Bycatch and Foraging Ecology of Sea Turtles in the Eastern Pacific

by

Shaleyla Kelez Sara

Department of Environment
Duke University

Date:_________________________
Approved:

____
Larry B. Crowder, Supervisor

____
Jeffrey A. Seminoff

____
Patrick N. Halpin

____
Scott A. Eckert

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

2011

ABSTRACT

Bycatch and Foraging Ecology of Sea Turtles in the Eastern Pacific

by

Shaleyla Kelez Sara

Department of Environment
Duke University

Date:_______________________
Approved:

____
Larry B. Crowder, Supervisor

____
Jeffrey A. Seminoff

____
Patrick N. Halpin

____
Scott A. Eckert

An abstract of a 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

2011

Abstract

Sea turtles are long lived marine species that are currently endangered because their life history and population dynamics hinder them from withstanding modern anthropogenic threats. Worldwide, fisheries bycatch in on the major threats to the survival of sea turtles and that is also the case in the Eastern Pacific. To establish regional conservation priorities for the mitigation of bycatch, it is essential to first obtain a comprehensive picture of the regional sea turtle bycatch situation. This comprehensive analysis was lacking for the Eastern Pacific; therefore one component of this dissertation (the first chapter) is focused on delivering a regional bycatch analysis for the Eastern Pacific. A literature review was conducted to obtain numbers of turtles captured, frequencies, bycatch and mortality rates per species and country in trawl, longline, and gillnet fisheries, and to compile results of mitigation measures. Moreover, estimates for current annual capture rates in trawl fisheries were obtained and compared with population numbers.

This regional bycatch used all the information compiled and synthesized to give conservation priorities at the regional level. The review underlines the high bycatch rates in trawls for Costa Rica, Guatemala, and El Salvador and the detrimental impact that these captures could have specially for hawksbill *Eretmochelys imbricata* due to its reduced population numbers and for green turtle *Chelonia mydas* due to its highest mortality rate. It also emphasizes the continuous lack of use of TEDs as a bycatch mitigation measure. In longline fisheries, the review identifies the high bycatch rates in pelagic longline fisheries of Costa Rica, Ecuador, and Nicaragua in a global context but given that olive ridley *Lepidochelys olivacea* is the most common species captured in these countries, it highlights the capture of loggerhead *Caretta caretta* and leatherback *Dermochelys coriacea* off Peru and Chile due to their small population numbers. Bottom longlines have high mortality rates compared with pelagic longlines in the region and the review identifies a need for further research in this area due to the scarce information but high mortality rates. The review also noted that some mitigation measures for pelagic longlines like circle hooks and hooks with appendages could bring improvements in the mitigation of bycatch in longline fisheries in the region, there is still considerable work to be done in technology transfer, sea turtle handling, and estimates of post-release mortality rates.

For gillnet fisheries, the most important highlight is how little information exists for the region given the high rates of bycatch for sea turtles in this gear. However, the difficulties of studying bycatch in highly dynamic and artisanal fisheries are recognized as the major impediment for this situation. Nevertheless, the high bycatch rates in areas where sea turtles congregate in high numbers like in foraging grounds for loggerhead in Baja California, Mexico and for greens in Paracas and Sechura, Peru, calls for either gear modifications (which has not been that successful), change of gear, or areas closed for gillnets.

The second half of the dissertation is focused on foraging ecology of oceanic sea turtles in the Southeast Pacific Ocean. Sea turtles in the oceanic stage are the least known

stage due to the difficulty of accessing these individuals. However, it is a very important stage in the life cycle and can be critical for the population dynamics of sea turtles as some population models have shown. Therefore, this dissertation is filling a gap in the life cycle of sea turtle populations in the Eastern Pacific.

To study foraging ecology, we used Stable Isotope Analysis (SIA) of turtle tissues as well as potential prey items from the oceanic realm. SIA is a great tool because it gives an integrated view, from days to weeks, of prey from a consumer tissue. SIA also can be used to link consumers to habitats when elements that have spatial trends are used. In chapter two, we investigate the foraging ecology of three species of sea turtles to compare trophic status and to observe if spatial patterns were shown in the SIA signatures of sea turtles. To our knowledge this is the first study employing SIA to research the ecology of three species of sea turtles from the same time and space. Our results show that spatial patterns in δ^{15}N and δ^{13}C were observed in sea turtle's tissues as correlations with latitude. We also found that loggerhead's signatures differed significantly from green and olive ridleys, especially in terms of δ^{15}N. Loggerheads had higher values of δ^{15}N and also a wider nitrogen trophic niche. Greens and olive ridleys were similar in isotopic nitrogen values but they were significantly different in carbon. When analyzing a smaller group of animals captured in a more restricted area, nitrogen differences were not found which suggests that latitudinal spatial patterns play an important role in the nitrogen signature. On the contrary, carbon signatures still differed among turtles in the restricted area which suggest that the inshore-offshore trend is strong and made us conclude that loggerheads are restricted to oceanic areas but that greens and olive ridleys could be using both coastal and oceanic areas.

