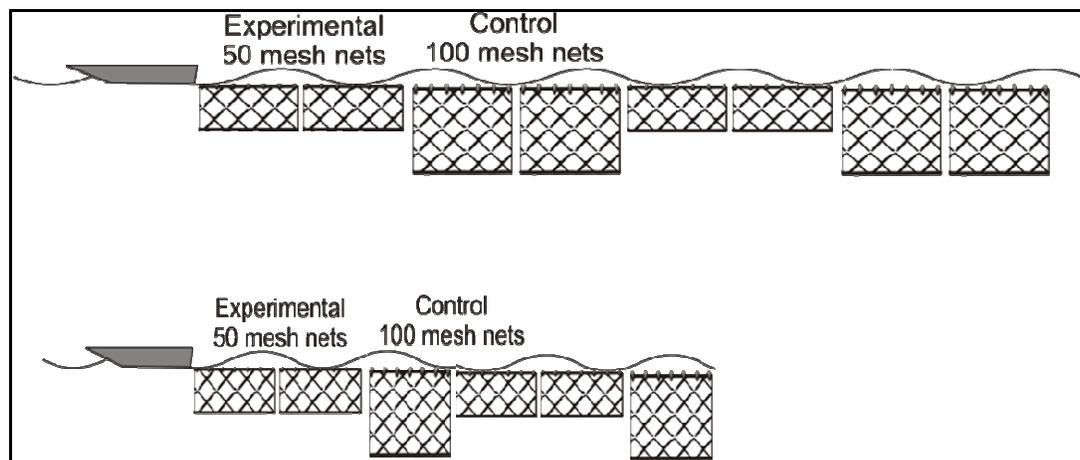


Figure 3.6: Experimental design of field trials to test the effect of modified gillnet configuration on leatherback bycatch. Upper image represents the 2007 design, lower panel the 2009 design. Source: Eckert (2009).

Only data from the control nets were analyzed here because they represent the configuration of the typical fishing gear. The results of the 2007 trials indicated that the reduction in leatherback capture frequency was significantly different between the two ports (Eckert 2008). Fishers suggested that the differential use of net marking lights by fishers from one port may have been responsible for this effect (Gearhart & Eckert 2009). To test this hypothesis the 2008 research design incorporated the presence and type of lights on the boat as a factor in bycatch rates therefore the 2008 results were not included in the analysis. The 2009 experimental design modification produced equal net areas for control and experimental nets.

Data processing

Each year's data was received as an Excel spreadsheet. The information included date of the fishing trip, the location and timing of start and retrieval of each fishing set, (a single deployment and removal of the gear, up to two per trip), duration fished and number and location of turtles caught. The 2009 data format required aggregating the record to create unique sets (the unit of this analysis). Fields were matched and the two spreadsheets were appended together for a multiyear dataset of 252 observed sets (70 in 2007, 182 in 2009).

Points of fishing locations that were more than 60 km away from the port were considered unrealistic range of travel and were removed. Fishing sets where gear deployment and retrieval were more than 10 km apart were also removed as unlikely

distance between start and end locations of a set (S.A. Eckert, *pers. com.*). I used the “distance between points” tool in Hawth Tools (Beyer 2004) to identify these sets which were subsequently excluded. The data processing steps resulted in 211 sets being retained for the bycatch analysis (Figure 3.7).



Figure 3.7: Distribution of fishing sets from experimental mitigation trials, 2007 and 2009.

Environmental predictors

I examined the distribution of turtles and fishing sets with respect to static variables (distance to nesting beach, shelf, and depth) and oceanographic variables (sea surface temperature and chlorophyll a).

Distance variables

I used the WIDECAST Atlas of Western Atlantic Nesting Beaches (Dow *et al.* 2007) and ArcGIS 9.3 to create a point feature shapefile of leatherback nesting beaches. The WIDECAST Atlas consists of geo-referenced information on sea turtle nesting beaches in each wider Caribbean territory, compiled by biologists, government officials and informed community leaders. The latitude and longitude coordinates for each point represents the approximate mid-point of the nesting beach. I used ArcGIS 9.3 to create 1 km x 1 km grid cell raster maps of Euclidean distances in the ocean from each of the leatherback rookeries. The relative density or frequency of turtles in the surrounding environment may depend on the annual numbers of turtles converging on nesting beaches. Beaches were categorized as large, medium or small based on the number of nesting crawls (emergences) per annum, using breakpoints consistent with the data bins in the Atlas. Large (> 500 crawls/ year) and medium (100-500 crawls/ year) were subsequently combined because only 38 beaches of the 465 were assessed as having more than 100 leatherbacks crawls/year and were designated as major nesting beaches. Rasters were created for three categories; distance to major nesting beach, distance to small leatherback nesting beach (<100 crawls/year) and distance to any leatherback beach.

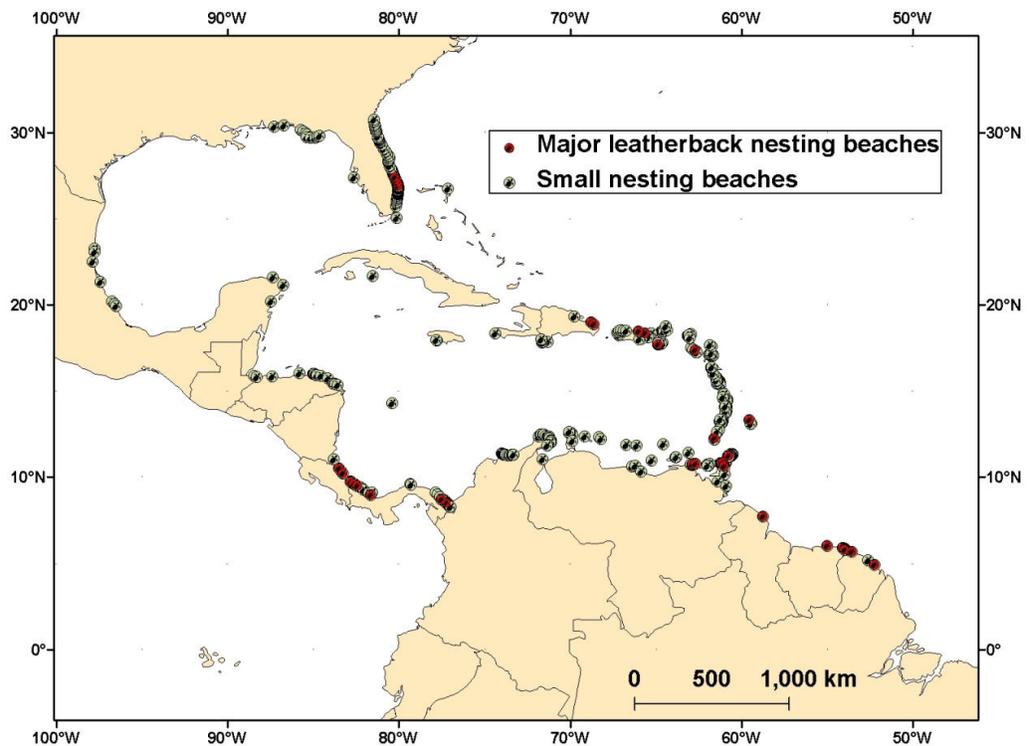


Figure 3.8: Distribution of leatherback nesting beaches ($n=465$) in the west Central Atlantic (excluding Brazil). Beaches with red symbol ($n=38$) have more than 100 leatherback crawls per year. (Source: Dow *et al.* 2007).

To investigate whether leatherback occurrence and bycatch risk are related simply to the distance from shoreline rather than proximity to a rookery, I created a raster of Euclidean distances from the shore using the Global Self-Consistent Hierarchical High Resolution Shoreline (GSHSS) file (Wessel & Smith 1996).

I used the 200 m depth contour, a common proxy for the shelf (Spalding *et al.* 2007) to create a raster of distance from continental shelf. The 200 m isobath data was extracted from the National Aeronautics and Space Administration (NASA) Shuttle

Radar Topography Mission (SRTM) global bathymetry and elevation data, SRTM30-PLUS (Becker *et al.* 2009). This dataset provides bathymetry at a 30 arc-second resolution (approximately one kilometer at the equator).

Other environmental variables

I investigated three variables relating to ocean condition; ocean depth, SST, and chlorophyll a. Ocean depth was estimated from the SRTM-30 PLUS dataset. Mean monthly night-time sea surface temperatures (SST) were obtained from the National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua satellites. The temporal coverage of the NOAA MODIS satellite spans the dates of the bycatch data (2007 & 2009) and the AVHRR data covers the period for the telemetry data (1995 to 2003). The SST estimates used were those interpolated at the 4 km resolution. To investigate the role of ocean productivity chlorophyll a (annual 9 km resolution) estimates were obtained from SeaWiFS, the Sea-viewing Wide Field-of-view Sensor (NASA Ocean Color Group, Feldman & McClain). Estimates of chlorophyll a were also collected from MODIS Aqua for comparison with estimates from the SeaWiFS platform

I extracted values of each of these predictors at each point in both datasets (telemetry and bycatch) by sampling the predictor rasters using Marine Geospatial Ecology Tools (MGET) in ArcGIS. The sampling tool intersects points with rasters or

polygons and writes the values of the raster's cell or polygon attributes to fields of the points (Roberts *et al.* 2010). By matching points to dates the MGET tools extracts values of remotely sensed time series data of oceanographic parameters such as SST and chlorophyll a. Values were interpolated using the nearest neighbor method.

The impact of effort and fishing port of origin (Toco or Matelot) on leatherback capture was also examined. Bycatch in net fisheries may be related to the area available for entanglement and the duration the gear is in the water (Price & Van Salisbury 2007b). Fishing effort was therefore computed for each set as the net area (m²) multiplied by the duration of the set (in hours). The resulting metric is net area hours. The environmental predictors are summarized in Table 3.4.

Table 3.4: Summary of variables relating to leatherback occurrence and bycatch in gillnet fisheries.

Variable	Source	Description
Distance from nesting beaches	WIDECAST Atlas of nesting beaches (Dow et al. 2007)	Rasterized surface representing the Euclidean distance to nearest leatherback nesting beach category
Distance from shoreline	GSHHS (Wessel and Smith 1996)	Rasterized surface representing Euclidean distance to closest point on the shoreline
Distance from 200 m isobath	NOAA global elevation dataset (SRTM- 30 PLUS).	Rasterized surface representing Euclidean distance from 200 m isobath. The 200 m depth contour was estimated from SRTM30-PLUS bathymetry layer
Bathymetry	NOAA global elevation dataset (SRTM- 30 PLUS).	2009 Global elevation data at 30 arc-seconds resolution

Table 3.4 continued

Variable	Source	Description
Chlorophyll a	NOAA MODIS Aqua and SeaWiFS (NASA Ocean Color Group) satellites	Annual chlorophyll a (mg/m ³) estimates (9 km resolution)
SST	NOAA MODIS and NOAA AVHRR satellites	Mean monthly SST (night time) at 4 km resolution
Fishing effort	Net area * duration fished	m ² hr
Port	Fishing port of origin for fishing trials	Toco or Matelot

A tabulation of summary statistics and distribution of missing values for both dataset are provided in Tables 3. 5 and 3. 6.

Table 3.5: Summary statistic for predictors sampled for the telemetry regression data. Values were extracted using MGET sample rasters tool.

Statistic	Distance to any nesting beach (km)	Distance to small nesting beach (km)	Distance to large or medium (km)	Distance to shore (km)	Depth (m)	SST (°C)	Chl a (mg/m ³)
N	242	242	242	242	223	221	178
Mean	29.85	26.92	38.65	41.93	-343.45	24.41	2.47
Std.Dev.	30.35	26.26	38.31	42.47	582.74	5.32	2.13
Min	0	0	0	0	-2365	8.78	0.20
Q1	6.08	8.94	7.66	2.87	-196	25.80	0.79
median	18.03	17.10	26.99	28.90	-57	26.93	2.06
Q3	45.17	38.42	58.28	71.42	-19.5	27.30	2.95
max	147.63	120.60	181.96	150.66	-2.	28.50	10.24
missing values	0	0	0	0	19	21	64

Table 3.6: Summary statistics for fishing sets observed during bycatch mitigation trials, Trinidad, 2007 and 2009.

Statistic	Fishing effort	Distance to nearest major beach (km)	Distance to nearest beach (km)	Distance to shelf (km)	Distance to shore (km)	Depth (m)	Residency log10 seconds)
N	211	211	211	211.00	211.00	205.00	211.00
mean	12972.21	4.14	2.74	24.46	1.78	-15.03	6.08
Std.Dev.	9999.43	2.51	1.58	2.79	1.20	13.23	0.34
min	2000	0	0	17.72	0.00	-49.00	5.04
Q1	6666	2.24	1.41	23.19	1.00	-24.00	5.71
median	9334	3.60	2.24	23.77	1.41	-12.00	6.37
Q3	13750	5.83	3.60	25.08	2.00	-2.00	6.38
max	43732	13	7.81	39.81	7.00	-2.00	6.40
missing values	0	0	0	0	0	6	0

Statistic	SST (°C)	Chl a (SeaWiFS, mg/m ³)	Chl a (MODIS, mg/m ³)
N	178.00	86.00	97.00
mean	25.69	3.06	3.47
Std.Dev.	1.03	1.79	0.71
min	24.16	1.09	1.98
Q1	24.97	1.98	3.12
median	25.77	2.71	3.40
Q3	26.72	3.83	3.61
max	27.51	7.76	4.75
missing values	33	125	114

Kernel density estimation for leatherback sea turtles

Kernel density estimates (KDE) were computed in R using the package ks (Duong 2007). Kernels were computed for all turtles and separately for east and north coast nesting turtles. I used the Hpi plug-in method for selection of the smoothing parameter (h), a measure of the spread or bandwidth of the kernel around each

observation (Rodgers & Kie 2010). Plug-in methods for bandwidth selection are popular alternatives to least squares cross-validation (LSCV). The LSCV method is sensitive to outliers and tends to under-smooth the kernels (Boente *et al.* 1997). The Hpi plug-in is the multivariate plug-in selector of Wand and Jones (1994). Contour levels for the 25, 50%, 75% and 95% isopleths were extracted from the UD and exported as shapefiles using functions in the *sp*, *PBSmapping* and *maptool* packages in R. The models based on the Hpi plug-in selector are referenced hereafter as H_{hpi} .

Kernel density estimation was also computed using a fixed kernel approach and a standard bivariate Gaussian function. The estimation was performed in R using the package “*adehabitat*” (Calenge 2006). The Least Squares Cross Validation (LSCV) method was used to select h . However, the LSCV method either failed to find a value of h that minimized the error or did so at values that under-smoothed the UDs, resulting in many small clusters of points. The smoothing parameter therefore was set by examining a plot of the LSCV. The resulting probability density function of the UD was exported as an ASCII file and converted to an ArcInfo grid. The probability density function and associated contours from this model are designated as the h_{man} model.

To assess the extent of the overlap of the kernel home ranges of the north and east coast nesting turtles I calculated the spatial overlap of the home ranges of the two groups based on the 95% and 50% UDs from the h_{man} model. Several indices of spatial overlap have been developed (see Fieberg & Kochanny 2005 for a review). That review

recommended estimating spatial overlap using UD-based methods such as the Utilization Distribution Overlap Index (UDOI), Battacharyya's affinity(BA), Volume Intersection(VI) and PHRij. The review also concluded that the UDOI, which is based on Hurlbert's Index, is likely to be the most appropriate index for quantifying overlap in terms of space-use sharing, while the BA statistic is likely to be most appropriate for quantifying the degree of similarity among UD estimates. The PHRij is a probabilistic index (the probability of finding animal or group in the home range of animal or group j) and is easily interpretable measure, and is useful in conjunction with other metrics. I calculated the aforementioned indices using functions included in adehabitat package.

Kernel density estimation for fishing

Kernel density estimation for fishing was carried out using the Hpi plug-in bandwidth selector for smoothing parameter selection. Contour levels for the 25%, 50%, 75% and 95% were extracted and shapefiles exported for mapping in ArcGIS. The R code for the analyses is included in Appendix C.

3.3. Results

Distribution with respect to environmental variables

Distance predictors (from all nesting beach categories and the shoreline) and chlorophyll a for sea turtle locations (presence) were positively skewed in contrast to the left-skewed distribution for depth (Figure 3.9). All the distance variables and depth

displayed large differences in frequency and shifts in distribution between presence and absence points, signaling their likely significance.

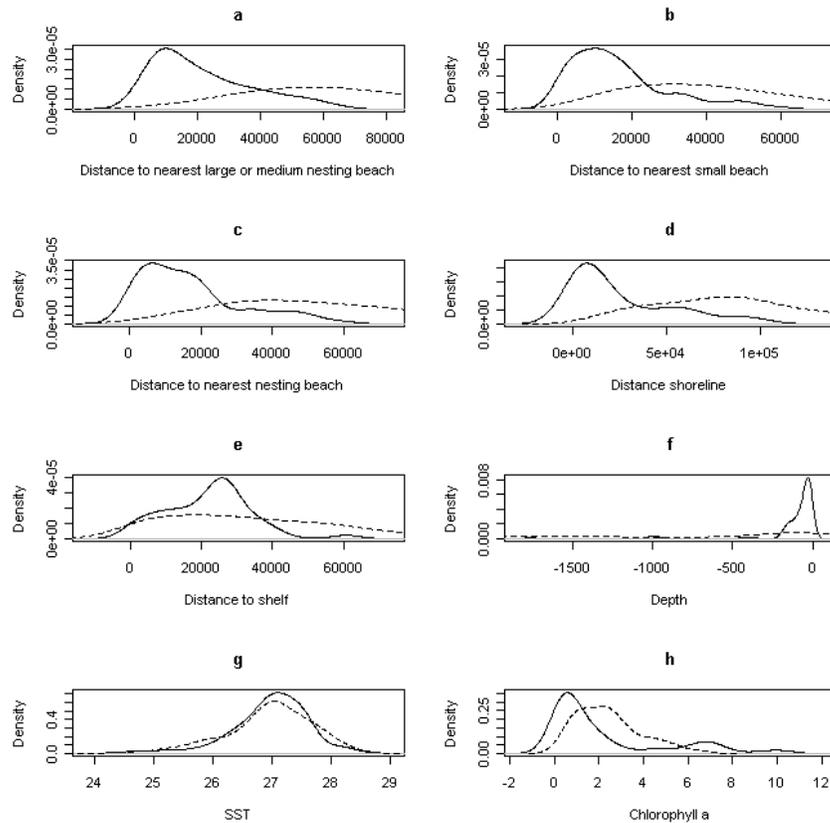


Figure 3.9: Density plots of environmental variables for leatherback occurrence model. Each plot shows the distribution of the variable for the points where leatherbacks occur (solid lines) and the pseudo absence points (dashed line). Distance-related variables are shown in plots (a-e) and ocean variables in plots (f-h).

Differences in the distribution of bycatch and zero bycatch sets were found for distance to large or medium nesting beach, distance to shelf and SST (Figures 3.10 and 3.11).

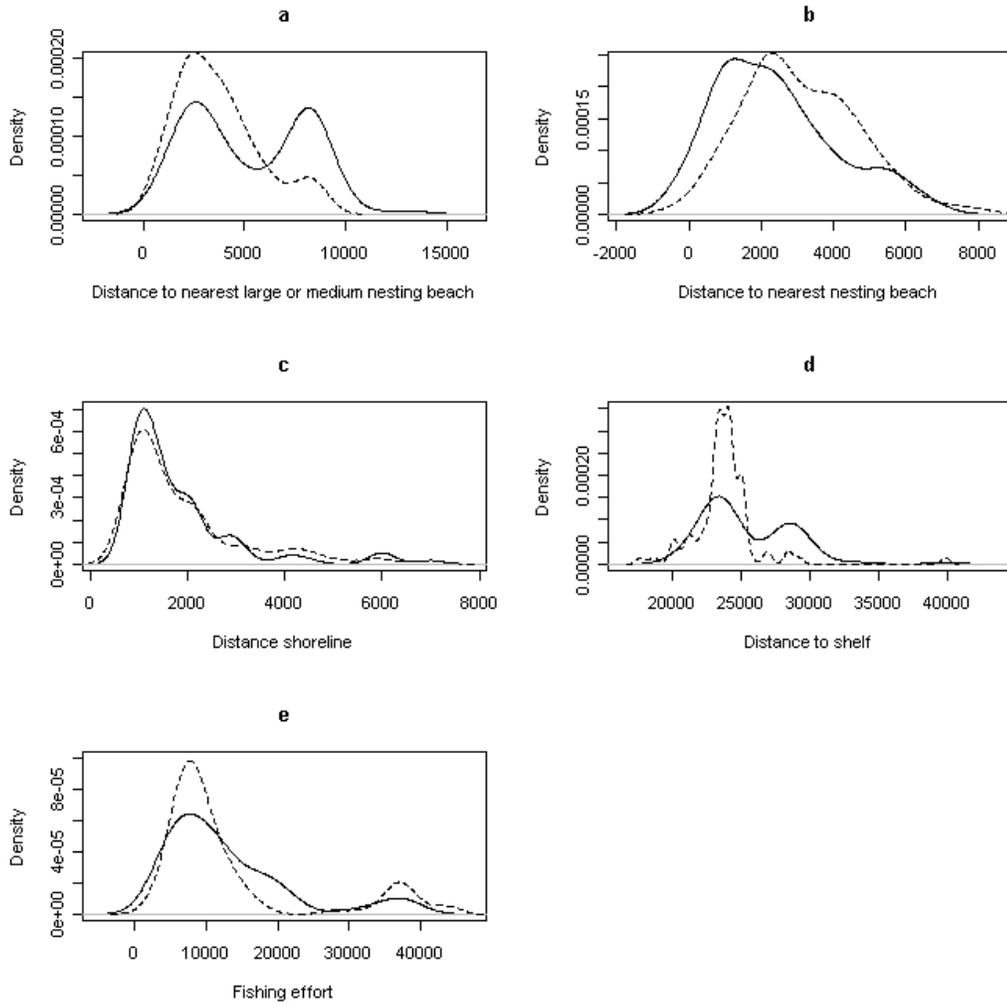


Figure 3.10: Density plot showing frequency distribution of distance predictors and fishing effort in bycatch and zero-bycatch fishing sets for bycatch data. Solid lines represent the bycatch positive sets, and dashed lines the zero bycatch sets.

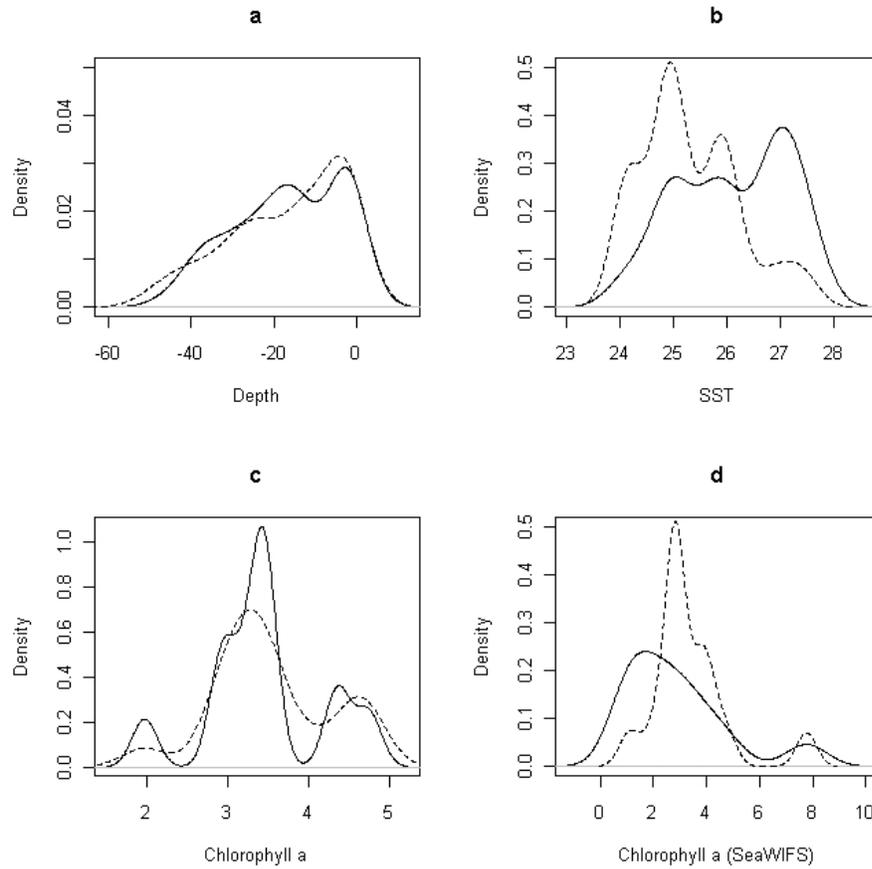


Figure 3.11: Density plots for bycatch data showing distribution of zero bycatch (dashed line) and bycatch positive fishing (black line) sets for variables related to ocean conditions; depth, SST and chlorophyll a. Plot c represents chlorophyll a estimates the MODIS Aqua satellite, and plot d data from the SeaWiFS satellite.

Kernel Density Estimation

Kernel home ranges (KHR) based on least squares cross validation for the telemetered animals (*hman*) show core areas (50% UD) in the northeastern corner of Trinidad between Matura and Grande Riviere Beaches (Figure 3.12).

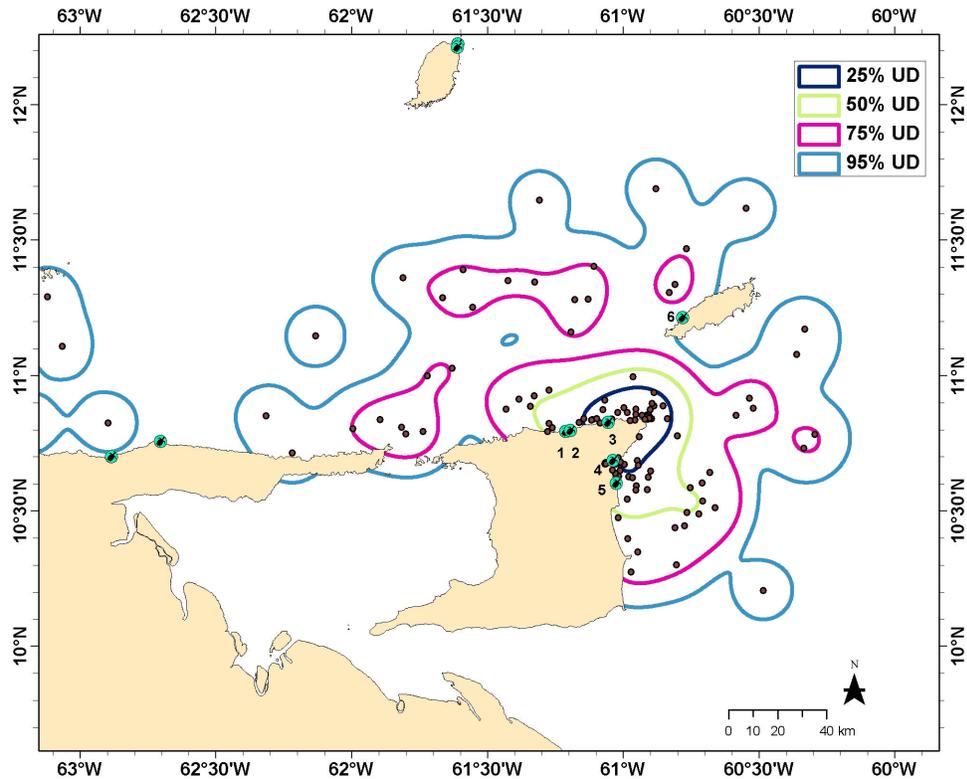


Figure 3.12: Location points and combined interesting kernel home range for nine nesting leatherbacks satellite tagged at Matura Beach and Grand Riviere, 1995-2003. Nesting beaches are (1) Madamas, (2) Grand Tacaribe, (3) Grand Riviere, (4) Matura Beach, (5) Fishing Pond and (6) Turtle Beach. Contours represent the 25%, 50%, 75% and 95% utilization distributions (UDs) estimated using kernel density estimation in adehabitat (Calange 2006) with manually set smoothing parameter (*h_{man}* model).

The indices on the estimated overlap in home ranges show moderate overlap between the home ranges of the east and north coast tagged turtles (Table 3.7). For example, the PHRij index estimated probability of finding a north coast turtle in an east coast turtle's home range was 0.72 and for an east coast turtle in a north coast turtles home range was 0.69 for the 95% UD. This is similar to BA index but lower than the VI measure. The UDOI index is marginally greater than 1 showing a high degree of

overlap. In the core area (50% UD), the overlap indices estimate 19% to 43% overlap in the 50% UD volume.

Table 3.7: Kernel home range spatial overlap indices for east coast (EC) turtles (tagged at Matura Bay) and north coast (NC) turtles (tagged at Grande Riviere) estimated using the kerneloverlaphr function in R. Upper values are for overlap to the 95% contour and lower panel for the 50% contour. The indices include UD-based estimates (PHRij, VI, UDOI, BA) and simple proportionality index, HR.

		PHRij		HR		VI		BA		UDOI	
		EC	NC	EC	NC	EC	NC	EC	NC	EC	NC
95%	EC	0.95	0.72	1.00	0.43	0.95	0.52	1.00	0.75	3.02	1.09
	NC	0.69	0.95	0.52	1.00	0.52	0.95	0.75	1.00	1.09	2.52
50%	EC	0.50	0.42	1.00	0.78	0.50	0.35	1.00	0.75	0.28	0.19
	NC	0.43	0.50	0.73	1.00	0.35	0.50	0.75	1.00	0.19	0.31

The non-parametric Wilcoxon signed-ranks test (Mann & Whitney 1947) was used to test the hypothesis that east coast and north coast turtles were drawn from the same distribution with respect to the various environmental covariates. The results (Table 3.8) indicate that east coast and north coast turtles are drawn from non-identical populations for all the predictors with the exception of depth and distance to the shelf.

Table 3.8: Wilcoxon signed-ranks test for east and north coast tagged turtles. W is the sum of the ranks in the first group, minus the minimum value it can attain.

Variable	W	p-value
dis2_2or3	397.5	0.08
dis2_any	377.5	0.05
dis2_200	580.5	0.75
dis2_shore	284.5	0.0027
Depth	675	0.16
SST	768	0.015

Kernel density estimation using plug-in bandwidth selector.

The UD_s from the kernel density estimated using plug-in bandwidth estimator show less under-smoothing and smaller core areas than those estimated in “adehabitat” (Figure 3.13). The 50%UD contour is not symmetrical around the northeastern tip and in general the core areas are shifted westward in comparison to the h_{man} model.

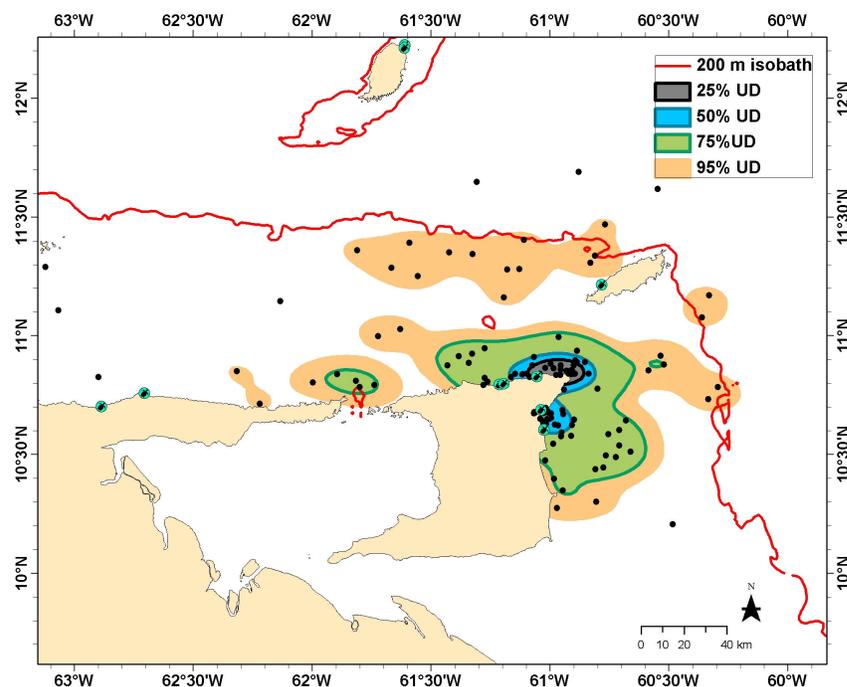


Figure 3.13: Kernel density estimation for leatherback occurrence using plug-in bandwidth selection (Hpi model). Contour levels were set for 25%, 50%, 75% and 95% UD.

An overlay of the kernel density estimates from the Hpi models of turtle occurrence and fishing demonstrate that the home range of the north coast turtles overlaps with the fishing areas to a greater degree than the home ranges of the east coast turtles (Figures 3.14 and 3.15).

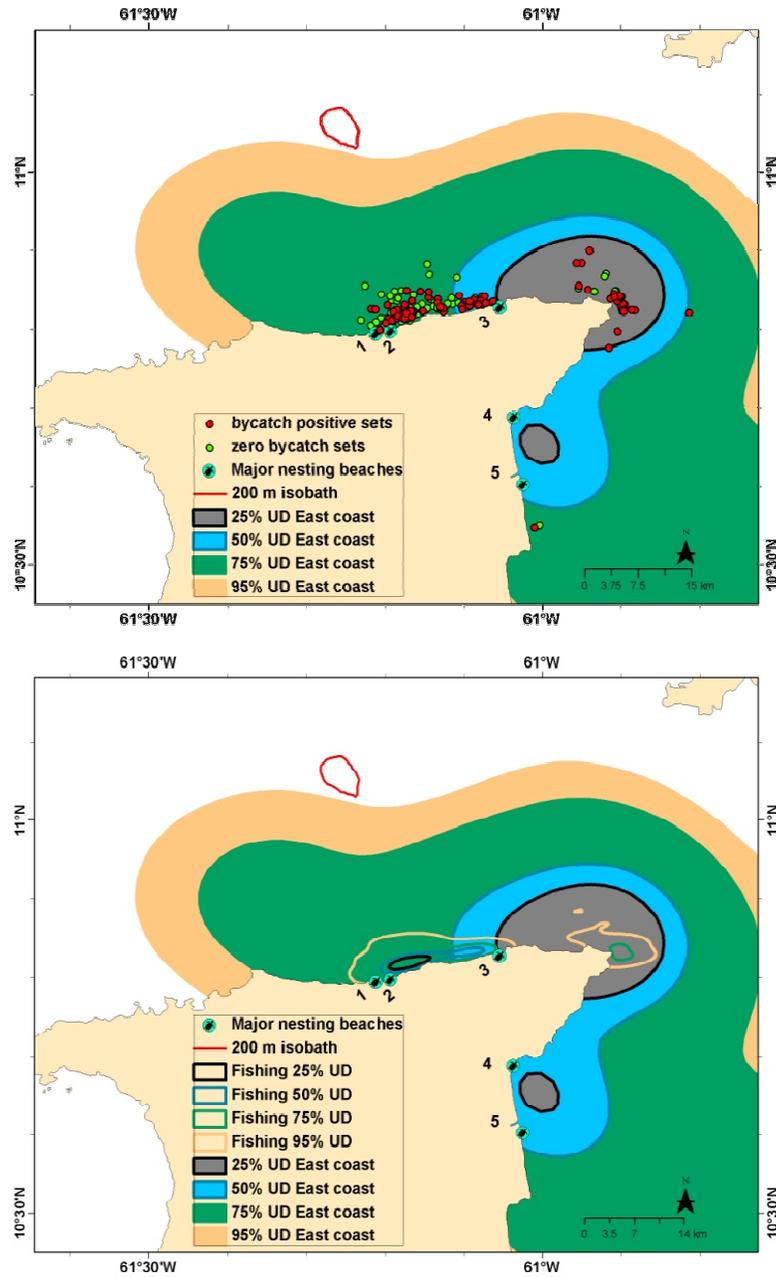


Figure 3.14: Comparison of kernel home ranges of leatherback sea turtles and observed fishing sets in Trinidad (top panel) and kernel density estimates using Hpi-plug in bandwidth selector for east coast nesting turtles and fishing sets (lower). Solid cores are contours for east coast turtles, hollow cores are kernels for fishing. Beaches numbered 1= Grand Tacaribe, 2=Madamas Bay, 3=Grande Riviere, 4=Matura, 5=Fishing Pond.

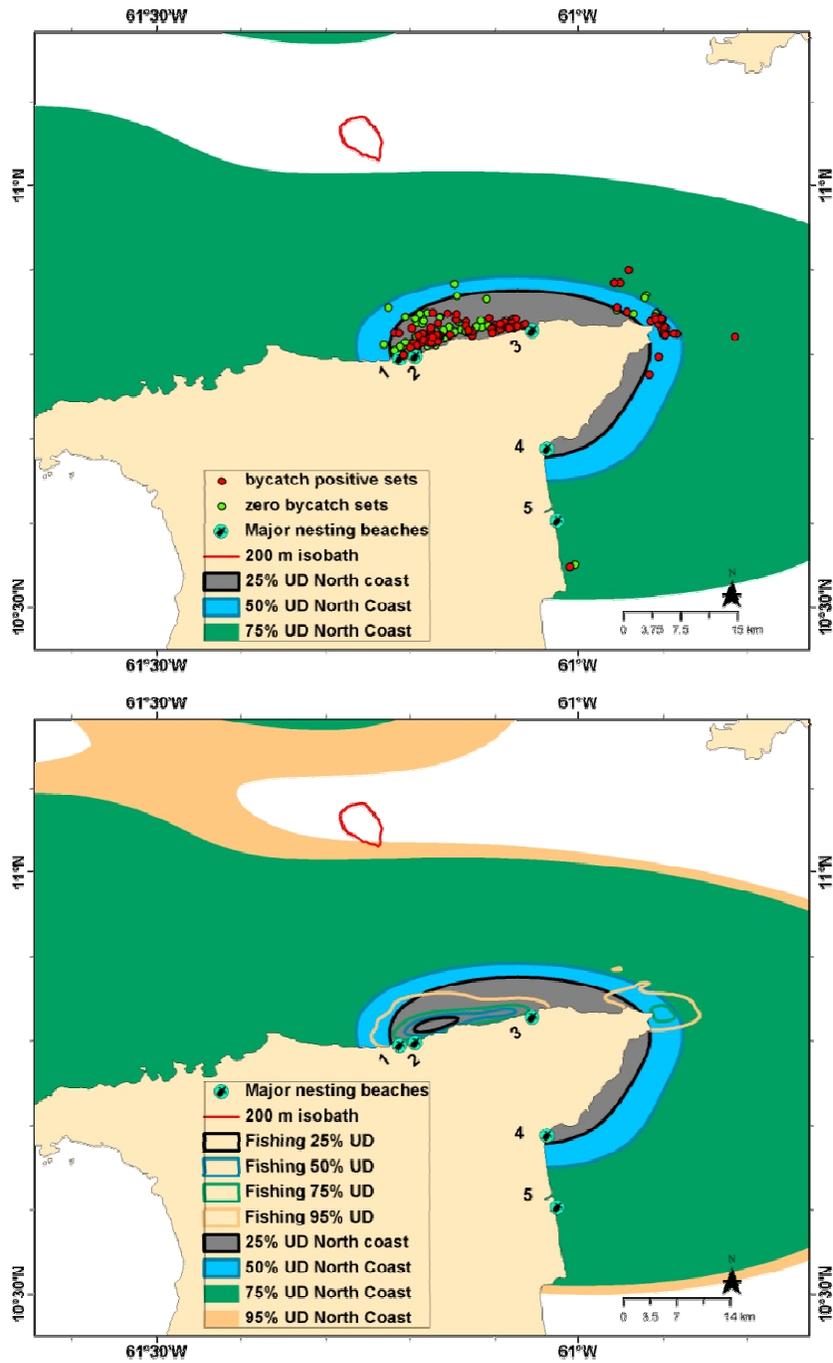


Figure 3.15: Comparison of kernel home ranges of leatherback sea turtles and observed fishing sets in Trinidad (top panel) and kernel density estimates using Hplug in bandwidth selector for north coast nesting turtles and fishing sets (lower). Solid cores are contours for north coast turtles, hollow cores are kernels for fishing.

Only 8 of the 211 sets (3.8%) were outside the 50% UD of the north coast nesting population, whereas 132 of the 211 sets (62.6%) were outside the 50% UD of the east coast turtle population. There is, however, evidence for significantly higher frequencies of bycatch for east coast animal in the 25% UD (Table 3.9).

Table 3.9: Frequency table comparing bycatch in fishing sets in the 25% UD for north and east coast turtles. Chi-squared test ($\chi = 19.9$, p-value < 0.001)

	25% UD East Coast	25% UD North Coast
Zero-bycatch sets	9	99
Bycatch sets	33	62
Total	42	161

This may be due in part to the higher observed bycatch rates of the fishers from Toco, who were the only crew that operated inside the 25% UD of the east coast nesters (Figure 3.16). Never-the-less, the high rates in 25% UD probably arise from both fishing practice and the distribution and behavior of the turtles. Toco fishers have a barely significant greater frequency of bycatch than Matelot fishers if fishing effort in the 25% UD of the east coast turtles is excluded ($\chi = 3.92$, p-value=0.05).

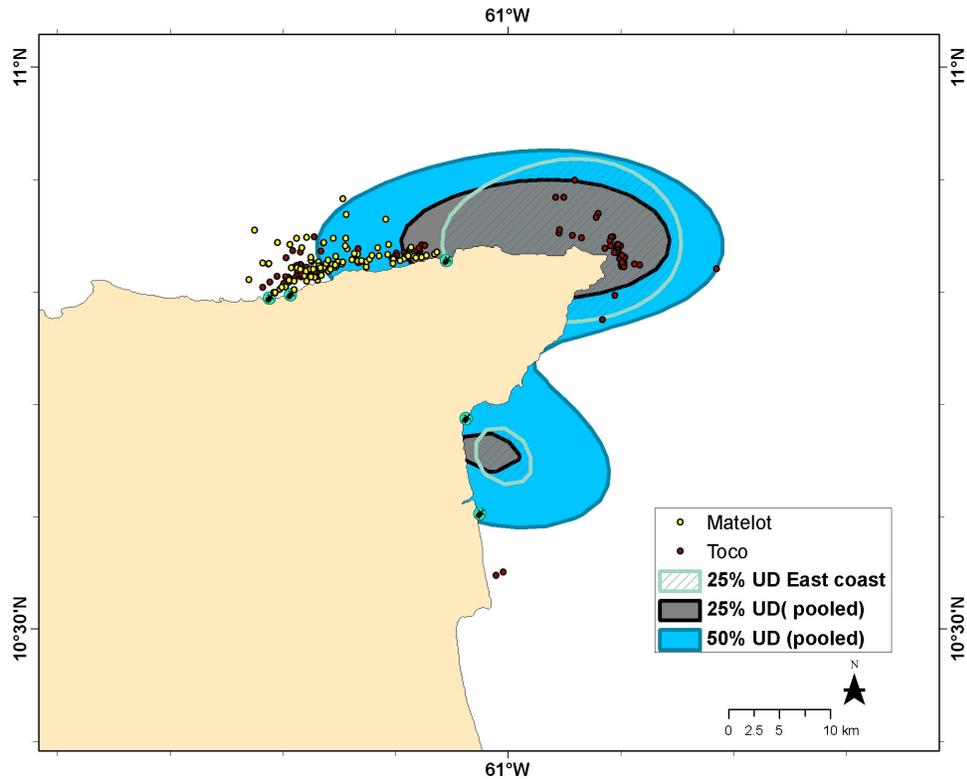


Figure 3.16: Distribution of fishing sets by port of origin with respect to the kernel densities for the 25% and 50% UD for the pooled animals and the 25% UD for the east coast animals. Only the Toco crew fished inside the east coast turtle home range.

In summary, the distance variables and depth are potentially significant predictors of occurrence, while distance to shelf, distance to major nesting beach and SST are potentially significant variables for leatherback bycatch. The analysis provides evidence that the east and north coast are generally distributed differently in interesting with respect the covariates in question, except in the case of depth and distance to the shelf. Overall, north coast turtles may overlap more and have greater risk, but the east coast turtles 25% UD have higher encounter rates than north coast

turtles in their 25% UD. Longer residency time (possibly due to better foraging opportunities) and/or exposure to the fishing practice of Toco fishers (light use?) in the 25% UD are possible contributors to this situation.

3.4 Discussion

Integrating fisheries and sea turtle telemetry data to identify areas of potential interaction is a critical first step towards understanding the nature of bycatch events (Žydelis *et al.* 2011). Most developing nations struggle to allocate resources to implement and sustain long-term monitoring programs for fisheries. Additionally, it is a challenge to apply statistical methods to data that were collected to answer a different suite of questions (bycatch mitigation trials versus bycatch monitoring). This study applied non parametric approaches such as kernel density estimation to address some fundamental questions about sea turtle interesting occurrence and fisheries bycatch.

Separating the telemetered animals by primary rookery area (east coast versus north coast) reveals differences in association with several environmental variables and in the spatial overlap with the observed gillnet fishery. An analysis of the movement and behavior patterns of the turtles and of the fishery suggest that both spatial measures and fishery practice must be included in the mitigation tool kit. Fully one-third of the observed interactions occur in the 25% UD of the east coast turtles, and exclusion of those sets still leaves significant (although reduced) differences in encounter rates

between the two ports. More data including extended observation of the fishing fleet may help determine if the difference in bycatch between the two ports is an artefact of sample size and/or natural variability in catch rates.

This study is the first to quantify how bycatch rates are impacted by fishing activity in leatherback core interesting area. Displacing fishing effort and activity from the 25% UD to the area between the 25% UD and the 50% significantly changes interaction rates. The 25% UD of leatherback interesting habitat should be considered sensitive areas and overlap of fishing in these areas should be monitored. This strategy would reduce the monitoring and assessment burden. This approach could be used as part of a regional bycatch reduction strategy; to identify the 25% UD for leatherbacks in the interesting habitat and to overlay this against the recently developed Caribbean fishing effort database (Dunn *et al.* 2010).

An experimental gear trial such as the one used to generate the bycatch dataset here demonstrated has a different design and sampling plan than that of a fisheries observer program. In a fisheries monitoring program, a proportion of the fishing fleet would be observed based on a sampling framework that would incorporate the spatial and temporal range of the fishery and would facilitate inter annual comparisons. Those design issues would be unnecessary or counter to the experimental gear trials objectives. Thus the Trinidad field trials for bycatch mitigation pre-selected the localities and time frame for peak bycatch, were conducted over a limited temporal span (May to July) and

coverage of the fishery (one vessel each from 2 of the 13 ports in northeast Trinidad). Additionally, the observations were obtained from the same vessel at each port throughout the study. Because of the standardized-paired testing framework of the mitigation trials, the project could not fully sample the variability in fishing practices (set depth, length of net panels, use of net marking lights) or other factors that may affect interaction rates. Given the primary objectives, the bycatch mitigation study did not collect information on important ecological covariates (such as water temperature, depth) that could supplement data from remote platforms which often contain many missing values or are inaccurate in nearshore areas with limited relief, as is the bathymetry layer around Trinidad.

The telemetry dataset was also restricted to animals nesting on two beaches and this sample may not reflect the true extent of the movement and home range of Trinidad's nesting leatherbacks. Moreover, the telemetry data spanned an eight-year period which did not overlap with the time frame during which the bycatch data were collected.

I addressed spatial and temporal autocorrelation in the telemetry dataset by using only the best location per day, eliminating 80% of the data. The resulting dataset may have lost significant information while retaining some measure of autocorrelation (Cushman 2010). A less blunt tool for dealing with the autocorrelation could use more locations per day up to the average number of records per day per animal, or to consider

locations points as uncorrelated if they lie outside an envelope related the maximum distance travelled by the animal. Alternative approaches include permutation tests , post-hoc adjustment of model degrees of freedom and mixed-effects modeling (Aarts *et al.* 2008)

Future modeling efforts

To properly describe the spatial and temporal variability in bycatch in Trinidad will require implementing a design that collects data from the fishery in prescribed sampling frame. The observations should be made across multiple vessels and include samples drawn from a wider range of fishing communities that deploy drift gillnets. The temporal window of monitoring should extend throughout the period during which leatherbacks occur in the coastal waters.

Future statistical approaches for modeling include general additive models (GAMs). GAMs are non-parametric with respect to the link between the predictors and the response (Hastie & Tibshirani 1990; Redfern *et al.* 2006). While the interpretation of GAM models may be more complex, they are increasingly easy to implement in a range of statistical software.

With a more extensive fisheries dataset, Bayesian conditional auto regressive (CAR) approaches such as undertaken by Sims *et al.* (2008) could be used generate more accurate maps of bycatch rates. This would facilitate an evaluation of predicted models (e.g., from GAMs) against these Bayesian-estimated bycatch rates.

The relationship of occurrence of sea turtles to environmental variable may have been impacted by the method of selecting of pseudo absences and the definition of interesting area. A number of approaches have been developed to improve the selection of pseudo absences for use in presence-only models. Cushman (2010) suggested path-based analyses(e.g., correlated random walks). Recent examples of this approach include dynamic seabird habitat model developed for Laysan (*Phoebastria immutabilis*) and black-footed (*P. nigripes*) albatrosses (Žydelis *et al.* 2011)

It would be interesting to compare the nature and extent of the interesting area as defined by the methods in this study with an assessment derived from the use of state space modeling such as undertaken by (Shillinger *et al.* 2010). That study defined two behavioral modes (interesting and postnesting migration) based on a first difference correlated random walk.

Improvement to measurement /estimation of existing predictors

The lack of a difference in SST between presence and pseudo absence locations supports the hypothesis that Atlantic leatherbacks may forage rather than seek cooler temperatures to optimize energy requirements (Shillinger *et al.* 2010). The difference in SST distribution between bycatch and non bycatch is interesting given those results from the telemetry data. Distance to nesting beach and SST are correlated, and so the potential predictor list for bycatch is comparable to those for occurrence (i.e., distance to the nesting beach and distance to shelf).

The spatial resolution of the SST and chlorophyll a estimates (4 km and 9 km respectively) may be too coarse for the scale of movement of the fishers. In general, the bathymetry layer on which depth estimates are based are less accurate close to the shoreline. This is particularly true for Trinidad where the offshore shelf has limited relief. The bathymetry layer was also used to create the distance to 200 m proxy for the continental shelf. However discontinuities in the isobath around Trinidad create pockets which do not correspond to the shelf (Figure 3.17)

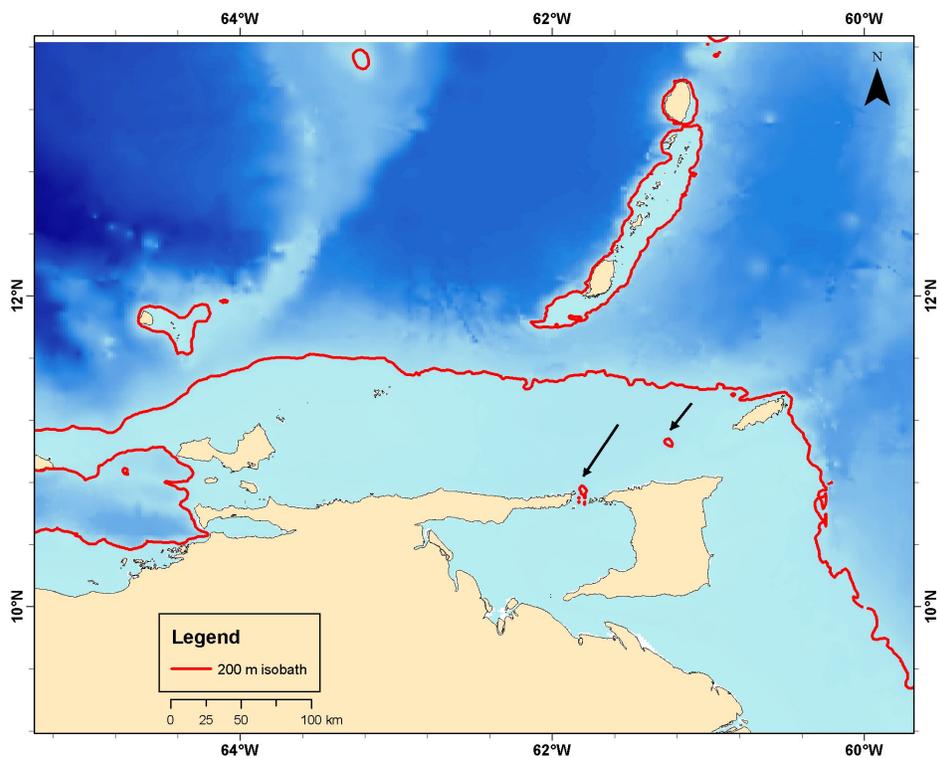


Figure 3.17: Map of Trinidad and Venezuela showing 200 m isobaths, Discontinuities in the isobaths (black arrows) bias distance to shelf estimates.

Additional predictors

Fine-scaled assessment of the movement and dynamics will require future modelling efforts to incorporate other predictors such as distance to the sea surface temperature front, salinity, dissolved oxygen and current velocity. Gelatinous jellyfish (including prey species for *Dermochelys*) are known to aggregate around discontinuities such as fronts, shelf break, upwellings, haloclines and thermocline (Graham *et al.* 2001). The northeastern corner of Trinidad is the confluence of strong currents (Figure 3.18)

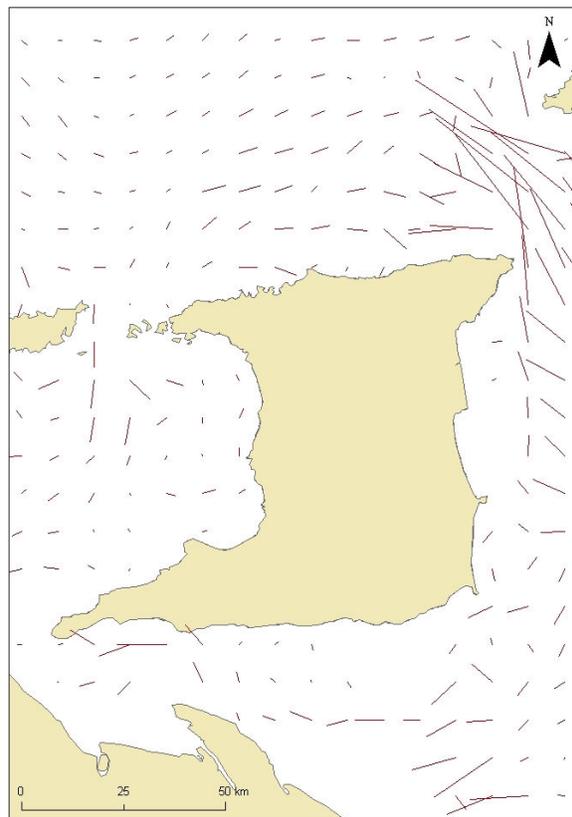


Figure 3.18: Seafloor-level currents in the waters around Trinidad based on Hybrid Coordinate Ocean Model (HYCOM) data. Current speeds represented by the length of the vector arrows. Current convergence and maximum speeds occur off Trinidad’s northeastern tip.

and possibly an area of accumulation prey. The mixing of the chlorophyll-rich, less saline inflows of waters off the South American continent and the Atlantic waters in the area of northeast Trinidad can increase surface-water stratification that may promote jellyfish aggregations and coastal fisheries.

Achieving effective spatial and temporal separation of fishing effort and the bycatch taxon is an important area for mitigation research and policy (National Marine Fisheries Service (SW Region) and National Marine Fisheries Service Science Center 2009). The information available on leatherback bycatch in Trinidad provides a unique opportunity. Future efforts should build upon the existing experience and datasets. While the lack of ecological information is a major challenge (Pittman et al. 2008), It is important to use the all available information to inform the process, while acknowledging the uncertainty or limits surrounding that information. Used in an adaptive management framework, models such as those developed here provide the foundation for testing the impact of future management and mitigation policies and intervention. Current and future information inputs should be used to construct flexible management tools to meet fishing and conservation needs, for Trinidad, and the greater Caribbean region. Application of the Trinidad data to fill in gaps in management of sea turtle bycatch in the wider Caribbean should be pursued.

4. Sea turtle bycatch in the Venezuelan industrial pelagic longline fishery.

4.1 Introduction

Longline fishing gear targeting ocean pelagics such as tunas (thunnids) and swordfish (*Xiphias gladius*) are not perfectly selective and billfish, sharks, seabirds, sea turtles and marine mammals are among the taxa incidentally captured (or bycaught) in such fisheries (Hall 1996; Lewison *et al.* 2004b). Sea turtles migrating across ocean basins between feeding and breeding grounds may consume bait or become entangled, and these interactions may result in serious injuries or mortalities. Loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles are the primary species taken by pelagic longline gear, but olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and Kemp's ridley (*L. kempii*) are also captured (Gilman *et al.* 2006). Loggerhead and leatherback bycatch in pelagic fishing gear has been implicated in the severe decline of nesting populations of those species in the Pacific basin (Spotila *et al.* 2000b; Kamezaki *et al.* 2003; Limpus & Limpus 2003). Concern about the leatherback and loggerhead bycatch in US fisheries in the northwest Atlantic resulted in the closure to longline fishing of a large section of traditional fishing grounds, including the productive Grand Banks area (Gilman *et al.* 2006). Internationally, the reduction of the rate of these interactions has been a priority of regional fisheries management organizations (Hall 1996; Kerstetter & Graves 2006).

Global tuna and swordfish fishing effort is intense. In 2000 an estimated 1.4 billion hooks were deployed (Lewison *et al.* 2004b) and industrial longline fisheries have come under intense scrutiny because of their global importance and the availability of relatively substantial amounts of high-resolution catch and effort data supplied to regional fisheries management organizations (Lewison & Crowder 2007). Consequently there are more investigations of bycatch in industrial longline fisheries than of any other gear (Valdemarsen & Suuronen 2003; Wallace *et al.* 2010) and the observer coverage is the highest for any global fishery (Dietrich *et al.* 2007).

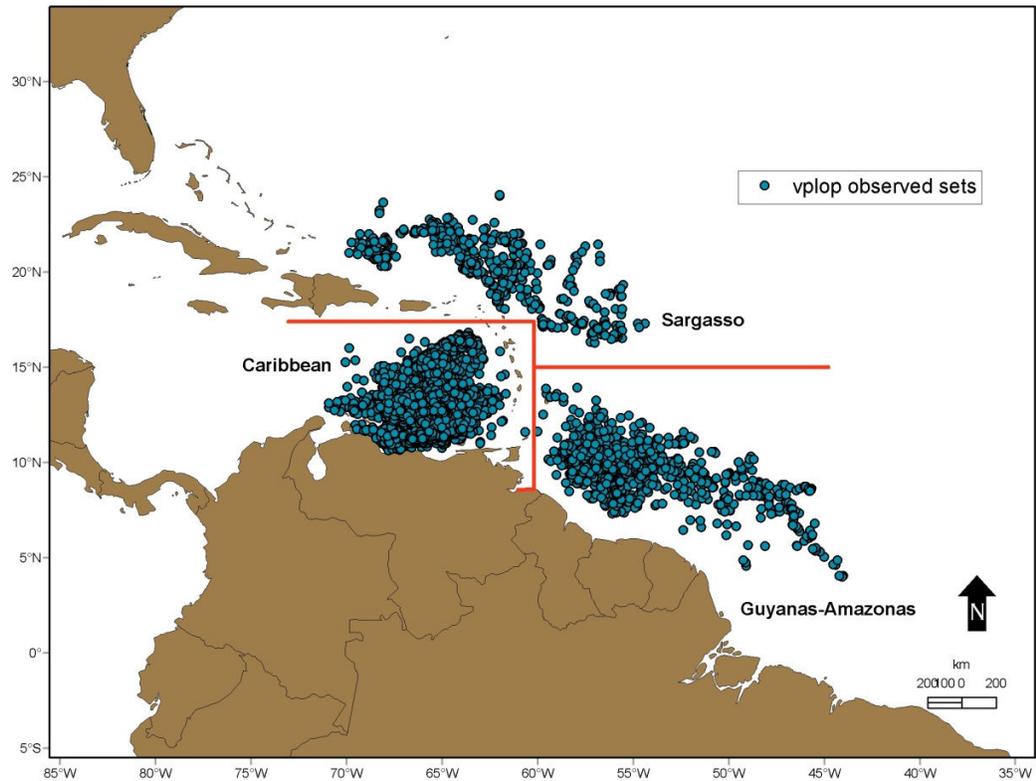
Information on non-target species captured in longlines is however uneven among regions and taxa. Only 15 of the 40 major longlining nations conduct fishery observer programs (Gilman & Lundin 2010). In the northwestern and west Central Atlantic, data exists primarily for US fisheries, which have been assessed since the mid 1990s (Witzell 1999; Garrison 2005; Fairfield Walsh & Garrison 2007). Most other (non-US) fisheries have focused more extensively on billfish (Istiophorids) and shark bycatch, with few assessments of sea turtles. Ulloa Ramirez & González Ania (1998) presented the results of observations of sea turtle bycatch by the Mexican longline fleet in the Gulf of Mexico. Territories such as Bermuda and Anguilla have observed experimental trials of longline fishing gear (Bermuda Department of Environmental Protection (Marine Resources Section) 2011), but observed effort and number of trips

were very small. The limited data on sea turtle bycatch in the Caribbean basin is apparent in the global bycatch review of Wallace *et. al* (2010)

Industrial longline fishing in the west central Atlantic is conducted by fleets from several nations, including the distant water fleets (Japan, Korea and Taiwan), the US, Mexico, Cuba, and Venezuela. Mexico's activities are confined to the Gulf of Mexico and Cuba no longer conducts long range fishing operations. The distant water fleets have limited and declining activity within the Caribbean basin, and fish mainly in the Atlantic east of the Lesser Antillean archipelago. The remaining large industrial longline fleets within the Caribbean Large Marine Ecosystem (CLME) are therefore those of US and Venezuelan operators and the only one for which no assessment of sea turtle bycatch has been undertaken.

The Venezuelan fleet in the Atlantic is the smaller of Venezuela's two industrial longline fleets (Pacific and Atlantic). While the fishery increasingly targets yellowfin tuna (*Thunnus albacares*), it is in many respects a multispecies fishery. Bigeye (*T. obesus*), Albacore (*T. alalunga*) and swordfish (*Xiphias gladius*) are important components of the catch (Arocha *et al.* 2004b). Venezuelans began industrial longline operations in the 1970s (Marcano *et al.* 2004b) and the industry underwent significant expansion between 1986 and 1996, increasing from 9 to 41 vessels in that period, but decreasing to 37 by 2000 (Marcano *et al.* 2004b). A frame survey in 2000 estimated the average length of these vessels was 20 m but the fleet also included Korean-style vessels longer than 26m

(Arocha *et al.* 2004a; Marcano *et al.* 2004b). The majority of vessels use longlines 30-50 km in length and fish under 1000 hooks per set, but the larger vessels set longer lines (50-120 km) and more hooks (between 500-1800) per set (Arocha & Marcano 2001). The Venezuelan fleet's fishing grounds extend throughout much of the southwestern Caribbean basin, from Venezuela to northeastern Hispaniola and the Atlantic, and east to northeastern Brazil (Figure 4.1). Within this area are three distinct fishing regions; the Caribbean, the Guyanas-Amazonas and the Sargasso sea (Ortiz & Arocha 2004). The Caribbean fishing grounds are influenced by wind-induced coastal upwellings in the first half of the year and river discharges from the Orinoco in the rainy season in the second half of the year. The Guyanas-Amazonas region is also strongly influenced by the freshwater flow which provides important organic inputs into the marine environments (Arocha *et al.* 2004a; Marcano *et al.* 2004b).



4.1: Distribution of observed fishing sets of the Venezuelan pelagic longline fishery by the Venezuelan Longline Observer Program (VPLOP).

Since 1991, the International Commission for the Conservation of Atlantic Tuna (ICCAT) has sponsored the placement of trained scientific observers to collect detailed information on pelagic longline fishing operations, gear characteristics and biological data from a sub-sample of the Venezuelan industrial fishery (Arocha *et al.* 2004b). The Venezuelan Pelagic Longline Observer program (VPLOP) was established primarily to monitor the bycatch of billfish by the Venezuelan fleet, but information on sea turtle bycatch was also recorded by observers. VPLOP is managed jointly by the Instituto

Nacional de Investigaciones Agropecuarias (INIA) and the Instituto Oceanografico de Venezuela-Universidad de Oriente (Arocha & Marcano 2001; Ortiz & Arocha 2004). In 2007 the VPLOP database was reviewed, corrected and made available to the wider community with the support of Duke University's bycatch assessment project (Project GloBAL).

The VPLOP database on sea turtle catch is contemporaneous with publicly-available observer and vessel log book data for US longline fisheries in the western Atlantic. The US Pelagic Observer Program (POP) monitors the US longline fleet from the Grand Banks to Brazil since 1992. The logbook (Fisheries Logbook System or FLS) data is based on a self-reported but mandatory (since 1991) program to collect complete fleet-wide data for the US longline fishery. Both datasets are available from the Southeast Fishery Science Center (Southeast Fisheries Science Center (SEFSC) 2006a, b). A comparison of sea turtle bycatch during this period (1991-2006) for the coincidental fishing areas of the two fleets indicate that the nominal bycatch rates (number of sea turtles / number of hooks set) appear to differ by an order of magnitude for these fisheries (Table 4.1).

Table 4.1: Observed fishing effort (hooks) by the US Pelagic Observer Program (US POP), the Venezuelan Pelagic Longline observer Program (VPLOP) and self-reported effort from the US logbook program)

STATISTICS	US POP	VPLOP	US FLS
Dataset years	1992-2005	1991-2006	1992-2005
Number of hooks	240,382	7,283,000	5,585,834
Number of turtles caught	35	80	249
Number of positive sea turtle bycatch sets	30	67	229

Such differences in encounter rates within the same broad spatial extent and time period may arise from differences in fishing practices and effort related to target catch. In contrast to the Venezuelan fishers, the US longline fleet targets swordfish, with tunas (and to a lesser degree sharks) as secondary objectives (Ortiz & Diaz 2004). Higher catch rates of turtles have been observed in swordfish-targeting sets which are generally shallower, night time sets in contrast to the deeper, day time tuna sets (US Western Pacific Regional Fisheries Management Council 1993; Witzell 1999). Other fishing practices that affect bycatch rates include the type and condition of the bait and the use of phosphorescent light sticks designed to attract fish (Garrison 2003; Watson *et al.* 2004; Southwood *et al.* 2008).

The data on observed sea turtle bycatch in Venezuelan longlines consists of 98.73% zero-bycatch observations. Additionally, only 9 of the 67 sets with turtles caught

more than one animal and no set had more than 3 animals, for a total catch of 80 animals (Figure 4.2).

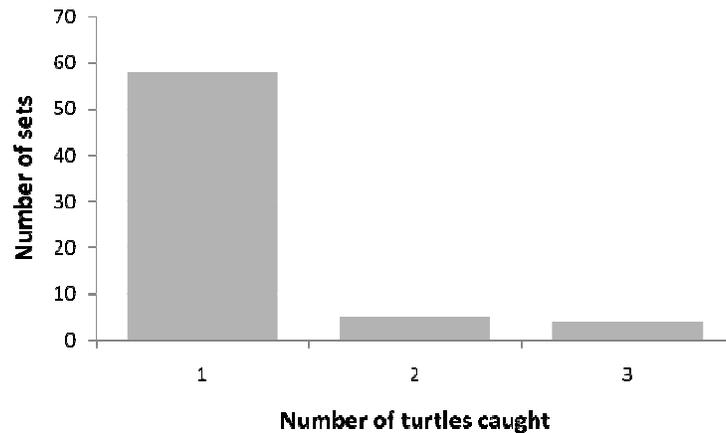


Figure 4.2: Distribution of sea turtle bycatch in non-zero sets in the Venezuelan pelagic longline fishing fleet. A total of 80 animals were caught between 1991 and 2006.

Thus the observed bycatch in this fishery is a rare and an almost binomial event (bycatch, no bycatch). The large proportion of zeros is the range of many longline bycatch datasets, wherein 96% to 99% of the sets of many operations producing zero bycatch (McCracken 2004) and zero-inflated and hurdle models have been developed to account for excess zeros (Minami *et al.* 2007; Pons *et al.* 2008; Zeileis *et al.* 2008; Zuur *et al.* 2008). Both approaches model the count process and the probability of zero catch separately, but differ in their formulation and interpretation. However the combination of a very few captures, excessive zeros and many years (16) creates an extreme case. Studies that have modeled zero-inflated bycatch data using current statistical methods

have had larger bycatch samples than the Venezuelan fishery. For example, observers of the Hawaiian longline industry identified 207 sea turtles in 5 years in 40% fewer sets than this study (McCracken 2004). Between 1992 and 2003, the US program observed 765 loggerhead and leatherback turtles in the 11 statistical reporting regions in the western Atlantic (Gardner *et al.* 2008b). The observed Uruguayan and Brazilian pelagic longliners in the southwestern Atlantic captured 3778 loggerheads between 1998 and 2007. Thus the bycatch levels observed by VPLOP are so low that it may be impossible to build well-fitting quantitative model to either predict bycatch, develop annual standardized catch rates or investigate spatial and temporal autocorrelation between bycatch,

My objectives are therefore to describe and summarize the spatio-temporal distribution of bycatch in relation to target catch, effort and environmental covariates. Researchers have identified correlations between fishing effort, bycatch and environmental variables including mesoscale oceanographic features, water temperature and bottom depth (Kobayashi & Polovina 2000; Gardner *et al.* 2008c). I will investigate sea turtle bycatch in the Venezuelan fleet with regards to variables relating to fishing practice (fishing effort, bait type, latitude and longitude, temporal factors (year, season, moon phase) and oceanography (depth and SST and chlorophyll-a), factors that have been shown to predispose sea turtle- fishery interactions in longline gear (Wetherall 2003; Kot *et al.* 2010). Focusing on the fishery target serves as a proxy for fishing practices for which information was not made available (e.g. time of setting, setting

depth). A preliminary analysis of the potential predictors and spatio-temporal patterns and periodicity in catch and bycatch, affords a comparison and contrast to the recent analyses of US longline fleet bycatch in the western Atlantic (Gardner *et al.* 2008a; Kot *et al.* 2010). Target catch and sea turtle bycatch in longline fisheries was found to increase with the fullness of the moon (Kot *et al.* 2010), as nocturnal predators such as swordfish may use lunar illumination to locate their prey. Periodicity in these rates may therefore be an avenue for temporally-based actions to mitigate bycatch. Because the US observer program (POP) data has a more limited spatial overlap with the VPLOP data, I will use the US logbook FLS data for comparison. Understanding the factors driving bycatch can guide managers and policy makers in gauging the impact of future decisions. As the first assessment of pelagic longline sea turtle bycatch in a non-US Caribbean fleet, this analysis facilitates the development of strategies to minimize and mitigate bycatch (e.g., assessing the role of spatio-temporal management of fishing effort versus gear modification). Additionally, I will place longline bycatch in perspective with respect to other Venezuelan fisheries, as assessments of sea turtle bycatch in the industrial trawl fisheries and artisanal bottom-set longlines for demersal species have been published (Wildermann *et al.* 2009; Alio *et al.* 2010).

4.2 Methods

4.2.1 Data

Venezuelan Pelagic Observer Program

Between 1991-2006 trained personnel observed 5288 fishing sets, covering an estimated 13% of the trips undertaken by Venezuela's Atlantic fleet (Arocha 2007). Observers boarded 9-12 vessels annually, but vessel selection was not based on a statistical sampling design, as cooperation by vessel owners was voluntary. The program provided year-round, albeit lower coverage in December and January (Arocha 2007). The VPLOP data is maintained as Microsoft Access database and is structured to fulfill ICCAT reporting requirements. I received VPLOP data with fields including catch, effort, bycatch, hook type and spatial locations of each set. The VPLOP data was aggregated in Excel to summarize the information by unique set. Data cleaning included removing points representing obvious location errors (*e.g.* on land). The VPLOP monitoring records also included observations of the artisanal longline fleet. Such vessels have a different gear configuration and were identified with the assistance of the VPLOP administrator and excluded from the analysis. A total of 5165 sets were kept for the analysis. The data was mapped in ArcGIS 9.3 using the latitude and longitude of the start of the set (*i.e.* when the first piece of gear hits the water). This dataset was then used to examine spatio-temporal patterns in the distribution of catch and bycatch.

US logbook data (FLS)

The US National Oceanic and Atmospheric Administration (NOAA) Southeast Fisheries Science Center (SEFSC) requires longline vessels to report information on fishing operations, catch and interactions with protected species and makes this data

publicly available online (Southeast Fisheries Science Center (SEFSC) 2006a). The dataset spans the period from 1986, but sea turtle catch data was not included until 1992. I extracted logbook data from 1992 until 2005 with information on the location, gear, effort, finfish catch (main tuna spp. and swordfish), sea turtle bycatch by species. Initial processing included removal of sets with missing effort data or unrealistic (less than 100 hooks) or the reported location was not within the designated NOAA SEFSC longline fishing regions. Records were clipped to the general extent of the VPLOP regions in ArcGIS 9.3. The number of sets retained was 8, 546.

4.2.2 Bycatch in relation to environmental covariates

VPLOP data

The VPLOP database contains information on the estimated species composition of the catch (individuals and weight) and the date of the start of the set (usually one set is made per 24 hour period). Because of the multispecies nature of the fishery, VPLOP researchers derived information about the target species from the vessel captains (Arocha 2007). Sets were generally characterized as either yellowfin, swordfish or mixed. Target species and the catch composition generally coincided with certain characteristics of the set including the time of set, bait type and the use of light sticks. However an assessment of the target objective was supplied only for the bycatch-positive sets. Given the uncertainty surrounding the determination of the target of the

fishery and the unavailability of information on the timing and depth of sets, I used Catch per unit effort (CPUE) as a proxy for the fishery target. CPUE was calculated as (individuals per 1000 hooks) for each of the three main tuna species (YFT, BET and ALB) separately and combined (“TUN”) and for swordfish catch (SWO). The number of hooks in a set was calculated as the number of hooks between floats (“baskets”) multiplied by the number of baskets (Figure 4.3).

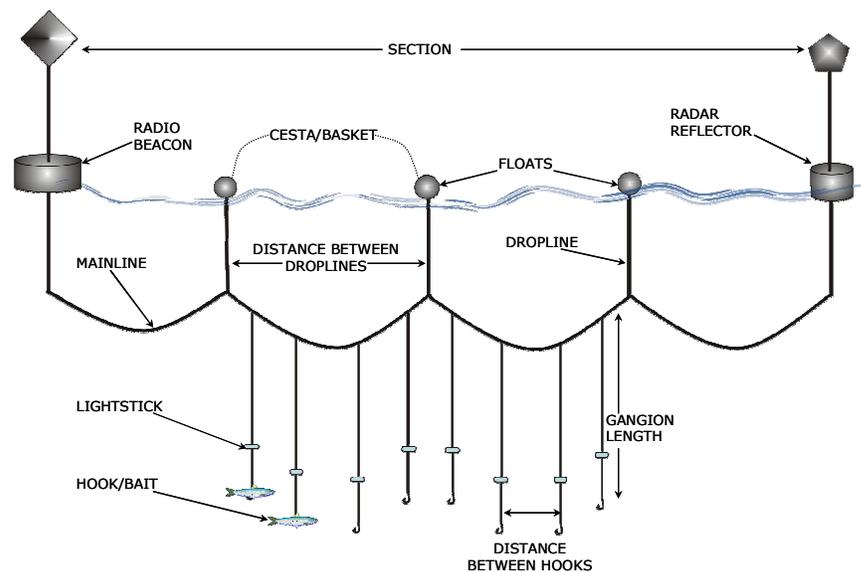


Figure 4.3: Configuration of pelagic longline gear used by the industrial fishery in Venezuela. Source: Arocha (2007).

Several data fields contained many missing values. For example, data on the use of light sticks was not recorded for the period 1995-2000. Information on hook type, use of fluorescent dye on baits were also unavailable for most sets, being recorded specifically for experimental bycatch mitigation trials between 2001 and 2003 (Arocha

2007). In contrast, bait type which has demonstrated impacts on bycatch rates (Swimmer *et al.* 2005; Southwood *et al.* 2008) and was generally recorded by observers throughout the entire study period. The data was therefore only subset to include those sets for which information on bait type had been recorded (5157 sets).

Tunas and billfish are highly migratory species, and their movement and distribution, and hence the movement and distribution of fisheries are linked to oceanographic correlates. Given the migratory nature of the target species, I investigated the impact of oceanographic variables such as depth, SST and chlorophyll a on bycatch. SST values, interpolated from mean monthly day time SST values obtained from the NOAA AVHRR-5 satellite were extracted for each set using Marine Geospatial Ecology Tools in ArcGIS 9.3 (Roberts, 2010 #53). Interpolated 8-day chlorophyll a values for sets were obtained from the Sea-viewing Wide Field of Sensor (SeaWiFs) satellite and depth estimates for each set were sampled from the SRTM30 plus elevation dataset. A description and summary of the predictors is in Table 4.2.

Table 4.2: Summary of variables included in the analysis of sea turtle bycatch rates from the VPLOP database

PREDICTORS	DESCRIPTION
Gear and fishing practice	
Effort	Total number of hooks in the set; calculated as number of hooks between floats(baskets) multiplied by the number of baskets
Target species CPUE	Number of individuals/0000 hooks a) main tuna species individually (YFT, BET ALB) CPUE b) YFT, BET and ALB (combined) CPUE c) Swordfish (SWO) CPUE
Bait type	1= squid(<i>Illex</i> spp.) 2 = other(<i>Sardinella</i> , mackerel (<i>Trachurus</i>) , herring (Clupeidae))
Temporal	
year	From 1991 to 2006 ;
Moon phase	Fraction of the moon illuminated (0=new moon, 1=full moon) summarized into 15 bins.
Spatial	
Latitude	Coordinates of the start of the set
Longitude	Coordinates of the start of the set
Oceanographic	
SST	Monthly mean daytime values from NOAA AVHRR satellite (C)
Depth	SRTM-30 PLUS Global bathymetry (m)
Chlorophyll a	SeaWiFS satellite 8-day (mg/m ³)

4.2.3 Spatio-temporal analyses

The distribution of bycatch and zero bycatch sets and their relationship to observed fishing effort was plotted in ArcGIS 9.3. The distribution of the main bycatch species (loggerheads and leatherbacks together) was also mapped. Fishing effort (hooks) observed between 1991 and 2006 was summed across $0.5^\circ \times 0.5^\circ$ grid cells using MGET in ArcGIS 9.3.

I calculated the distribution of average monthly estimates for effort, bycatch rates and target catch (SWO, ALB, BET, TUN). Temporally stable high bycatch rates at predictable intervals would thus support the case for time area management strategies (Kot *et al.* 2010) Understanding whether or not a periodicity exists in catch and bycatch may indicate the potential for time and area options. The VPLOP dataset does not contain enough turtles captures to determine periodicity, but if fishing practices relating to the target catch are important drivers of bycatch, then understanding periodicity in target species catch may offer insights into the potential of time-based mitigation solutions. I applied an approach similar to Kot *et al.* (2010), to examine periodicity of swordfish and tuna catch rates using a fast Fourier Transform (FFT) method. The FFT procedure was elaborated by Cooley and Tukey (1945) and allows for the analysis of continuous periodic functions of time (Brigham & Morrow 1967). The FFT analysis was

conducted for each of the three main tuna species and swordfish catch rates (fish/1000 hooks) using MATLAB signal processing toolbox (Mathworks 2008).

Comparison with US FLS

To compare the spatial distribution of fishing and bycatch between the two fleets, I mapped the distribution of sea turtle bycatch sets with respect to zero bycatch sets and effort. Mean monthly values of effort and catch and bycatch rates were also calculated. I plotted the density of bycatch sets and zero bycatch sets for target catch rates, effort, longitude, latitude and surface water temperature (*in situ* measurement by the observers).

4.3 Results

4.3.1 Spatio-temporal

Sea turtle bycatch in the Venezuelan fleet was observed in the Caribbean and Guyanas-Amazonas area, but not in the Sargasso Sea fishing area (Figure 4.4). In the Sargasso grounds, swordfish catch is much lower (Figure 4.5) and the fishery operates in deeper waters (Figure 4.6). Vessels in the Sargasso may be targeting *T. obesus* (BET), which is caught at greater depths than yellowfin or albacore tuna.

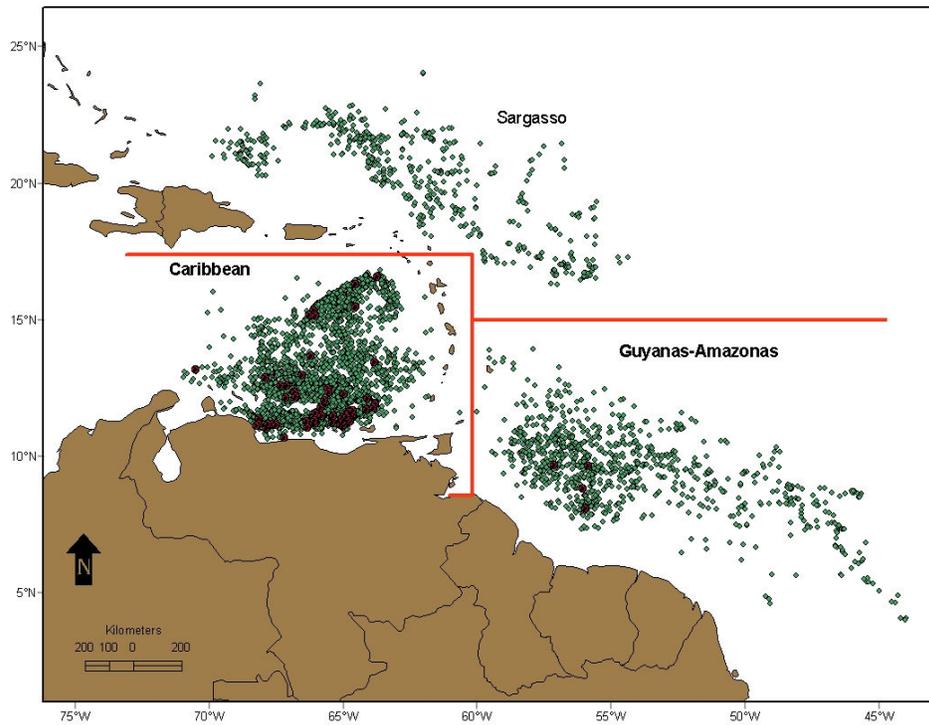


Figure 4.4: Observed sea turtles bycatch in the Venezuelan industrial fisheries, 1991-2006. Red symbols represent sets where at least one sea turtle was caught.

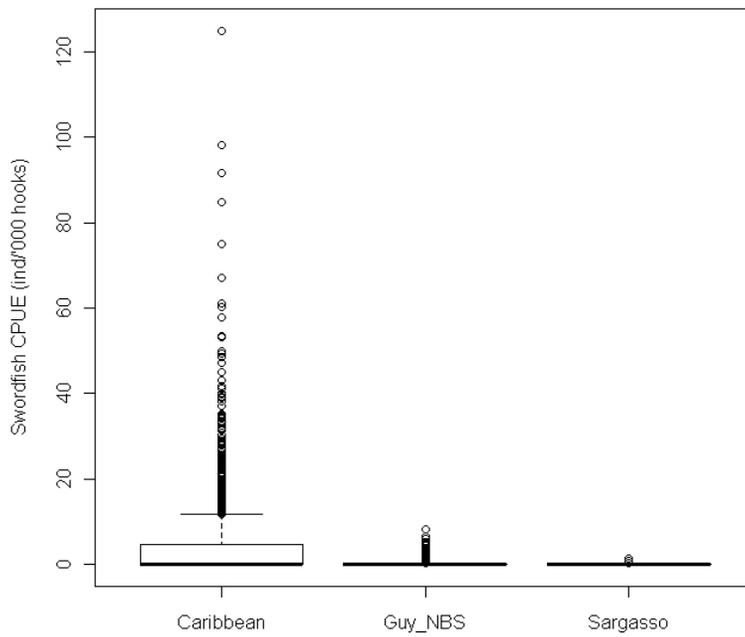


Figure 4.5: Boxplot showing swordfish CPUE by fishing ground for the Venezuelan fleet.

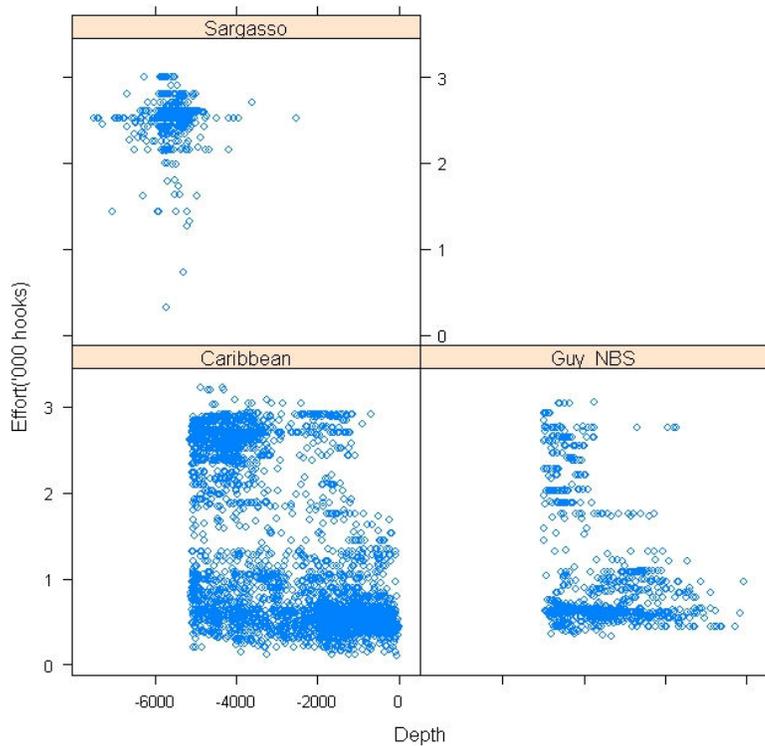


Figure 4.6: Relationship between bathymetry and effort by sub region for the Venezuelan fleet. Vessels in the Sargasso area set over deeper waters rarely set less than 1000 hooks.

Extensive overlap between the US and Venezuela occurs in the Sargasso and Guyanas-Amazonas fishing grounds (Figure 4.7). In the Caribbean fishing grounds however common extents are mainly in the area north of 15 ° and in an area north of the Gulf of Venezuela in the west.

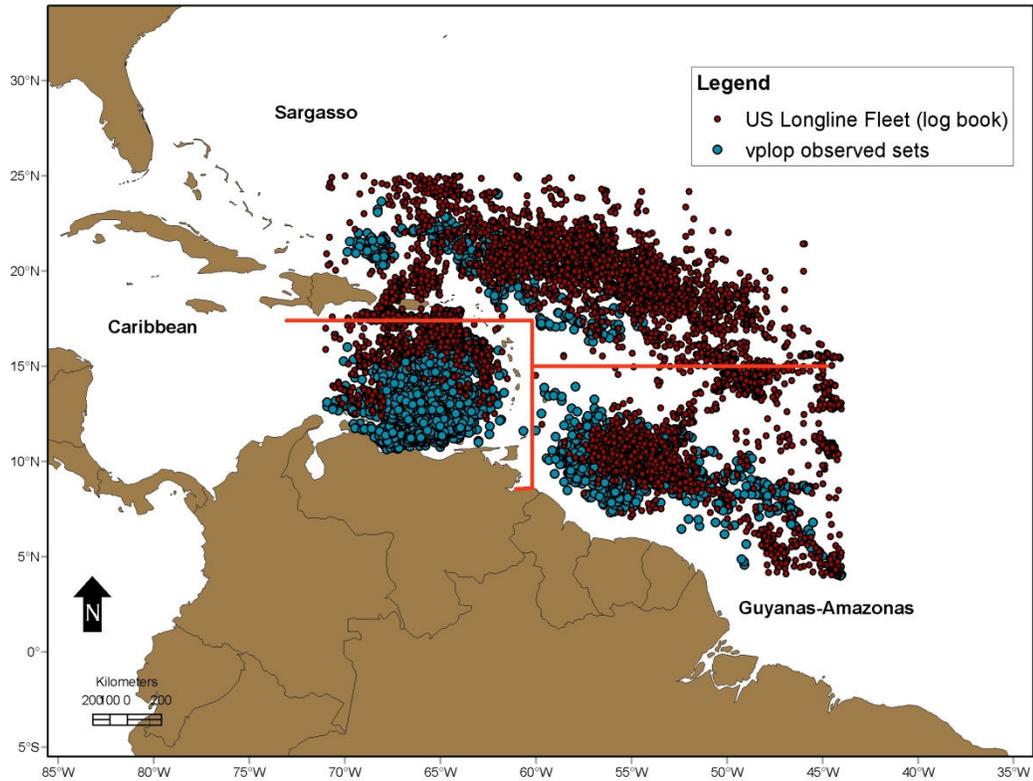


Figure 4.7: Distribution of fishing sets for the Venezuelan pelagic longline observer program (VPLOP), 1991-2006 and the US pelagic longline fleet, fishery logbook system (FLS), 1992-2005.

In the Caribbean and Guyanas/Amazonas areas, sea turtle bycatch from the VPLOP data are clustered offshore the central Venezuelan shelf area (Figure 4.8).

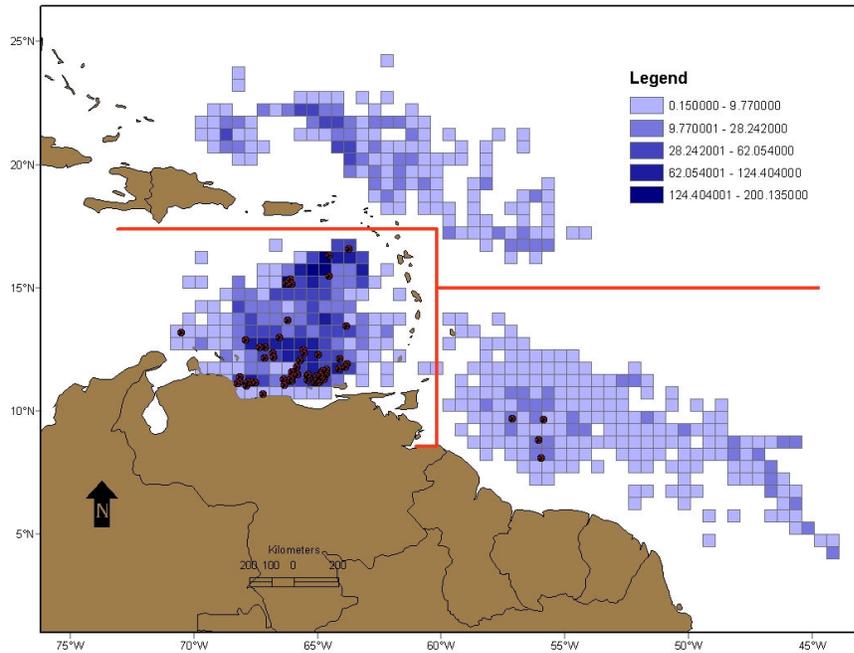


Figure 4.8: Distribution of observed fishing effort and sea turtle bycatch sets (red circles) of the Venezuelan industrial fleet, 1991-2006. Effort ('000 hooks) is summed for the period in 0.5° x 0.5° gridded cells.

The US fleet was not active in the areas off the central Venezuelan platform and bycatch occurred in all three fishing grounds, there is very little overlap between the fleets on the location of bycatch-positive sets (Figure 4.9). Sea turtle bycatch in the US fishery closely matches areas of high fishing effort fishing effort.

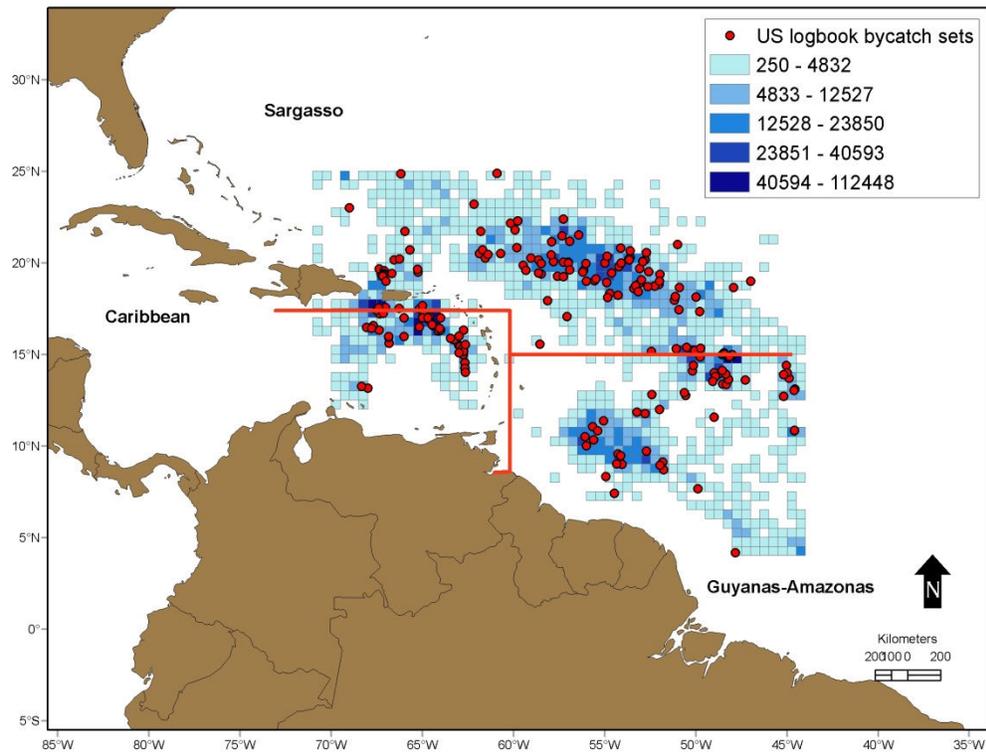


Figure 4.9: Distribution of fishing effort of US fleet based on logbook records, 1992-2005 and location of bycatch sets. Effort is number of hooks per set summed in a 0.5° x 0.5° grid for the period.

Bycatch numbers and composition

A total of 80 turtles were taken in the period 1991-2006 by the Venezuelan fleet and annual total bycatch was zero for several years during the study period (Table 4.3).

Table 4.3: Annual totals of observed sea turtle bycatch, VPLOP, 1991-2006.

Year	Trips	Bycatch	Year	Trips	Turtle bycatch
1991	15	0	1999	39	3
1992	32	0	2000	33	18
1993	34	7	2001	27	0
1994	35	16	2002	18	0
1995	37	2	2003	25	0
1996	33	8	2004	21	5

Table 4.3 continued.

Year	Trips	Bycatch	Year	Trips	Turtle bycatch
1997	45	7	2005	20	2
1998	32	8	2006	16	4

Bycatch in the Venezuelan fishery is dominated by leatherbacks, but greens,

loggerheads and hawksbills were also recorded (Table 4.4).

Table 4.4: Composition of observed sea turtle bycatch in the Venezuelan pelagic longline fishery, 1992-2006.

Species	Number
<i>Caretta caretta</i>	9
<i>Chelonia mydas</i>	8
<i>Dermochelys coriacea</i>	59
<i>Eretmochelys imbricata</i>	4

All six wider Caribbean sea turtle species were taken by the US fleet, with

leatherback and loggerheads comprising 80% of the take (Table 4.5).

Table 4.5: Distribution of sea turtle bycatch by species in US longline sets in the Caribbean based on logbook data, 1992-2005.

Species	Turtle bycatch						Positive sets
	0	1	2	3	4	6	
<i>C. caretta</i>	8473	70	2		1		73
<i>Chelonia mydas</i>	8532	13	1				14
<i>D. coriacea</i>	8421	119	4	2			125
<i>E. imbricata</i>	8538	7	1				8
<i>L. kempii</i>	8544	2					2
Other	8539	6				1	7

Spatial distribution of main bycatch species

Leatherback and loggerhead bycatch by the Venezuelan longliners is clustered off the central Venezuelan shelf, while bycatch for those two species by the US fleet is dispersed throughout the Sargasso and Guianas-Amazonas fishing grounds (Figure 4.10). Within the area of overlap in the Caribbean fishing grounds, bycatch of the two main sea turtle species is clustered in an arc along the Aves Ridge, a north-south oriented submarine ridge extending from 500 km north of Margarita Island to the vicinity of St Croix (Schubert & Laredo 1984), west of the lesser Antillean chain. This is also an area of high effort for the fishery. Clustering of leatherback and loggerhead events in the US fishery also occurs off the edge of the continental shelf off the Guianas. A cluster of loggerhead sea turtle bycatch events also appears in an area north of Puerto Rico in the Puerto Rico Trench.

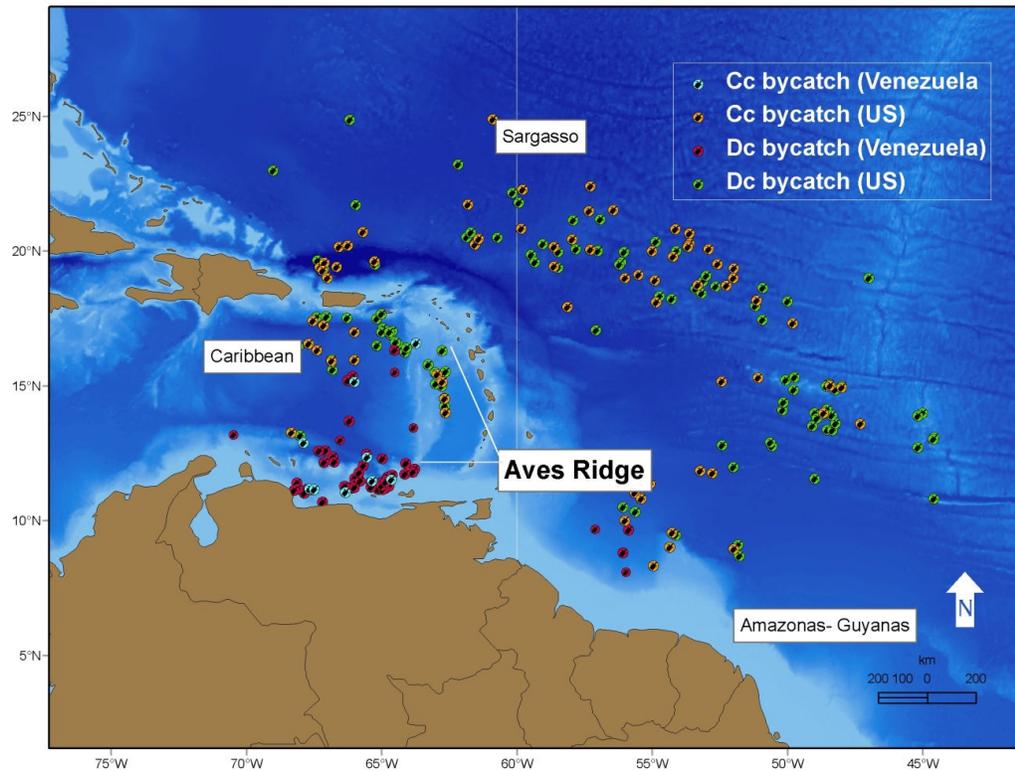


Figure 4.10: Spatial distribution of leatherback and loggerhead bycatch in the Venezuelan (VPLOP data, 1991-2006) and US (FLS, 1992-2005) pelagic longline fleets. Within the Caribbean basin fishing grounds, sea turtle bycatch by the US fleet is clustered in an arc along the Aves Ridge north to the southern Puerto Rican shelf.

Temporal patterns

Sea turtle bycatch by the Venezuelan longliners occurs in all months, with peaks in February and August/ September, while mean effort is highest between May and September, with a low in the spring (Figure 4.11).

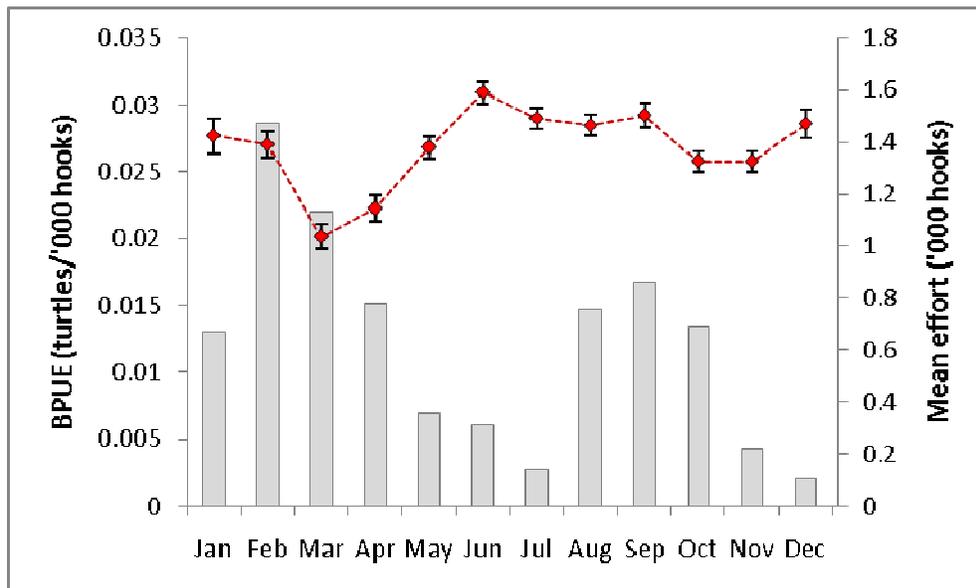


Figure 4.11: Observed nominal sea turtle bycatch rates (turtles/'000 hooks) averaged by month by the Venezuelan industrial pelagic fleet, 1991-2006. Turtle bycatch rates (grey bars) shown on left axes and average effort ('000 hooks, diamonds) on the right axis.

Swordfish CPUE by the Venezuelan fishery declines throughout the year from a spring high. Periods of lower bycatch correspond to peaks in YFT and TUN CPUE (Figure 4.12 and (Figure4.13). Correlation tests found significant positive correlation between turtle BPUE and swordfish CPUE ($\tau=0.11$, p-value <0.001) and significant negative correlation with tuna CPUE ($\tau=-0.04$, p-value <0.001).

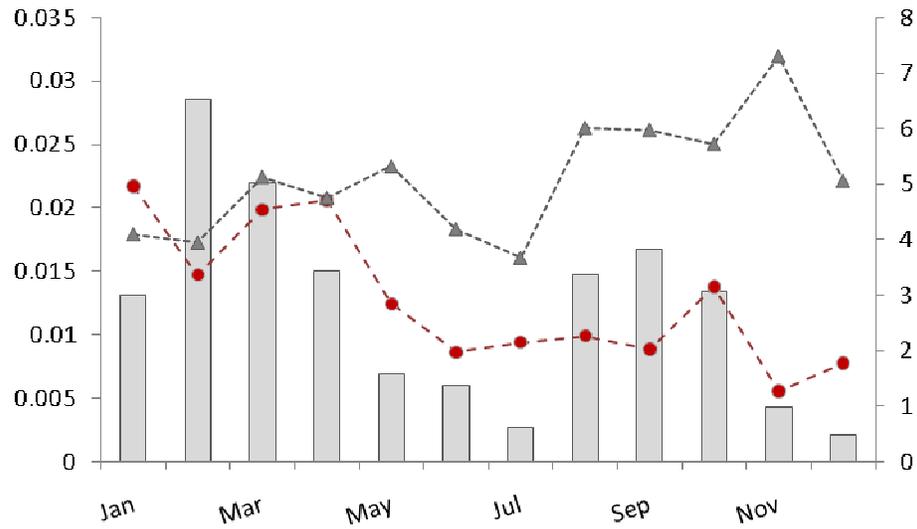


Figure 4.12: Monthly bycatch rates (turtles per 1000 hooks), swordfish and YFT CPUE (fish/ 1000 hooks) observed between 1991 and 2006 for the Venezuelan fishery. Light gray bars represent sea turtle bycatch (left axis), red circles swordfish CPUE and triangles YFT CPUE.

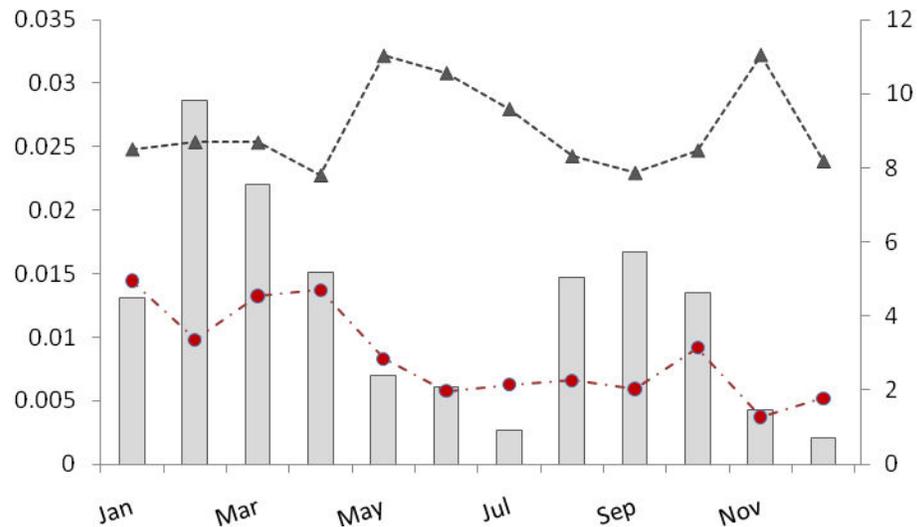


Figure 4.13: Monthly bycatch rates (turtles per 1000 hooks) and swordfish and TUN (main tuna species combined) CPUE (fish/ 1000 hooks) observed between 1991 and 2006.

and 2006 for the Venezuelan fishery. Light gray bars represent sea turtle bycatch (left axis), red circles swordfish CPUE and triangles TUN CPUE.

In contrast, effort in the US fleet is steady, with an average low period in the summer (Figure 13).

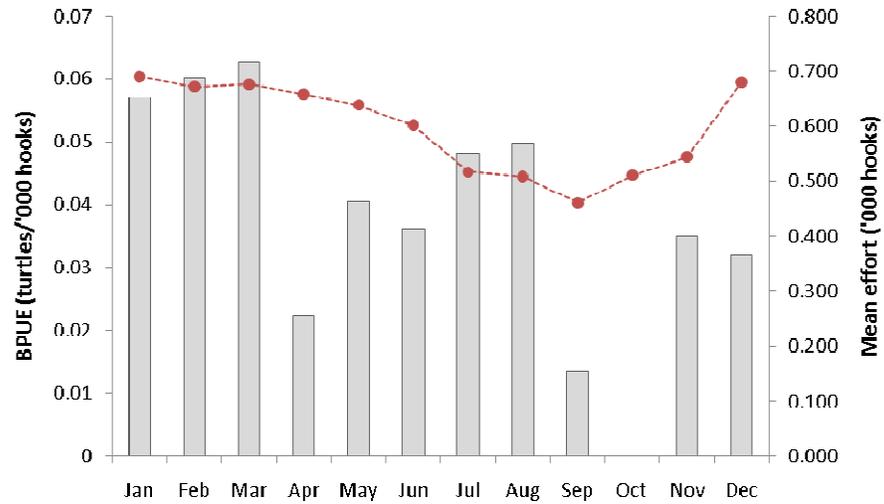


Figure 4.14: Monthly distribution of sea turtle bycatch (individuals /000 hooks) and effort ('000 hooks) for US fleet, 1992-2005, based on Fishery Logbook System (FLS). Sea turtle catch rates shown as grey bars; red circles represent fishing effort.

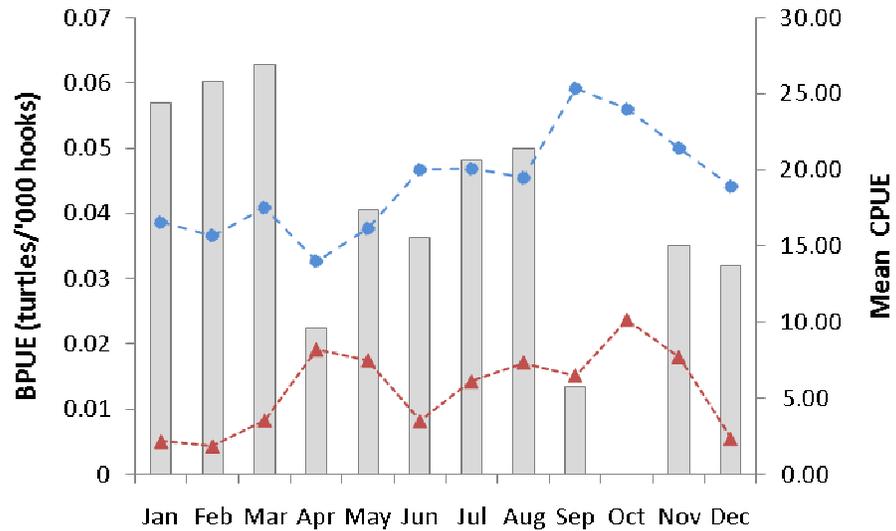


Figure 4.15: Mean sea turtle bycatch rates (BPUE) and target catch rates by month, US fleet (FLS data). Sea turtle BPUE (light gray bars), swordfish CPUE (light blue circles) and yellowfin tuna (red triangles) calculated as individuals/000 hooks.

The US fleet’s swordfish CPUE demonstrates a different pattern from the VPLOP data, with swordfish rates increasing from a spring low, and peaking in the fall. Tuna catch rates in the fishery are fairly steady, but show a winter low.

Periodicity

The FFT analysis identified periodicity on an annual scale (~ 362 days) for albacore (Figure 4.16) and yellowfin tuna (Figure 4.17) catch rates.

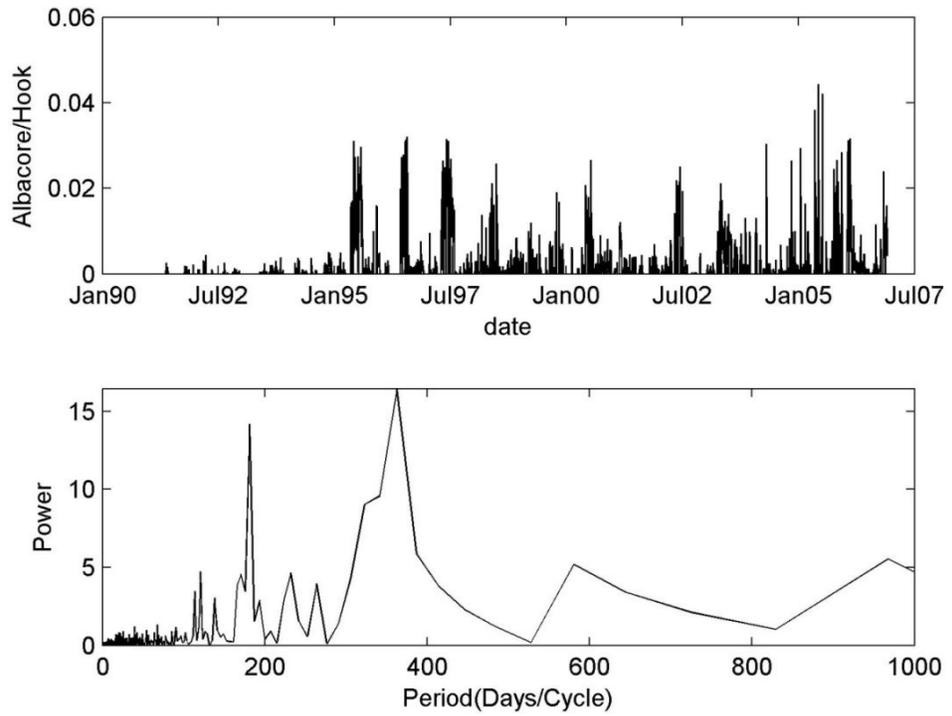


Figure 4.16: Spectral analysis graph (above) and power of periodic peaks (below) for Albacore catch in the Venezuelan fishery. Albacore CPUE show a clear yearly peak ~ 362 day.

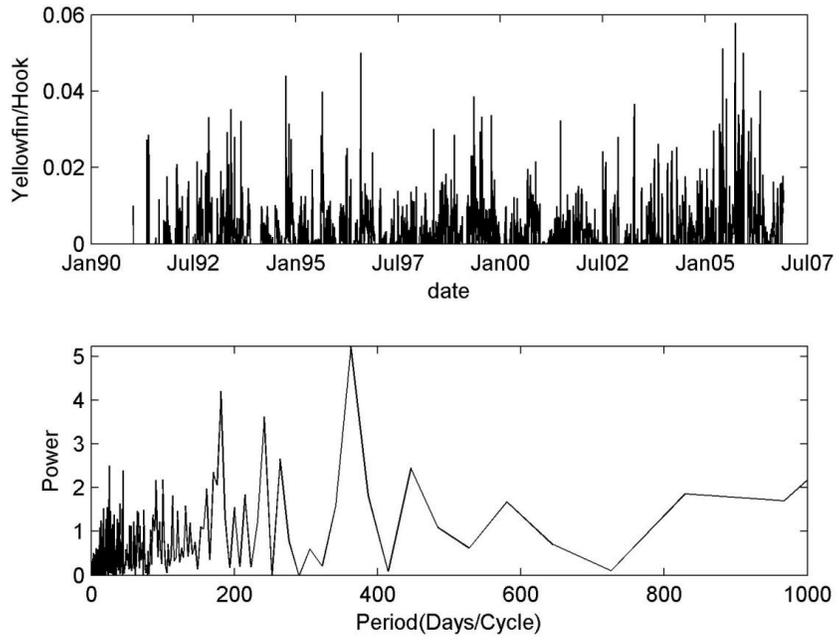


Figure 4.17: Spectral analysis and power of periodic peaks for yellowfin tuna. The yellowfin tuna CPUE show a modest 362 day signal.

No annual cycles were observed for Bigeye tuna (Figure 4.18).

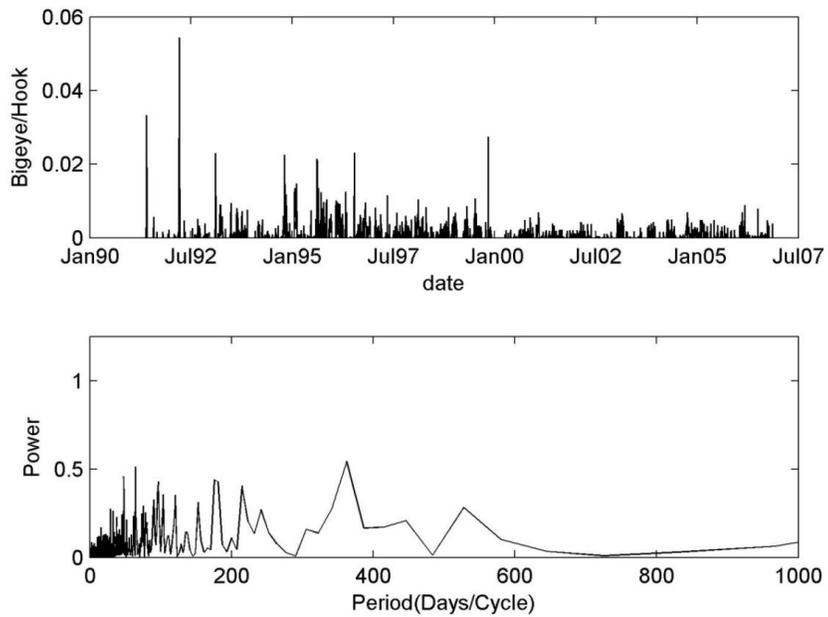


Figure 4.18: Spectral analysis and power of periodic peaks for Bigeye tuna. BET CPUE showed no clear periodic pattern.

The spectral analysis of swordfish catch rates identified no annual signal, but evinced a 29 day periodicity corresponding to a lunar cycle (Figure 4.19).

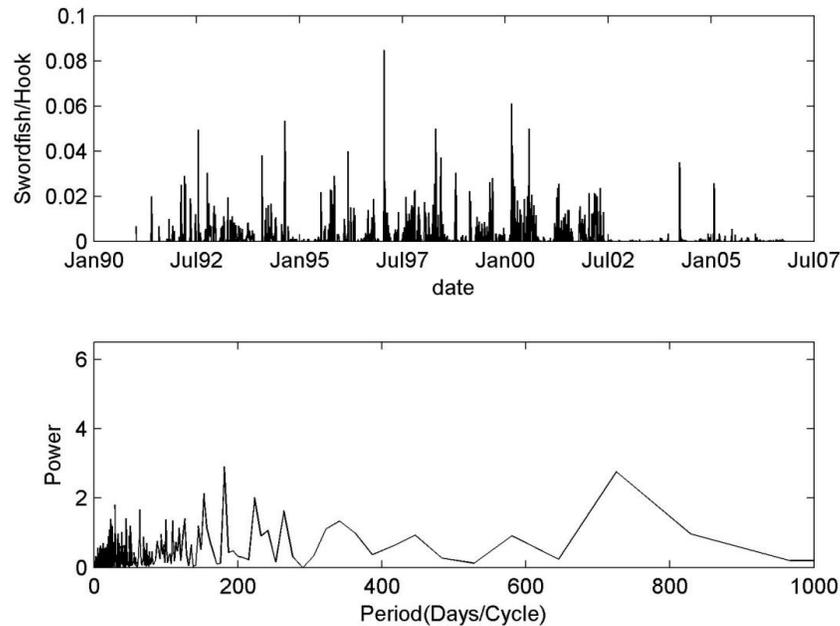


Figure 4.19: Spectral analysis and power of periodic peaks for swordfish catch. Swordfish CPUE displays a 29 day periodicity, but this signal is weaker after 2000.

However these signals are weaker than the annual ones and in the case of swordfish very diminished after 2000. This may signal a change in the fishery; declining swordfish catch rates after 2001 may have made this signal harder to detect.

Summarizing, only Albacore and yellowfin tuna catch rates display any annual periodicity and only swordfish CPUE show a lunar cycle. This is in contrast to the findings of Kot *et al.* (2010) that target catch rates by the US fishery in the tropical latitudes (Caribbean and Guyanas- Amazonas regions) exhibited stronger lunar periodicity than in the higher latitudes. target catch rates show weaker annual and limited lunar periodicity when compared to the US fishery(Anonymous

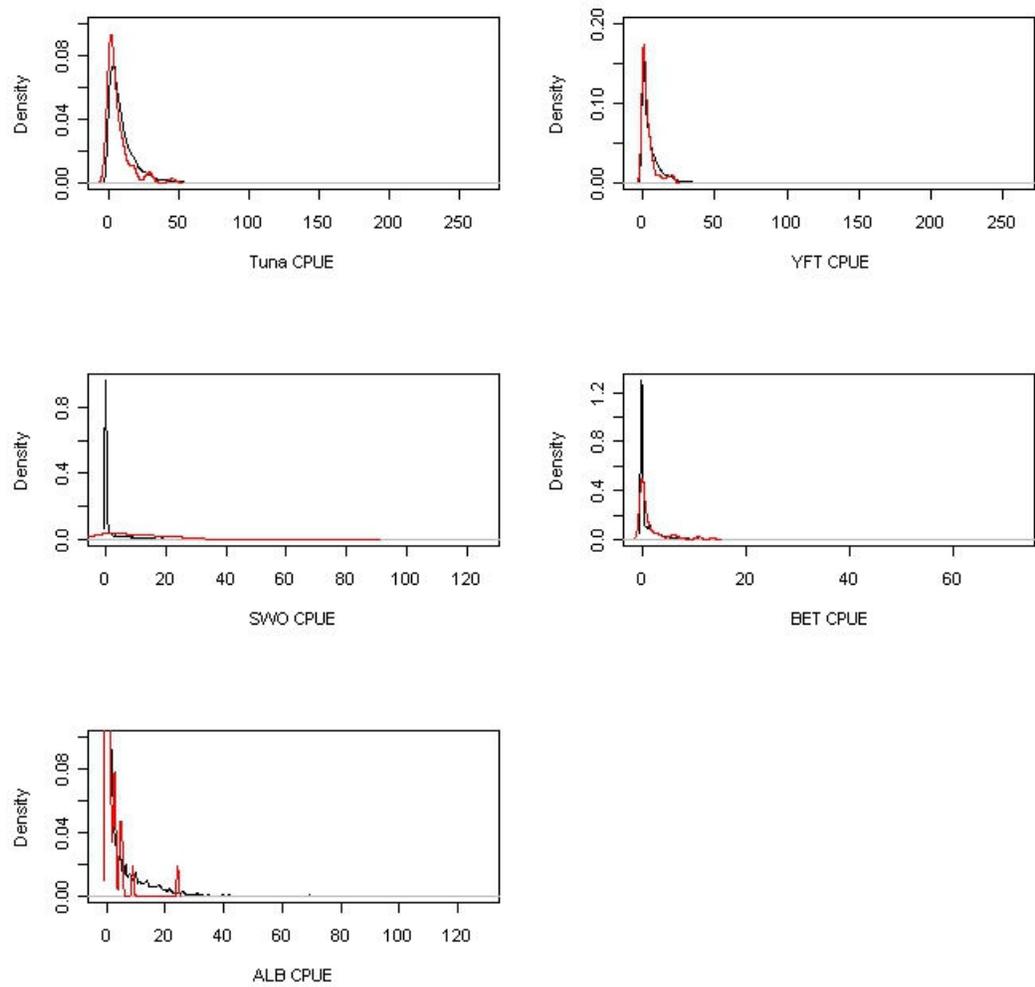


Figure 4.20: Density plots for catch rates (fish/ 1000 hooks) of main target species (YFT, BET, ALB, and TUN (all 3 combined) for the Venezuelan pelagic longline fishery. Density plots for bycatch sets in red, and zero bycatch sets in black.

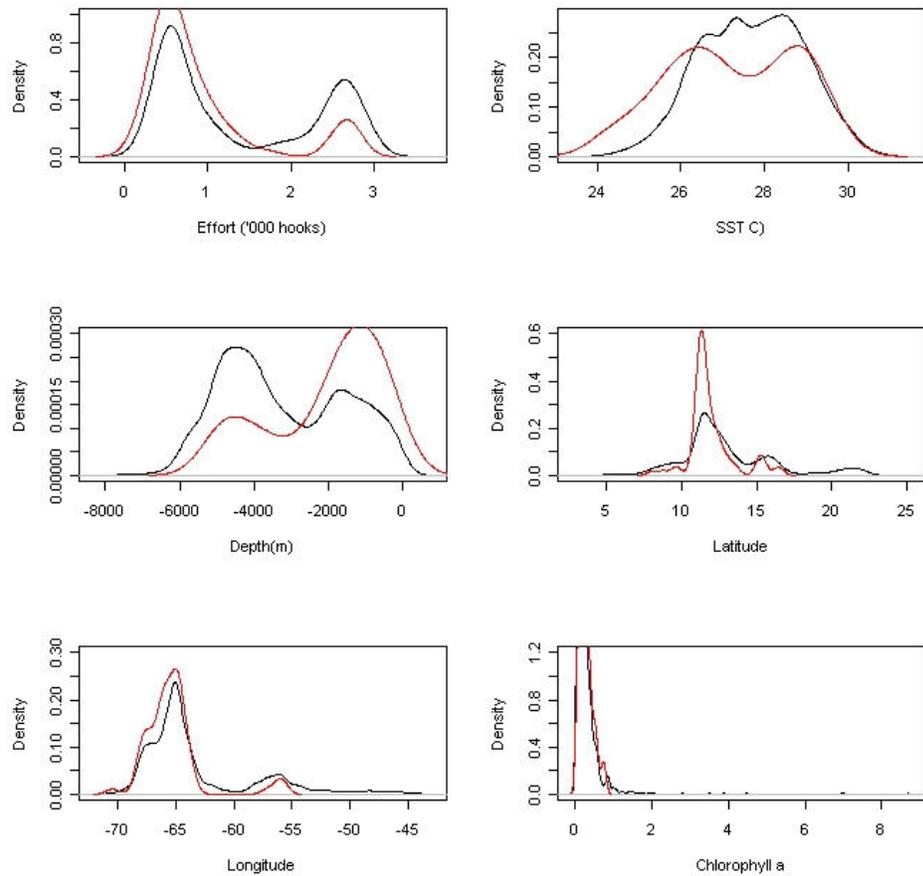


Figure 4.21: Density plots for effort and environmental covariates (depth, SST and chlorophyll a) for the Venezuelan pelagic longline fishery. Plots for zero-bycatch (black line) and bycatch sets (red).

The target catch rates are all positively skewed. Fishing effort (hooks) showed a bimodal distribution and probably reflects a dichotomy between operations in the Sargasso and vessels operating elsewhere. Bycatch events have a lower frequency in sets with more than 1200 hooks, which may be related to the higher swordfish catch rates in

the smaller sets (Figure 4.22) which tend to be located within the Venezuelan basin in the Caribbean fishing ground.

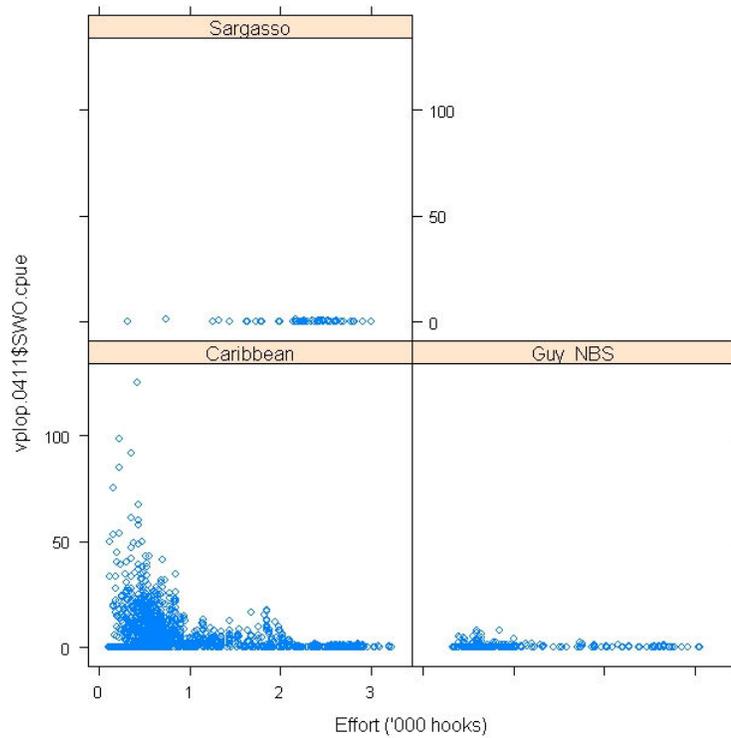


Figure 4.22: Swordfish CPUE (y axis) against effort by fishing ground for the Venezuelan fleet. Swordfish catch rates are higher in sets with fewer hooks in the Caribbean, but catch rates are very low outside of the Caribbean fishing basin.

Because the number of hooks is an interaction (multiplication) of the number of baskets and the number of hooks between baskets, I investigated whether each variable in turn was significantly different between low and high-effort sets. Low-effort sets (less than 1200 hooks) differ significantly from high effort sets both in the number of baskets and the number of hooks between baskets (Wilcoxon ranks sum test, p-value < 0.001).

The density plot for bathymetry also shows a polynomial distribution, with frequency of bycatch becoming more likely where bottom depth is less than 1000m.

I used a box plot to compare nominal sea turtle bycatch rates by moon phase for the Venezuelan fleet. Median values for lunar illumination (represented by increasing moon phase fraction) were marginally higher for bycatch sets (Figure 4.23). A periodicity in sea turtle bycatch related to moon phase would not be unexpected, given the periodicity in swordfish catch rates. However, given the declining signal in swordfish CPUE periodicity and the small bycatch sample, the situation regarding turtle bycatch timing is inconclusive.

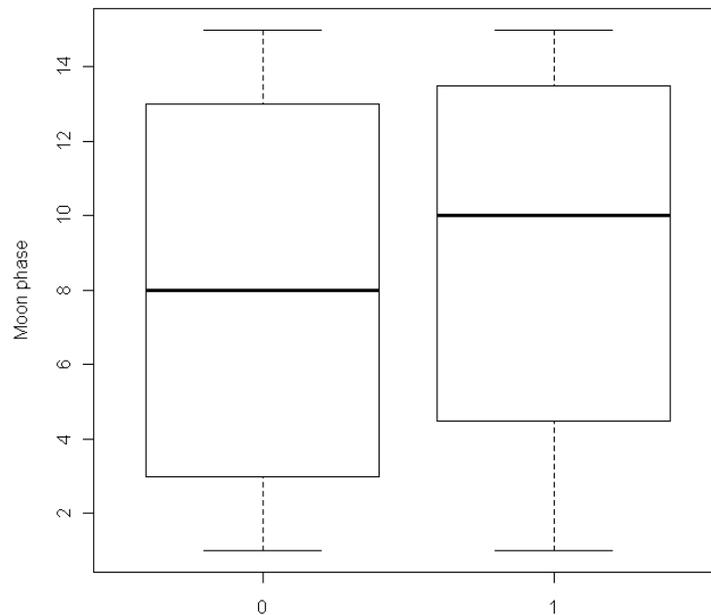


Figure 4.23: Box plot of distribution of bycatch and zero-bycatch sets from VPLOP data with respect to moon phase. Lunar illumination increases with

increasing moon phase from the darkest (new moon or 0) to the brightest (full moon or 1) representing 15 incremental bins.

The distribution of bycatch in the US fishery in relation to target species CPUE is positively skewed (Figure 4.24). The frequency of bycatch-positive sets and zero-bycatch sets is not different for swordfish and Albacore CPUE. Yellowfin and Bigeye tuna show different frequencies, albeit the general shape of the distribution is similar for bycatch and no-bycatch sets.

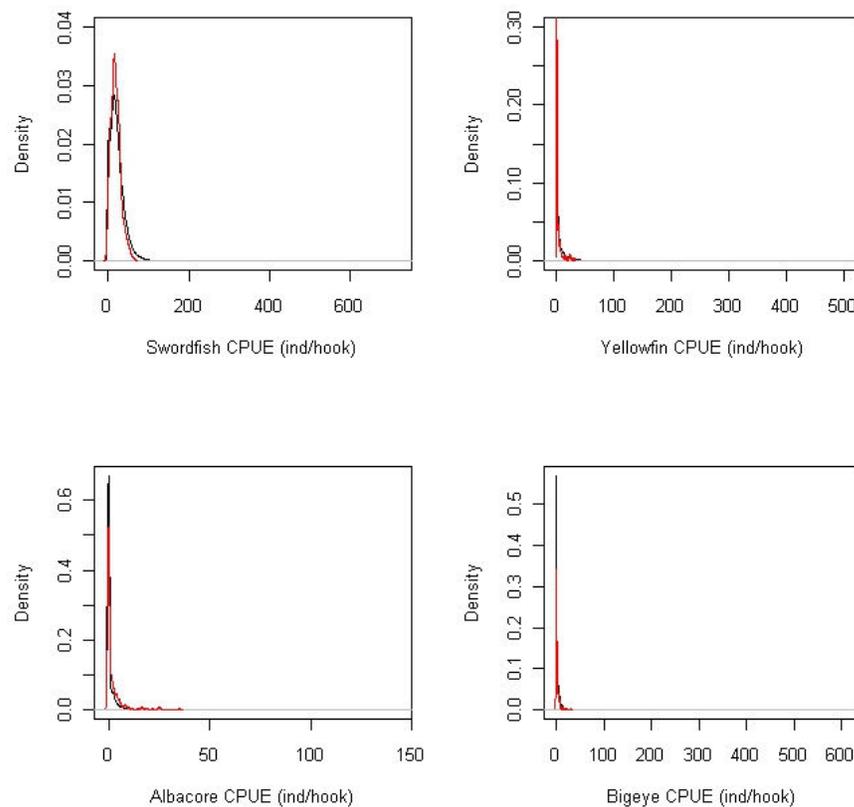


Figure 4.24: Density plots for catch rates (fish/ 1000 hooks) of main target species (YFT, BET, ALB, and TUN (all 3 combined) for the US pelagic longline fishery

from FLS data(1992-2005). Density plots for bycatch sets in red, and zero bycatch sets in black.

Sea turtle bycatch frequency in the US fishery appears to have a different distribution with respect to the number of hooks deployed. The bycatch-positive sets have a greater frequency as the effort increases (Figure 4.25).

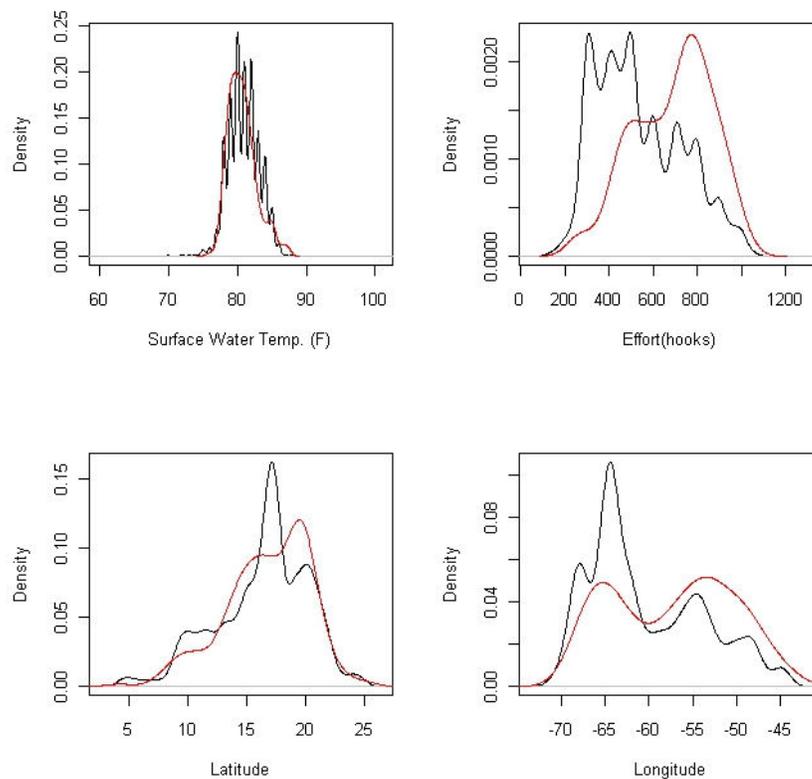


Figure 4.25: Density plots for effort, longitude, latitude and surface water temperature for zero bycatch (black line) and bycatch sets (red) in the US pelagic longline fishery, based on FLS data (1992-2005).

In the US fishery, the density plots shows the frequency of bycatch –positive sets is greater than zero-bycatch sets between 17° and 20° N. The frequency of bycatch is

lower for areas west of longitude 60°W. The surface water temperature did not exhibit a different distribution between bycatch and no-bycatch sets.

4.4 Discussion

Sea turtle bycatch rates in the Venezuelan longline fishery are among the lowest observed for any fleet and there are several reasons to accept the reported bycatch levels. Although recording sea turtle bycatch in the longline fishery was not mandatory, the VPLOP program had links to observer programs for other industrial fisheries that were recording sea turtle bycatch (Freddy Arocha, Instituto Oceanografico de Venezuela, *pers. com.*). It is not an unreasonable assumption that observers considered noting sea turtle bycatch as an important part of the data collection process. Furthermore, the meta-analysis of global bycatch rates by Wallace *et al* (2010) which did not include this data assessed the reported bycatch rates for Caribbean longlines to be among the lowest in the world. This supports to the characterization of the region as low sea turtle bycatch region with respect to industrial pelagic longline gear.

The ultimate goal of most bycatch research is the modeling of the relationship between sea turtle catch rates and the environmental correlates in support of separating fisheries and bycatch taxon. Statistical analysis of sea turtle bycatch in the Venezuelan longline industry may be severely limited, given the data structure. A generalized additive mixed modeling (GAMM) may be useful approach for future studies. This would allow for random effects for the many-level factor of year, while

allowing for a non-parametric smoothing of non-linear variables. However, GAMMs are on the forefront of statistical modeling and the documentation, although growing rapidly, is still limited (Zuur *et al.* 2008).

Never-the-less important insights have been gained from this initial summarization of the main characteristics of sea turtle bycatch by the industrial longline fleet from Venezuela and from the inter fleet comparison. The characterization by the VPLOP database administration of the 67 positive bycatch sets identified 59 of these as swordfish-targeting sets suggesting a strong relationship between fishery target and bycatch. This was also seen in the density plots of distribution of bycatch and non-bycatch sets in relation to swordfish CPUE for the Venezuelan vessels. If practices relating to targeting swordfish strongly influence bycatch then the greater swordfish effort of the US may explain the difference in bycatch rates (mean swordfish CPUE of the US fleet is nearly eight times that of the Venezuelan fleet, 17.1 and 2.7 fish/1000 hooks respectively). It would be useful to re-examine this data with information on estimated set depth, time of setting, vessel characteristics and captains' assessment of fishery target for all sets.

Of interest too is the similarity in distribution between bycatch and non-bycatch sets with respect to SST. Several studies have noted that temperature was not significant in predicting leatherback bycatch numbers but in predicting the probability of bycatch in zero inflated and mixture models (Gardner *et al.* 2008b; Pons *et al.* 2010). Sea surface

temperature ranges in the lower latitudes are always within the physiological tolerance levels of adult leatherbacks but maybe important in habitat selection for juvenile leatherbacks (Eckert 2002). The role of SST in movement dynamics in the tropical reproductive habitat is only now being elucidated (James *et al.* 2005b; Fossette *et al.* 2009) may have life-stage and region-specific differences. SST may influence the distribution of fishing effort for the target catch.

Within the Caribbean basin there appears to be an important center of activity of fishing and bycatch by the US along the Aves Ridge arc and southern edge of the continental slope off Puerto Rico. The Aves Ridge in the region of 14° N -16 ° N is the location of the Caribbean's most active anticyclonic eddy fields. The greatest and most energetic eddies of the Caribbean Sea originate in the Venezuela Basin or enter through Antillean passages (Andrade & Barton 2000; Jouanno *et al.* 2009). Leatherback and loggerhead bycatch in Caribbean longline fisheries maybe be correlated with these mesoscale features. Eddies may entrain chlorophyll-rich, low salinity river waters (Corredor *et al.* 2004)and may represent areas of enhanced foraging opportunities for pelagic catch as well as sea turtles. Data from observer programs on industrial shrimp trawlers in Venezuela found that four species of sea turtles are also captured by trawl fisheries. The estimated fleet-wide take by shrimp trawlers was 330 animals per year, with an associated mortality of $19 \pm 9.7\%$ (Alio *et al.* 2010). Previous analyses using the delta lognormal distribution for longline bycatch rates (previous Chapter) estimates that

1900 turtles were taken during the period under review. While the estimated trawl take is considerably higher than the pelagic longline fleet and engenders a greater mortality, it is comparatively low (0.0011 ± 0.0003 turtles h^{-1}) for an industrial shrimp fishery, further evidence for low bycatch characterization of the Caribbean with respect to industrial fisheries.

A study by Wildermann *et al.* (2009) estimated that loggerhead mortality in the artisanal bottom-set longline fisheries in the Zapara Island area of the Gulf of Venezuela ranged between 147 and 490 animals a year. This fishery targets benthic taxa such as catfish (*Arius* spp.), elasmobranchs, scombrids and snook (*Centropomus undecimalis*). The bottom-set long fishery operates in shallow waters six to sixteen kilometers offshore in a loggerhead foraging hotspot (Párraga *et al.* 2010). This scenario may be similar the Baja Mexico example documented by Peckham *et al.* (2007), in which a nearshore artisanal fishery operating in a sea turtle hotspot engenders bycatch rates equal to or exceeding those of industrial fisheries. The majority of the loggerhead captures were juveniles and large sub-adults (Párraga *et al.* 2010).

Population impact

The immediate mortality rates in the Venezuelan fishery was 0.025, with 78 out of 80 turtles were released alive. The average size of the three bycaught species for which demographic data were collected indicate that this fishery, takes juvenile sea turtles, following the cutoff size categories of Wallace *et al.* (Table 4.6). The preferences and

characteristics of juvenile leatherback habitat is relatively unknown, but the areas offshore Venezuela may be important habitat for juvenile leatherbacks. Leatherback turtles less than 100 cm are believed to remain in tropical waters (Eckert 2002) and the few existing records include Venezuela and the Guianas.

Table 4.6: Size distribution of sea turtle bycatch in the Venezuelan longline fishery, 1991-2006. Carapace length measured from nuchal notch –tip. The size ranges suggest the average turtles taken were juvenile life stages.

Species	<i>n</i>	Average carapace length (carapace notch to tip, in cm)	SD
<i>C. caretta</i>	8	66.38	10.08
<i>C. mydas</i>	3	72.67	17.79
<i>D. coriacea</i>	19	99.79	17.22

The herbivorous green sea turtle is an uncommon take in longline fisheries, but the presence of regionally significant rookeries and extensive sea turtle foraging habitat offshore Venezuela (Guada & Solé 2000) may explain the occurrence of green sea turtles among the bycaught species; known sea turtle foraging have been identified by the Venezuelan national Sea Turtle Recovery Action Plan (Figure 4.26).

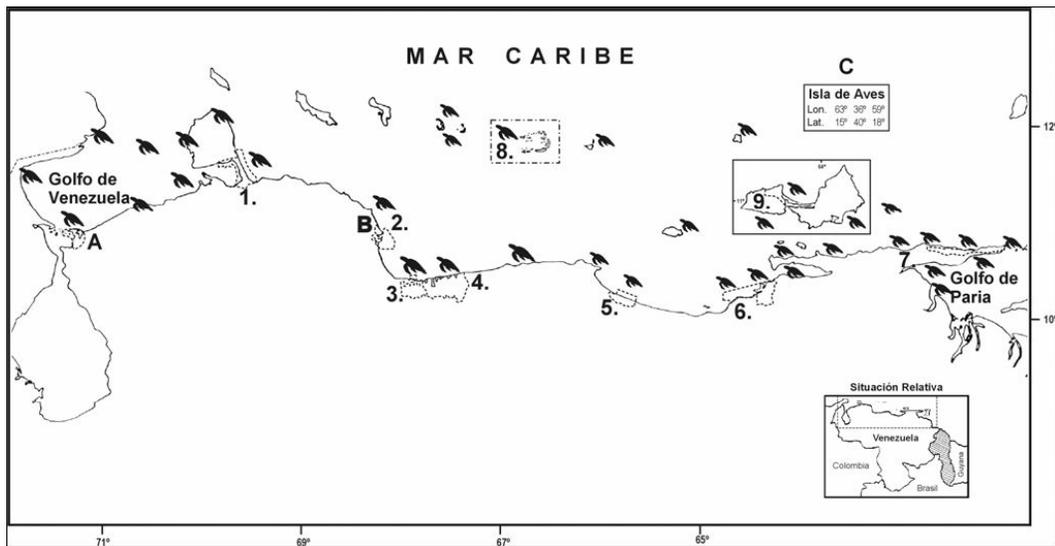


Figure 4.26: Sea turtle foraging areas in Venezuelan waters. Source: Venezuelan National Sea Turtle Recovery Action Plan (Guada & Solé 2000).

Recommendations for bycatch mitigation

Bycatch mitigation strategies for pelagic longlines have focused on changes in gear and fishing practices and spatio-temporal management (Teo & Block 2010). The relatively low rates of sea turtle bycatch in the industrial longline fishery in Venezuela, and the large influence of bait kind and fishery target on bycatch rates suggest that gear and technological changes may be more appropriate than spatio-temporal measures. Such changes (gear/ methods) may have already taken place, as swordfish catch rates (and by extension, either the targeting or incidental capture of swordfish by the fishery) have declined around the period of reported shift to Taiwanese style vessels. The relatively small signal for 29- day periodicity and year to year variability for swordfish catch, also argue against time- area management approaches.

Never-the-less there are areas of that should receive further investigation. The area just east of the Gulf of Venezuela (Zapara Island) has been identified as an important loggerhead foraging area (Wildermann *et al.* 2009). The area north of the Gulf of Paria may also intersect with important inter-nesting corridors for adult leatherbacks (previous chapter) and animals utilizing those zones may face both gillnet bycatch risk in Trinidad and longline bycatch risk in Venezuela

The analytical framework devised by Dunn *et al.* (2011) seeks to enhance targeted spatio-temporal management solutions to reduce bycatch. This assessment of establishes the first branches of the decision tree with regards to managing sea turtle bycatch in pelagic longline fisheries in the southern Caribbean.

5. Regional strategies for mitigating and monitoring sea turtle bycatch in the Wider Caribbean Region

5.1 Introduction

The research presented in the previous chapters reviewed sea turtle bycatch in the wider Caribbean Region (WCR). The research incorporated case studies of industrial and artisanal fisheries to categorize the bycatch landscape for the region and to develop methods to support large-scale bycatch assessment. In this final section, I identify information and data gaps that exist and efforts needed to address them as a means to develop and implement a region-scale bycatch assessment and I recommend broad scale strategies and action to advance management efforts to mitigate sea turtle bycatch. Additionally, I highlight current and potential contributions of some key regional and international entities and instruments that impact fisheries and marine turtle conservation and management.

5.2 Major themes

The previous analyses confirmed that the region was relatively data poor with respect to bycatch information on sea turtles. The paucity of information is not unexpected because Caribbean fisheries primarily are artisanal, nearshore operations which are logistically difficult to observe and operationally complex because they target multiple species and use multiple gear types. Data gaps are particularly acute for

artisanal small scale fisheries (Berkes *et al.* 2001), and information on bycatch is not available for many of the insular territories. Based on the limited information for approximately one-third (14 out of 41) of the non-US territories, approximately 10,000 - 20,000 sea turtles per year encountered fishing gear. In comparison to other ocean basins, however, sea turtle bycatch rates in the WCR by gillnet, longlines and trawl gears was relatively low (Wallace *et al.* 2010).

Industrial pelagic longline fishing efforts occur mainly in the southern part of the basin and also east of the Lesser Antilles. As noted in previous chapters, the different reported bycatch rates between the Venezuelan and US pelagic longline fleets operating within the same spatial and temporal extents may reflect different fishing practices. That assessment and the relatively low bycatch rates suggest that technological changes and/or modifications to fishing practices may be appropriate and effective strategies for mitigating bycatch in pelagic fisheries in this region.

There is some evidence to suggest that bottom set (demersal) longlines present a considerable threat to sea turtle populations in the WRC because of hooking and possible entanglement. Data from US fisheries and recent information from Venezuela's artisanal fisheries indicate that the bottom-set longline fisheries may take hundreds of turtles annually, and exceed the take of the pelagic gear operations in areas where the number of fishers and intense fishing effort and sea turtle habitat overlap. Those demersal target species (elasmobranchs, weakfish) often occur on bottom types (muddy

soft-bottom substrates) and areas favored by loggerheads (*Caretta caretta*). The area off Zapara Island, Venezuela is an example of this overlap of loggerhead foraging habitat and targeted finfish (Wildermann *et al.* 2009). Southern Caribbean populations of loggerheads are not well studied or assessed (Amarocho 2003) even though they may be very important with respect to maintaining the genetic diversity of the species and mortality sources such as incidental capture in fisheries on the South American continental margins should be investigated..

Trawl fisheries in the WCR currently are confronting a decline in catch and competition with imports, and recently Venezuela and Belize have imposed moratoria on this type of industrial operations. Bycatch in trawl fisheries for penaeid shrimp has been the focus of much of the bycatch mitigation and reduction efforts in the region. For example, FAO in conjunction with United Nations Environment Programme (UNEP) and the World Bank recently executed a multi-year project on tropical shrimp fisheries that includes bycatch. These projects and mitigation and experimental trials, involve short-term manipulation or paired testing of fishing operations and typically do not provide the spatio-temporal coverage to capture the variability of catch and effort in the fisheries. While finfish bycatch and target catch rates have been reported from this project, no such information currently is available on sea turtle bycatch from those trials. While robust inferences about sea turtle bycatch numbers or rates may not be possible

from limited sampling or mitigation trials, access to these data would facilitate comparisons with other regions where similar trials have been conducted.

Gillnets are ubiquitous and their design and deployment vary extensively depending on the target objective. My research indicates that large-mesh bottom set gillnets and gillnets set adjacent to large sea turtle rookeries and foraging areas are a major cause for concern because they affect multiple species and are associated with high mortality rates. At least one territory (Mexico) has prohibited the placement of gillnets in front of important nesting beaches (NOM-029-PESC 2006). The use of gillnets in hard-bottom coral reef and seagrass habitat have a high probability of capturing green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) sea turtles. Significant gillnet bycatch occurs in all sub-regions of the WCR, on the continental margins (e.g., Trinidad and the Guianas), the insular Caribbean (e.g., Guadeloupe) and the Gulf and Caribbean coasts of Mexico. Most of the available information on gillnet bycatch pertains to drift gillnets, but mortality rates in bottom set gear may exceed 50% (Delcroix 2003). More data is needed on the distribution and impact of bottom set gillnets in the WCR.

5.3 Closing the gap: observations and recommendations

Spatial-temporal data needs

How can bycatch mitigation and management proceed in this large, geopolitically diverse region given the financial and logistic constraints of acquiring high resolution catch and effort data? The approach discussed in Chapter 2 identifies

strategies to select areas for the detailed investigation of strategic bycatch data collection and reporting called for by some investigators (Wallace *et al.* 2010). Integrating fisheries and telemetry data confirms that fishing in core areas in the nesting season for leatherback sea turtles (*Dermochelys coriacea*) results in more frequent interaction events. Potential high risk areas for sea turtles are those overlap regions where there is a high level of fishing and core home ranges of sea turtles. Identification of kernel home ranges for all sea turtle species in the WCR is an important step that can significantly advance the ability to predict bycatch space. The resolution and accuracy of these predictions can easily be updated as additional data are acquired. Although the interesting and foraging areas for green, hawksbill and loggerhead sea turtles are not as spatially and temporally disjunct as those of the temperate-foraging leatherback sea turtles, association with such static habitat features (e.g. coral reefs and seagrass beds) are well established for those species. Including these in envelope models for those species would greatly improve the utility of these models for those species. The acquisition and sharing of high-resolution geospatial data on bathymetry and bottom habitat to create a regional geospatial database would be of enormous advantage to both regional fisheries management as well as to sea turtle conservation. In the interim, applying the model developed by Dunn and Halpin (2009) to identify hard bottom habitats could be a useful first step.

Recommendation: Enhance the collaboration and sharing of geospatial data on bathymetry and bottom type to provide improved envelope models.

Oceanographic data needs

An understanding of the oceanographic processes and conditions that influence prey distribution is important to help delineate the spatial patterns of sea turtle species, such as loggerheads, leatherbacks and ridley (*Lepidochelys* spp.), which consume mobile prey items. Leatherback prey (e.g., Phylum Cnidaria) occur in the Caribbean (Fossette *et al.* 2009), but estimating their density and distribution is challenging. The effect of oceanographic features and eco-geographical variables on the distribution of sea turtle foraging within the interesting zones and in determining migration corridors remains an important knowledge gap.

Recommendation: Caribbean sea turtle researchers and conservationists need to foster a closer association with regional oceanographic institutions and experts to analyze and identify the relationship between sea turtles and oceanic processes and features..

Fishing effort data needs

Enhanced information on the distribution and timing of fishing effort is another critical link in reducing sea turtle-fisheries encounters. The fishing effort database developed by Dunn *et al.* (2010) for the region can be used to identify the overlap of sea turtle core areas with zones of high fishing intensity Improving the resolution of the

fishing effort metric in the database, as well as gathering information on those fisheries that are not well characterized (numbers of fishers, size of boats, depth and distance from shore) would permit more precise targeting of potential hotspots.

Recommendation: The regional fisheries organizations should support, maintain and expand the current regional fishing effort database.

The Role of Regional Institutions in Bridging This Gap: Recommendations

The Food and Agriculture Organization (of the United Nations) (FAO) Committee on Fisheries (COFI) has the responsibility for fisheries. FAO's Code of Conduct for Responsible Fishing (CCRF) has been a global driver for sustainable fisheries. Biodiversity conservation, including efforts to minimize incidental catch of non-target species are addressed on Article 7.2.2d of the CCRF). FAO held an expert consultation (FAO 2004) which contributed to the identification of geographical areas where interactions between sea turtles and fisheries may have impacts at the population level. Additionally, this consultation developed guidelines to reduce sea turtle mortality in fishing operations (FAO 2005). FAO noted however that formal commitment to and actual implementation of the FAO guidelines is not yet a standard in the fisheries commissions for which turtle bycatch may be an issue.

Recommendation: FAO should support capacity-building of the Regional Fisheries Management Organizations (RFMO) to incorporate non-fish bycatch in the stock assessments and scientific reviews.

Regional Fishery Bodies and Regional Fisheries Management

Several Regional Fisheries Bodies (RFBs) and Regional Fisheries Management Organizations (RFBs with a managerial mandate) implement fishery agreements in the west central Atlantic. In addition to the International Commission for the Conservation of Atlantic Tunas (ICCAT), fisheries-related institutions include the West Central Atlantic Fishery Council (WECAFC) and the Latin American Organization for Fisheries Development (OLDEPESCA). ICCAT and WECAFC jurisdiction encompass the entire west central Atlantic region.

ICCAT through its Sub-Committee on Ecosystems has advanced the organization's ecosystem-based fisheries management, including an increased focus on sea turtle, seabird and marine mammal bycatch in tuna fisheries. ICCAT's expressed agenda is to take a "leading role in the conservation of species caught incidentally in the tuna fisheries, thereby setting an example to other regional fisheries management organizations (RFMOs)". The Commission "encourages the collection and reporting of all available information on interactions with sea turtles in ICCAT fisheries, including incidental catches and other impacts on sea turtles in the Convention area, such as the deterioration of nesting sites and swallowing of marine debris" (ICCAT accessed 3/17/2011). With its target of 5% observer coverage and standards for data collection, ICCAT has an important role in the maintenance of high-resolution database. The existence and availability of the main non-US observer data for longline fisheries

(Venezuelan Pelagic Observer Program) was sponsored by ICCAT under their enhanced billfish monitoring program.

Recommendation: ICCAT should consider mandating incidental catch reporting for sea turtles and air-breathing vertebrates.

Another important regional institution is the Caribbean Regional Fisheries Mechanism (CRFM). The CRFM is an inter-governmental organization established in 2003 to “promote and facilitate the responsible utilization of the region's fisheries and other aquatic resources for the economic and social benefits of the current and future population of the region”. The CRFM was created by an agreement between the Caribbean community of nations (CARICOM), and the CRFM’s membership includes the English-speaking Caribbean territories and Suriname. The CRFM provides technical support to member countries in developing stock assessment and management plans. Although legal sea turtle fisheries constitute a minor item for most Caribbean fisheries and are not included in most fisheries management plans, bycatch as a source of marine turtle mortality must be addressed as part of sustainable fisheries management.

The CRFM was also instrumental in supporting and providing the expertise in assembling the data for developing a geospatial database on Caribbean fishing effort and would be an obvious choice for administering and maintaining that product.

Recommendation: The CRFM should be encouraged to take up the issues of maintenance of the Caribbean fishing effort database and encourage review of sea turtle fisheries management plans by those members with legal turtle fisheries.

Treaties and multi-lateral instruments

The Cartagena Convention is the binding United Nations Environment Programme Regional Seas framework convention for the Wider Caribbean Region. Like other framework instruments, the Cartagena Convention is implemented through a series of protocols. One of these, the Specially Protected Areas and Wildlife Protocol (SPAW) came into effect in 2000 and provides a mechanism for regional scale protection of fragile ecosystems and endangered species. All six sea turtle species of WCR are included in Appendix II of the Convention which prohibits the possession, take or killing of listed species.

The Convention and its attendant SPAW Protocol have supported the Wider Caribbean Sea Turtle Conservation Network (WIDECAST) in the preparation of national sea turtle recovery action plans (STRAPs). The SPAW Protocol provides for the establishment of a “scientific and technical advisory committee” of government-designated experts. The identification of high use, interesting area by sea turtles fits well within the purview of SPAW, given the Protocol’s focus on ecosystems and key habitats. An important step in that direction has been the recent examination by SPAW of the feasibility of pooling available telemetry data on hawksbill sea turtles. The Trans-

Atlantic Leatherback initiative provides a model for collaboration to conduct occurrence and use at the ocean-basin scale.

Recommendation: The SPAW should consider creating a partnership between NGOs, academics and to integrate and analyze Caribbean hawksbill telemetry data.

The Inter-American Convention for the Protection of Sea Turtles (IAC) entered into force in 2001 and is one of three multilateral treaties specifically focused on sea turtle protection and conservation and the only one in the western hemisphere. Given its specific mandate for sea turtle protection and conservation, the IAC should spearhead the coordination of the resources of the relevant multi-lateral treaty organizations towards regional coordinated management of these transboundary resources

The NGO /Scientific Community

The Caribbean has benefitted from active and efficient technical networks such as WIDECAS. WIDECAS has disseminated information and provided training, technical expertise and regional database maintenance for the region. WIDECAS has Community engagement in finding solutions to unsustainable use of sea turtle and marine resources. The WIDECAS network on in country volunteers was central to uncovering information unpublished information and reports on sea turtles and fisheries. WIDECAS research projects and partnerships have been instrumental in providing data on nesting beaches and sea turtle movement and habitat use. The

collaboration between WIDECAST and Conservation International” State of the World’s Turtles in providing information on nesting population size and trends will also facilitate updating the characterization of rookeries, a key variable in the habitat models.

Recommendation: That the NGO, research and conservation community work with stakeholders to gather information on trends in nesting population and to maintain a dynamic atlas of wider Caribbean rookery sites.

The Millennium Assessment identified over exploitation, including bycatch, as driver of change and loss of marine biodiversity (Millennium Ecosystem Assessment 2005). Despite the many challenges, assessing and mitigating bycatch is an important regional environmental and economic issue. The research methods identified in the preceding chapters provide a broad outline of the bycatch landscape for this region and suggest topic areas and fisheries that warrant closer examination. Additionally, I offer strategies for countries in data poor regions to make preliminary assessments of bycatch. The discussion further demonstrates that it is possible to integrate existing literature sources, local ecological knowledge, expert opinion and spatial data on bycatch..

Appendix A:

Sea turtle, marine mammal and seabird species that occur in the Caribbean region
with respective IUCN Red List category

Species	Common Name	IUCN status	IUCN Category
<i>Caretta caretta</i>	Loggerhead sea turtle	Endangered	EN A1abd
<i>Chelonia mydas</i>	Green sea turtle	Endangered	EN A2bd
<i>Eretmochelys imbricata</i>	hawksbill	Critically endangered	CR A1bd
<i>Lepidochelys kempii</i>	Kemp's ridley sea turtle	Critically endangered	CR A1ab
<i>Lepidochelys olivacea</i>	Olive ridley sea turtle	Endangered	EN A1bd
<i>Dermochelys coriacea</i>	Leatherback sea turtle	Critically endangered	CR A1abd
<i>Balaenoptera acutorostrata</i>	Minke whale	Lower risk/not threatened	LR/nt
<i>Balaenoptera borealis</i>	Sei whale	Endangered	EN A1abd
<i>Balaenoptera edeni</i>	Brydes whale	Data deficient	DD
<i>Balaenoptera musculus</i>	Blue whale	Endangered	EN A1abd
<i>Balaenoptera physalus</i>	Fin whale	Endangered	EN A1abd
<i>Delphinus delphis</i>	Short beaked common dolphin	Lower risk/least concern	LR/lc
<i>Delphinus capensis</i>	Long-beaked dolphin	Data deficient	DD
<i>Eubalaena glacialis</i>	North Atlantic right whale	Endangered	EN D
<i>Feresa attenuata</i>	Pygmy killer whale	Data deficient	DD
<i>Globicephala macrorhynchus</i>	Short-finned pilot whale	Lower risk/conservation dependent	LR/cd
<i>Grampus griseus</i>	Rissos dolphin	Data deficient	DD
<i>Halichoerus grypus</i>	Gray seal	Lower risk/least concern	Lr/lc
<i>Kogia breviceps</i>	Pygmy sperm whale	Lower risk/least	LR/lc

Appendix A continued.

Species	Common Name	IUCN status	IUCN Category
<i>Kogia sima</i>	Dwarf sperm whale	Lower risk/least concern	LR/lc
<i>Lagenodelphis hosei</i>	Frasers dolphin	Data deficient	DD
<i>Megaptera novaeangliae</i>	Humpback whale	Vulnerable	VU A1ad
<i>Mesoplodon densirostris</i>	Blainvilles beaked whale	Data deficient	DD
<i>Mesoplodon europaeus</i>	Gervais beaked whale	Data deficient	DD
<i>Mesoplodon mirus</i>	Trues beaked whale	Data deficient	DD
<i>Mesoplodon bidens</i>	Sowerby's beaked whale	Data deficient	DD
<i>Orcinus orca</i>	Killer whale	Lower risk/conservation dependent	LR/cd
<i>Peponocephala electra</i>	Melon-headed whale	Lower risk/least concern	LR/lc
<i>Physeter macrocephalus</i>	Sperm whale	Vulnerable	VU A1bd
<i>Pseudorca crassidens</i>	False killer whale	Lower risk/least concern	LR/lc
<i>Sotalia fluviialis</i>		Data deficient	DD
<i>Stenella attenuata</i>	Pantropical spotted dolphin	Lower risk/conservation dependent	LR/cd
<i>Stenella clymene</i>	Clymene dolphin	Data deficient	DD
<i>Stenella coeruleoalba</i>	Striped dolphin	Lower risk/conservation dependent	LR/cd
<i>Stenella frontalis</i>	Atlantic spotted dolphin	Data deficient	DD
<i>Stenella longirostris</i>	Spinner dolphin	Lower risk/conservation dependent	LR/cd
<i>Steno bredanensis</i>	Rough-toothed dolphin	Data deficient	DD
<i>Tursiops truncatus</i>	Bottlenose dolphin	Data deficient	DD

Appendix A continued.

Species	Common Name	IUCN status	IUCN Category
<i>Ziphius cavirostris</i>	Cuviers beaked whale	Data deficient	DD
<i>Trichechus manatus</i>	West Indian manatee	Vulnerable	VU C1
<i>Pterodroma caribbaea</i>	Jamaica petrel	Critically endangered	CR D EN
<i>Pterodroma hasitata</i>	Black-capped petrel	Endangered	B2ab(i,ii,iii,iv,v)
<i>Pterodroma cahow</i>	Bermuda petrel	Endangered	EN D
<i>Puffinus lherminieri</i>	Audubon's shearwater	Least concern	LC
<i>Phaethon lepturus</i>	White-billed tropic bird	Least concern	LC
<i>Phaethon aethereus</i>	Red-billed tropic bird	Least concern	LC
<i>Pelecanus occidentalis</i>	Brown pelican	Least concern	LC
<i>Pelecanus erythrorhynchos</i>	American White pelican	Least concern	LC
<i>Phalacrocorax auritus</i>	Double-crested cormorant	Lower risk/least concern	LC
<i>Fregata magnificens</i>	Magnificent frigatebird	Least concern	LC
<i>Sula dactylara</i>	Masked booby	Least concern	LC
<i>Sula sula</i>	Red-footed booby	Least concern	LC
<i>Sula leucogaster</i>	Brown booby	Least concern	LC
<i>Sula nebouxii</i>	Blue-footed booby	Least concern	LC
<i>Stercorarius pomarinus</i>	Pomarine jaegar	Least concern	LC
<i>Stercorarius parasiticus</i>	Parasitic jaegar	Least concern	LC
<i>Larus atricilla</i>	Laughing gull	Least concern	LC
<i>Larus argentatus</i>	Herring gull	Least concern	LC
<i>Larus delawarensis</i>	Ring-billed gulls	Least concern	LC
<i>Sterna forsteri</i>	Forster's tern	Lower risk/Least concern	LC
<i>Sterna dougalli</i>	Roseate tern	Least concern	LC
<i>Sterna hirundo</i>	Common tern	Least concern	LC
<i>Sterna maxima</i>	Royal tern	Least concern	
<i>Sterna antillarum</i>	Least tern	Least concern	LC
<i>Sterna anaethetus</i>	Bridled tern	Least concern	LC
<i>Sterna eurygnatha</i>	Cayenne tern	Least concern	LC
<i>Sterna sandwicensis</i>	Sandwich tern	Least concern	LC

Appendix A continued.

Species	Common Name	IUCN status	IUCN Category
<i>Sterna nilotica</i>	Gull-billed tern	Least concern	LC
<i>Chlidonias niger</i>	Black tern	Least concern	
<i>Anous minutus</i>	Black noddy	Least concern	LC
<i>Anous stolidus</i>	Brown noddy	Least concern	LC

Appendix B

SURVEY OF INCIDENTAL CATCH

Interviewer Initials:

Date

Location

1. Landing beach

2. Home Port (if different)

3. Name (include alias(es):

4. Do you fish (Circle one):

Full time

part time

not as a rule

5. How many years? _____

6. What fishing gear do you use?

7. How do you fish (method, time of day)?

8. Where do you fish?

9. How far away from shore do you fish?

10. In waters how deep?

16. Do you know of any other instances of sea turtles, sea birds, whales, dolphins or manatees being incidentally captured in fishing gear?

YES

NO

17. If yes, which species?

18. If yes, when?

19. If yes, where?

20. If yes, how many?

Thank You!

APPENDIX C

R CODE USED TO PRODUCE FIGURES AND TABLES IN CHAPTERS 3 AND 4

```
library(MASS)
library(shapefiles)
library(adehabitat)
library(maps)
require(mapdata)
library(lattice)
library(trip)
library(argosfilter)
library(PBSmapping)
## reading in argos files using
dir.Trinidad = 'Z:/Academic_dissertation/Dissertation/base' ## directory
##containing Argos telemetry files
setwd ("Z:/Academic_dissertation/Dissertation/base")
argosTDAD<- list.files(dir.Trinidad, full.names=TRUE, recursive=TRUE)
TDADDraw<- readDiag(argosTDAD)      ## read Argos filters with function
##from package "trip"

## selecting best per day, using noon as reference point
TDADDraw = data.frame(TDADDraw, day=as.Date(TDADDraw$gmt),
                      day.noon = strptime(sprintf('%s 12:00:00', strftime(TDADDraw$gmt,
format="%Y-%m-%d", tz='gmt')), format="%Y-%m-%d %H:%M:%S", tz='gmt'),
                      filt.sda=character(nrow(TDADDraw)),
best.per.day=character(nrow(TDADDraw)), stringsAsFactors=F)
TDADDraw = data.frame(TDADDraw, day.noon.diff =
abs(as.numeric(difftime(TDADDraw$gmt,TDADDraw$day.noon, units='mins', tz='gmt'))))

# label points with filter result
for (id in unique(TDADDraw$id)){ # id = unique(TDADDraw$id)[1]
  idx = which(TDADDraw$id==id)
  ## applying argos filter, with max. speed set at 1.1 m/s and no turning angles
  filt.sda = sdafilter(TDADDraw[idx,'lon1'], TDADDraw[idx,'lat1'],
TDADDraw[idx,'gmt'], TDADDraw[idx,'lq'], vmax=1.1, ang=-1)
  TDADDraw[idx,'filt.sda'] = filt.sda
  ##argos filter returns vector with ID, LAT LON data, and designation
#("removed", "not removed", "end location")
```

```

# remove "removed" and get subset of tag by id data
# get best one per day, per tag
for (day in unique(TDADraw[TDADraw$filt.sda!='removed','day'])) { # day =
unique(TDADraw[TDADraw$filt.sda!='removed','day'])[1]
  idx = which(TDADraw$filt.sda!='removed' & TDADraw$day==day)
  TDADraw[idx[order(TDADraw[idx,'lq'], TDADraw[idx,'iq'], -
1*TDADraw[idx,'day.noon.diff'], decreasing=T)[1]], 'best.per.day'] = 'best'
}
}

table(TDADraw$id, TDADraw$lq) #summarizing the telemetry locations by
#animal id (Table 3. 1)
setwd ("Z:/Academic_dissertation/Dissertation/base")
filt_raw<-data.frame(TDADraw, filt.sda)
write.table (filt_raw, "filt_0408.csv", sep=",", header=T, quote=FALSE) ##
#telemetry data with filter result (filt.sda field), and best per day field that indicates if
#point is best per day (best") or not (Null)

y <- read.csv('tel12nov_resid2.csv', header=T) #This is the dataset with telemetry
#locations, with points where location process failed("Z), points land removed and
#clipped to interesting period in ArcGIS.
View(y)
dim(y)
table(y$id, y$lq) ##summarizing the locations by animal id (Table 3. 2)

presence= read.csv("tel_presence.txt" , header=T, sep=";", na.strings="-9999",
comment="") # 142 best locations per day in the interesting habitat
table(presence$id, presence$lq) #summarizing the 142 best per day in
#interesting area locations by animal id (Table 3. 3)

tel = read.csv("telemetry0408.txt" , header=T, sep=";", na.strings="-9999",
comment="") ## file with the 142 best lcoations per day plus 100 pseudo absences)
with values for environmental variables sampled using MGET Tools in ArcGIS
tel[tel== -9999] = NA
tel[tel== -999 ]= NA

## reading bycatch data
bc= read.csv("bycatch0307.txt" , sep=";", header= T, as.is =5, na.strings= "-9999",
comment="") # dataset of Trinidad fishing locations and bycatch data with values for
#the environmental variables sampled using MGET tools in ArcGIS

```

```

View(bc)
bc[bc== -9999]=NA

# summary statistics for telemetry and bycatch datasets
library(fields)
# Summary statistics for telemetry data
stats_c= cbind( tel$dis2_any/1000, tel$dis2small/1000, tel$dis2_2or3/1000,
tel$dis2_shore/1000, tel$dis2_200/1000, tel$depth, tel$SST, tel$chl )
colnames(stats_c) =c("Distance to nearest nesting beach", "Distance to nearest
small nesting beach" , "Distance to nearest major nesting beach", "Distance to shore",
"Distance to shelf", "Depth", "SST", "Chlorophyll a")
stats(stats_c)
# Summary statistics for bycatch data
stats.bycatch =cbind( bc$Effort_a, bc$dis2_2or3/1000, bc$dis2_any/1000 ,
bc$dis2_200/1000, bc$dis2shor_2/1000, bc$depth0823, bc$SST, bc$chl, bc$chl2,
bc$Residency)
colnames(stats.bycatch) =c( "Effort" , "Distance to nearest major nesting beach"
,"Distance to nearest nesting beach", "Distance to shelf" , "Distance to shore",
stats(stats.bycatch)

##Density plots to show frequency distribution of presence and pseudo absence
#locations with respect to environmental variables
tel.1= tel[tel$presence==1,] ## presence locations telemetry data
tel.2 =tel[tel$presence==0,] ## pseudo absence locations
query1=! (is.na (tel$QUAL)) # removes missing values and low accuracy SST
#values by removing missing values for the filed denoting the quality of the SST
estimate (QUAL)
tel.3 = tel[query1,] ## dataset with missing SST vlaues removed
tel.3a=tel.3[tel.3$presence==1,]
tel.3b=tel.3[tel.3$presence==0,]
## figure 3.9
par(mfrow= c (4,2))

plot(density(tel.1$dis2_2or3), xlab= "Distance to nearest large or medium nesting
beach", ylab= "Density" , main= "a" )
lines(density(tel.2$dis2_2or3),lty=2)

plot(density(tel.1$dis2small), xlab= "Distance to nearest small nesting beach",
ylab= "Density" , main= "b" )
lines(density(tel.2$dis2small), lty=2)

```

```

        plot(density(tel.1$dis2_any), xlab= "Distance to nearest nesting beach", ylab=
"Density", main="c" )
        lines(density(tel.2$dis2_any),lty=2)

        plot(density(tel.1$dis2_shore), xlab= "Distance shoreline", ylab= "Density",
main="d" )
        lines(density(tel.2$dis2_shore), lty=2)

        plot(density(tel.1$dis2_200), xlab= "Distance to shelf", ylab= "Density" , main="e"
)
        lines(density(tel.2$dis2_200), lty=2)

        plot(density(na.omit(tel.1$depth)) , xlab= "Depth", ylab= "Density", main="f" )
        lines(density(na.omit(tel.2$depth)), lty=2)

        plot(density(tel.3a$SST) , xlab= "SST",main="g", ylab= "Density" ) ## data with
mssing SST removed
        lines(density(tel.3b$SST), lty=2)

        plot(density(na.omit(tel.1$chl)), xlab= "Chlorophyll a",main="h", ylab= "Density"
)
        lines(density(na.omit(tel.2$chl)), lty=2)

##density plots for byacatch data (Figures 3.10 & 3.11)
bc1= bc[bc$bycatch_C==1,]      #bycatch-positive sts
bc0= bc[bc$bycatch_C==0,]      ##zero bycatch sets
dev.new()
par(mfrow= c (3,2))

        plot(density(bc1$dis2_2or3), xlab= "Distance to nearest large or medium
nesting beach",ylim=c(0, 0.0002), ylab= "Density" , main= "a" )
        lines(density(bc0$dis2_2or3), lty=2)

        plot(density(bc1$dis2_any), xlab= "Distance to nearest nesting beach", ylab=
"Density", main="b" )
        lines(density(bc0$dis2_any), lty=2)

        plot(density(bc1$dis2shor_2), xlab= "Distance shoreline", ylab= "Density",
main="c" )

```

```

lines(density(bc0$dis2shor_2), lty=2)

plot(density(bc1$dis2_200), xlab= "Distance to shelf", ylim=c(0, 0.00035),ylab=
"Density" , main="d" )
lines(density(bc0$dis2_200), lty=2)

plot(density(bc1$Effort_a), xlab= "Fishing effort",ylim=c(0, 0.0001), ylab=
"Density" , main="e" )
lines(density(bc0$Effort_a), lty=2)
dev.new()
par(mfrow= c (2 ,2))
plot(density(na.omit(bc1$depth0823)), xlab= "Depth", ylab= "Density",ylim=c(0,
0.05), main="a" )
lines(density(na.omit(bc0$depth0823)), lty=2 )

plot(density(na.omit(bc1$SST)), xlab= "SST",main="b", ylim=c(0, 0.5),ylab=
"Density" )
lines(density(na.omit(bc0$SST)), lty=2)

#
plot(density(na.omit(bc1$chl2)), xlab= "Chlorophyll a",main="c", ylab=
"Density" )
lines(density(na.omit(bc0$chl2)), lty=2)

plot(density(na.omit(bc1$chl)), xlab= "Chlorophyll a (SeaWIFS)",main="d",
ylim=c(0, 0.5),ylab= "Density" )
lines(density(na.omit(bc0$chl)), lty=2)

##kernel density estimation

## creating shapefile of kernel home range contour for all turtles, kernel density
#estimated using adehabitat package
library(adehabitat)
#function to create shapefile of contours for UD levels 25%,50%,75%,95%, 99%
exportshape<-function(ud,name,dir){

kv<-list()
class(kv) <- "kver"

kvtmp <- getverticeshr(ud, lev = 99)

```

```

kv$KHR99<- kvtmp[[1]]

kvtmp <- getverticeshr(ud, lev = 95)
kv$KHR95<- kvtmp[[1]]

kvtmp <- getverticeshr(ud, lev = 75)
kv$KHR75<- kvtmp[[1]]

kvtmp <- getverticeshr(ud, lev = 50)
kv$KHR50<- kvtmp[[1]]

kvtmp <- getverticeshr(ud, lev = 25)
kv$KHR25<- kvtmp[[1]]

xy <-presence[ ,c("lon1", "lat1")]
id<- presence[, "id"]
ud= kernelUD(xy, id, h = 0.09, hlim=c(0.05,1.5), grid = 600, same4all = TRUE, #
h set by examining LSCV plot
  kern = "bivnorm", extent = 0.5)
  image(ud, axes=FALSE,mar=c(0,0,2,0), addcontour=TRUE, addpoints=TRUE)#
image of the kernel home ranges

shp<-kver2shapefile(kv)
filename<-paste(dir,name, sep="")
write.shapefile(shp,filename,arcgis=TRUE) ## produces contours of
#kernel home range for all turtles (Figure3.12)
}
exportshape(ud, "khr_ud3", "Z:/Academic_dissertation/Dissertation/base")

## estimating overlap of east coast and north coast turtle home ranges
## creating field "Coast" to designate the coastline where each turtle was tagged;
#east coast (EC) or north coast (NC)
coast= rep(0, nrow(presence))
for (i in 1:nrow(presence)) {
  if (presence$id[i]==1199 )
  coast[i]= 1
  if (presence$id[i]==40982 )
  coast[i]= 1
  if (presence$id[i]== 40983)
  coast[i]= 1
}

```

```

    if (presence$id[i]==20884)
coast[i]= 1
    if (presence$id[i]== 20885)
coast[i]= 1
    if (presence$id[i]== 20886 )
coast[i]= 1
if (presence$id[i]== 23432 )
coast[i]= "2"
    if (presence$id[i]== 40984)
coast[i]= "2"
    if (presence$id[i]== 40985)
coast[i]= "2"
  }

presence = cbind(presence, coast)

## kernel overlap function in adehabitat
id= presence$coast  ## use east coast vs. north coast turtles for group identity

xy=presence[, c("lon1", "lat1")]

tempUD = kernelUD( xy, id, h = 0.09, hlim=c(0.05,1.5), grid = 600, same4all =
TRUE, #
    kern = "bivnorm", extent = 0.5)
#image(tempUD, axes=FALSE, mar=c(0,0,2,0), addcontour=TRUE)
## estimating overlap at 95% UD (Table 3.7)
overlapCoast =kerneloverlaphr(tempUD, method = "PHR", lev=95, conditional =
FALSE) ## PHR Index of overlap
overlapCoast1 =kerneloverlaphr(tempUD, method = "HR", lev=95, conditional =
FALSE) ##HR Index of overlap
overlapCoast2 =kerneloverlaphr(tempUD, method = "VI", lev=95, conditional =
FALSE) ## Vi Index of overlap
overlapCoast3 =kerneloverlaphr(tempUD, method = "UDOI", lev=95,
conditional = FALSE)## UDOI Index of overlap
overlapCoast4 =kerneloverlaphr(tempUD, method = "BA", lev=95, conditional =
FALSE) ## BA Index of overlap

####
## 50% UD overlap

```

```

tempUD = kernelUD( xy, id, h = 0.09, hlim=c(0.05,1.5), grid = 600, same4all =
TRUE, #
kern = "bivnorm", extent = 0.5)
overlapCoast =kerneloverlaphr(tempUD, method = "PHR", lev=50, conditional
= FALSE)
overlapCoast1 =kerneloverlaphr(tempUD, method = "HR", lev=50, conditional
= FALSE)
overlapCoast2 =kerneloverlaphr(tempUD, method = "VI", lev=50, conditional =
FALSE)
overlapCoast3 =kerneloverlaphr(tempUD, method = "UDOI", lev=50,
conditional = FALSE)
overlapCoast4 =kerneloverlaphr(tempUD, method = "BA", lev=50, conditional
= FALSE)

## # comparing east coast and north coast turtles distribution with respect to
environmental covariates using Wilcoxon signed ranks (Table 3.8)

wilcox.test( dis2_2or3~coast , data= presence)#distance to nearest major nesting
beach
wilcox.test(dis2_any ~ coast, data= presence) #distance to nearest beach
wilcox.test(dis2_200 ~coast, data= presence) #distance to shelf
wilcox.test(dis2_shore ~coast, data= presence)# distance to shore
wilcox.test(depth ~coast, data= presence) # depth
wilcox.test(SST ~coast, data=presence) #SST

## kernel density estimation using hpi plug in the ks package
HpiOut <- Hpi(locs)
# calculating UD
fhatOut <- kde(x=locs,H=HpiOut)
# get cutoff point in ud to generate 25% isopleth
fhat.contlev <- contourLevels(fhatOut, cont=c(25))
# get 25% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contour lines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)

```

```

attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
25","ESRI Shapefile")
##50% UD
fhat.contlev <- contourLevels(fhatOut, cont=c(50))
# get 50% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contour lines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
50","ESRI Shapefile" )

##75 UD
fhat.contlev <- contourLevels(fhatOut, cont=c(75))
# get 75% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)

```

```

proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1)          # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
75","ESRI Shapefile" )

```

```

##95 UD
fhat.contlev <- contourLevels(fhatOut, cont=c(95))
# get 95% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1)          # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
95","ESRI Shapefile" )

```

```

## do kernel density estimation by group (EC vs NC)
##EC turtles
tel.ec=presence[presence$coast=="EC",]
locs1 <- cbind(tel.ec$lon1,tel.ec$lat1)   HpiOuta <- Hpi(locs1)
# calculate UD
fhatOuta <- kde(x=locs1,H=HpiOuta)
# get cutoff pt in ud to generate 25% isopleth
fhat.contlev <- contourLevels(fhatOuta, cont=c(25))  ## change to "fhatouta"
# get 25% polygon vertices
fhat.contlines <-
contourLines(x=fhatOuta$eval.points[[1]],y=fhatOuta$eval.points[[2]],
z=fhatOuta$estimate, level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)

```

```

# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84") #
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
25_EC","ESRI Shapefile")
##50% UD
fhat.contlev <- contourLevels(fhatOut, cont=c(50))
# get 50% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
50_EC","ESRI Shapefile" )

##75 UD
fhat.contlev <- contourLevels(fhatOut, cont=c(75))
# get 75% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"

```

```

# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
75_EC","ESRI Shapefile" )

```

```

##95 UD
fhat.contlev <- contourLevels(fhatOut, cont=c(95))
# get 95% polygon vertices
fhat.contlines <-
contourLines(x=fhatOut$eval.points[[1]],y=fhatOut$eval.points[[2]], z=fhatOut$estimate,
level=fhat.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(fhat.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.new
95_EC","ESRI Shapefile" )

```

fishing density estimation (Figure 3.14 & 3.15)

```

## KDE on full set ( no removal for missing SST or depth values)
locs2= cbind(bc$Set_Longit, bycat$Set_Latitu)
View(locs2)
h.by= Hpi(locs2)
kde.by = kde(x=locs2, H=h.by, eval.points=locs2, binned=FALSE)

# get cutoff pt in ud to generate 25% isopleth
by.contlev <- contourLevels(kde.by, cont=c(25))
# get 25% polygon vertices

```

```

by.contlines <- contourLines(x=kde.by$eval.points[[1]],y=kde.by$eval.points[[2]],
z=kde.by$estimate, level=by.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(by.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.by25",
"ESRI Shapefile")
##50% UD
by.contlev <- contourLevels(kde.by, cont=c(50))
by.contlines <- contourLines(x=kde.by$eval.points[[1]],y=kde.by$eval.points[[2]],
z=kde.by$estimate, level=by.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(by.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1) # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.by50",
"ESRI Shapefile")
##75 UD
by.contlev <- contourLevels(kde.by, cont=c(75))
by.contlines <- contourLines(x=kde.by$eval.points[[1]],y=kde.by$eval.points[[2]],
z=kde.by$estimate, level=by.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(by.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons

```

```

sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1)          # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.by75
","ESRI Shapefile")
  ##95 UD
by.contlev <- contourLevels(kde.by, cont=c(95))
by.contlines <- contourLines(x=kde.by$eval.points[[1]],y=kde.by$eval.points[[2]],
z=kde.by$estimate, level=by.contlev)
# convert contlines to polygon object
sldf <- ContourLines2SLDF(by.contlines)
# convert to polyset object
ps <- SpatialLines2PolySet(sldf)
attr(ps,"projection") <- "LL"
# convert to spatial polygons
sp <- PolySet2SpatialPolygons(ps)
proj4string(sp) <- CRS("+proj=longlat +datum=WGS84")
dataframe <- as.data.frame(1)          # can also specify animal id
spdf <- SpatialPolygonsDataFrame(sp,dataframe,match.ID=TRUE)
writeOGR(spdf,dsn="Z:/Academic_dissertation/Dissertation/base",layer="ks.by95
","ESRI Shapefile")

#### Chapter 4
## Venezuelan longline data
vplop.0411 = read.csv( "vplop0304.csv", header= T)
vplop.0411[vplop.0411== -9999]=NA
View(vplop.0411)
dim(vplop.0411)
names(vplop.0411)

tapply(vplop.0411$Count_, vplop.0411$year_, sum)  ##turtle bycatch in
Venezuelan fleet by year (Table 4.3)
boxplot(vplop.0411$SWO.cpue~ vplop.0411$Subregion, ylab="Swordfish CPUE
(ind/'000 hooks)") #Swordfish CPUE by subregion

xyplot(vplop.0411$effort_vpl ~vplop.0411$Depth| vplop.0411$Subregion,
ylab="Effort('000 hooks)")# Figure 4.6

## Density plots for Venezuelan longline

```

```

vplop.by= vplop.0411[vplop.0411$bycatch==1,]
vplop.0 =vplop.0411[vplop.0411$bycatch==0,]

par(mfrow= c (2,2))
plot(density(vplop.0$YFT.cpue),xlab= " YFT CPUE", y="Density", main = "")
lines(density(vplop.by$YFT.cpue), lty=2)

###
dev.new()
par(mfrow= c (2,2))
plot(density(vplop.0$TUN_prop),xlab= "Proportion of tuna spp. in Catch",
ylim=0.1, y="Density", main = "")
lines(density(vplop.by$TUN_prop), col="red")

plot(density(vplop.0$YFT_prop),xlab= "Proportion of YFT in Catch", ylim=0.3,
y="Density", main = "")
lines(density(vplop.by$YFT_prop), col="red" )

plot(density(vplop.0$SWO_prop),xlab= "Proportion of swordfish in Catch",
y="Density", main = "")
lines(density(vplop.by$SWO_prop), col="red" )

par(mfrow= c (3,2))
plot(density(vplop.0$TUN.cpue),xlab= "Tuna CPUE",ylim=c(0,0.1), y="Density",
main = "")
lines(density(vplop.by$TUN.cpue), col="red")

plot(density(vplop.0$YFT.cpue),xlab= " YFT CPUE", ylim=c(0,0.2), y="Density",
main = "")
lines(density(vplop.by$YFT.cpue), col="red")

plot(density(vplop.0$SWO.cpue),xlab= "SWO CPUE", y="Density", main = "")
lines(density(vplop.by$SWO.cpue), col="red")

plot(density(vplop.0$BET.cpue),xlab= " BET CPUE", y="Density", main = "")
lines(density(vplop.by$BET.cpue), col="red")

plot(density(vplop.0$ALB.cpue),xlab= "ALB CPUE", ylim=c(0,0.1), y="Density",
main = "")
lines(density(vplop.by$ALB.cpue), col="red")

```

```

plot(density(vplop.0$SWO.cpue),xlab= "SWO CPUE", y="Density", main = "")
lines(density(vplop.by$SWO.cpue), col="red")

plot(density(vplop.0$BET.cpue),xlab= " BET CPUE", y="Density", main = "")
lines(density(vplop.by$BET.cpue), col="red")

plot(density(vplop.0$ALB.cpue),xlab= "ALB CPUE", y="Density", main = "")
lines(density(vplop.by$ALB.cpue), col="red")

##density plots for other variables
dev.new()    ##Figure 4.21
par(mfrow= c (3,2))
plot(density(vplop.0$effort_vpl) , xlab= "Effort ('000 hooks)",ylim=c(0,1),
ylab="Density", main="")
lines(density(vplop.by$effort_vpl), col="red")

plot(density(na.omit(vplop.0$SST) ) , xlab= "SST C)", ylab="Density", main="")
lines(density(na.omit(vplop.by$SST)), col="red")

plot(density(na.omit(vplop.0$Depth) ) , xlab= "Depth(m)", ylim=c(0, 0.0003),
ylab="Density", main="")
lines(density(na.omit(vplop.by$Depth)), col="red")

plot(density(vplop.0$LAT_INICIO) , xlab= "Latitude", ylim=c(0,
0.6),ylab="Density", main="")
lines(density(vplop.by$LAT_INICIO), col="red")

plot(density(vplop.0$LON_INIC_1) , xlab= "Longitude", ylim=c(0, 0.3),
ylab="Density", main="")
lines(density(vplop.by$LON_INIC_1), col="red")

plot(density(na.omit(vplop.0$Chl) ) , xlab= "Chlorophyll a", ylab="Density",
main="")
lines(density(na.omit(vplop.by$Chl)), col="red")

# Reading in US FLS data
log.b1 = read.table("USLogbook_VPOLP_Region_AllData.txt", header=T)  ##
#US Log book records clipped to extent of VPLOP

```

```

head(log.b1)
names(log.b1)
dim(log.b1)
log.b2= log.b1[log.b1$HOOKS_SET >100,]          ## new data with sets with
unrealistic effort (number of hooks) removed
log.b2=log.b2[log.b2$Year>1991, ] ## subset for years 1992 and onward (when the
#program began collecting data on sea turtles
dim(log.b2)
log.b2= log.b2[log.b2$SURFACE_WATER_TEMPERATURE >60,] ## data with
unrealistic water temperatures removed

##getting total number of individuals caught for each of main tuna species,
#combined and swordfish
US.yft = log.b2$YELLOWFIN_TUNA_KEPT +
log.b2$YELLOWFIN_TUNA_DISC_ALIVE + log.b2$YELLOWFIN_TUNA_DISCARDED
US.bet = log.b2$BIGEYE_TUNA_KEPT +
log.b2$BIGEYE_TUNA_DISC_ALIVE + log.b2$BIGEYE_TUNA_DISCARDED
US.alb = log.b2$ALBACORE_TUNA_KEPT +
log.b2$ALBACORE_TUNA_DISC_ALIVE + log.b2$ALBACORE_TUNA_DISCARDED
US.swo = log.b2$SWORDFISH_CAUGHT +
log.b2$SWORDFISH_DISC_ALIVE + log.b2$SWORDFISH_DISCARDED
##combined main tuna catch
US.TUN= log.b2$YELLOWFIN_TUNA_KEPT +
log.b2$YELLOWFIN_TUNA_DISC_ALIVE + log.b2$YELLOWFIN_TUNA_DISCARDED
+ log.b2$BIGEYE_TUNA_KEPT + log.b2$BIGEYE_TUNA_DISC_ALIVE +
log.b2$BIGEYE_TUNA_DISCARDED + log.b2$ALBACORE_TUNA_KEPT +
log.b2$ALBACORE_TUNA_DISC_ALIVE + log.b2$ALBACORE_TUNA_DISCARDED
#calculating cpue's (fish/1000 hooks)
US.yft.cpue= (US.yft /log.b2$HOOKS_SET)*1000
US.alb.cpue= (US.alb/log.b2$HOOKS_SET)*1000
US.bet.cpue= (US.bet/log.b2$HOOKS_SET)*1000
US.tun.cpue = (US.TUN/log.b2$HOOKS_SET)*1000
US.swo.cpue= (US.swo/log.b2$HOOKS_SET)*1000

cc= log.b2$LOGGERHEAD + log.b2$LOGGERHEAD_INJURED +
log.b2$LOGGERHEAD_KILLED ##summing turtle bycatch by species
dc= log.b2$LEATHERBACK + log.b2$LEATHERBACK_INJURED +
log.b2$LEATHERBACK_KILLED
cm1= log.b2$GREEN + log.b2$GREEN_INJURED + log.b2$GREEN_KILLED

```

```

    ei= log.b2$HAWKSBILLS + log.b2$HAWKSBILLS_INJURED +
log.b2$HAWKSBILLS_KILLED
    lk= log.b2$KEMPS_RIDLEY + log.b2$KEMPS_RIDLEY_INJURED +
log.b2$KEMPS_RIDLEY_KILLED
    other= log.b2$OTHER_TURTLE + log.b2$OTHER_TURTLE_INJURED +
log.b2$OTHER_TURTLE_KILLED
    table(other)
    Count = dc +ei +cc +cm1 + lk+ other ## sum of all turtles caught in a set
    Count
    log.b2=cbind(log.b2, US.swo.cpue, US.yft.cpue,US.alb.cpue,US.bet.cpue,
US.tun.cpue, dc, cm1, cc,ei, lk, other, Count )

## Swordfish catch rates in relation to subregion in Venezuela
dev.new()
boxplot(SWO.cpue ~ Subregion, data=vplop.0411, ylab= "Swordfish CPUE
(ind/'000 hooks)" ##Figure 4.22
## bycatch versus zero-bycatch in relation to moon phase

bin.o =ordered(vplop.0411$bin) # ordering categorical variable bin , which
represents increments of lunar phase 1 (new moon) through 15 (full moon)
vplop.0411 =cbind(bin.o, vplop.0411)
dev.new()
class (vplop.0411$bin.o)

boxplot(vplop.0411$bin.o~vplop.0411$bycatch , ylab= "Moon phase" )
## for Figure 4.23

## density plots US FLS (Figures 4.24 &4.25)
dev.new()
par(mfrow= c (2,2))
plot(density(log.0$US.swo.cpue) , xlab= "Swordfish CPUE (ind/hook)",
ylim=c(0,0.04), main="" )
lines( density(log.1$US.swo.cpue), col="red" )

plot(density(log.0$US.yft.cpue) , xlab= "Yellowfin CPUE
(ind/hook)",ylim=c(0,0.3), main="" )
lines( density(log.1$US.yft.cpue) , col="red" )

plot(density(log.0$US.alb.cpue) , xlab= "Albacore CPUE (ind/hook)", main="" )
lines( density(log.1$US.alb.cpue) , col="red" )

```

```

plot(density(log.0$US.bet.cpue ), xlab= "Bigeye CPUE (ind/hook)", main="" )
lines( density(log.1$US.bet.cpue ), col="red" )

plot(density(log.0$US.tun.cpue ), xlab= "Tuna CPUE (ind/hook)", main="" )
lines( density(log.1$US.tun.cpue ), col="red" )

dev.new()
par(mfrow= c (2,2))
plot(density(log.0$SURFACE_WATER_TEMPERATURE ), xlab= "Surface Water
Temp. (F)", main="" )
lines( density(log.1$SURFACE_WATER_TEMPERATURE ), col="red" )

plot(density(log.0$HOOKS_SET),xlab="Effort(hooks)" , main="")
lines( density(log.1$HOOKS_SET),col="red")

plot(density(log.0$Latitude),xlab= "Latitude", main="")
lines( density(log.1$Latitude),col="red")

plot(density(log.0$Longitude),xlab="Longitude", main="")
lines( density(log.1$Longitude),col="red")

```

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Biography

Rhema Hyacinth Bjorkland received her undergraduate degree from the University of the West Indies (Mona) in Botany and Zoology. She attended the University of Georgia on a Fulbright Fellowship, attaining her Master's degree in Conservation Ecology and Sustainable Development. A former zoo curator, Rhema has worked in government academic institutions in the US, Jamaica and Canada. Her research interests include biodiversity assessment, sea turtle conservation and small scale fisheries. She has published in the areas of sea turtle population assessment and monitoring, biometrics and freshwater assessment. As a member of the Duke University Marine Lab, Rhema participated in the Green Wave, the student-led campus sustainability organization and in K-12 outreach programs.