In chapter three, we conduct a mixing model analysis using the Bayesian program SIAR to identify the most important prey items for green, olive ridley, and loggerhead off Peru. Also, we wanted to identify the contribution of longline baits in the diet of oceanic turtles. The analysis was restricted to the central zone of our study area to avoid spatial trends in nitrogen. To use as sources in the model, we collected potential prey items offshore Peru during trips on longline fishing vessels and obtained their stable isotope signatures. Results from our mixing models show that for greens and olive ridleys, crustaceans, mollusks, and coastal *Ulva* (indicator of coastal prey) were the only important food items. In the case of greens, crustaceans had a very high proportional contribution and due to the fact that nitrogen values of crustaceans were the lowest ones among the sources it seems that greens would be eating in a lower trophic level. The importance of coastal *Ulva* for greens and olive ridleys is a confirmation of our findings from chapter two where we suggest that these two species could be using oceanic as well as coastal areas.

Results for loggerheads showed cnidarians, mollusks, mackerel and squid bait as foraging items and highlights the differences among this species and the other two. The lack of importance of coastal *Ulva* again suggests that loggerheads remain only in oceanic areas off Peru. Moreover, the importance of mackerel and squid, the most common longline baits, suggests this species is the one interacting the most with longline

fisheries and that cumulative effect of multiple interactions could have a detrimental effect in this population.

Dedication

Because I can only feel it if it is in Spanish:

Le dedico este trabajo a los grandes amores de mi vida:

la nona, mamá, papá y Michel;

porque para realizarlo tuve que estar lejos de ustedes y sin embargo,

ustedes siempre me apoyaron, me amaron y esperaron mi regreso.

Contents

2. Oceanic Isoscapes and the feeding ecology of sea turtles in the southeastern Pacific Ocean: a stable isotopic analysis 65

List of Tables

List of Figures

Acknowledgements

Thanks to my advisor, L. Crowder, for giving me the opportunity get a doctorate degree and trust in me during all these years. To my dissertation committee who helped me get here: S. Eckert, P. Halpin, and specially J. Seminoff who was closely involved in the research I conducted and was always available to answer any question I had.

Thanks to all that provided information or references about sea turtle bycatch and/or fishing effort in the Eastern Pacific, specially: M. Jolon, R. Sanchez, H. Santana, F. Rico-Mejia, J. Ramirez, J. Urteaga, L. Barreto, R. Arauz, C. Gomez-Cubillos, M. Ruiz, A. Fonteneau, and J. Azocar. Thanks to all the observers, fishermen and fishing companies that participated in the longline fisheries research, especially to Hayduk fishing company for allowing me to board their longline fishing vessels. Special thanks to N. Cassar, J. Montoya, C. van Dover, K. Arthur, and B. Popp for SIA advice, to R. Inger for SIAR advice and to G. Lemons for all his help in the lab. Thanks to IMARPE researchers M. Romero, P. Carbajal, R. Quesquen, A. Chipollini, J. Quiñones and to Dr. J. Finn for help identifying pelagic species I collected.

Thanks to all the funding agencies, organizations and people that contributed funds for this research or helped me in other ways. A special thanks to the Convention on Migratory Species (CMS), NMFS, Rufford Foundation, Oak Foundation, Duke Center for Marine Conservation, J. Seminoff, K. Steward, and I. Vilchis.

Thanks to my practice prelims committee: C. McClellan, K. Stewart, R. Schick, and B. Wallace who helped me finish the first marathon! Thanks to all that provided advice and mentoring during all these years, specially: C. McClellan, K. Stewart, M. Godfrey, F. Colchero, M. Hall, and A. Read. And an immense gratitude to my partner in crime, X. Velez-Zuazo, for constant motivation and encouragement.

Thanks to all my friends in North Carolina who became my family here and made me have a home away from home in an impressively short time, especially C. Penaloza, S. Black, Ron and Rhema Bjorkland, M. Santa Maria, L. Poser, D. Munoz-Nunez, C. McClellan, M. Vale, I. Diaz, E. Gaya,V. Swamy, L. Pokorny, B. Best, J. Sexton, C. Kot, M. Sims, M. Adeney, A. Boustany, A. Long, L. Thorne, L. Nichols, S. Nijhawan, C. Delgado, H. Dominguez, A. Tobler, M. Wise, O. Ratman, I. Manalopoulou, J. Wilson, L. Starke, N. Avisar, P. Maniloff and all the Global Fellows from 2005 to 2010.

1. Bycatch of sea turtles in the Eastern Pacific: a regional review

1.1 Introduction

Bycatch is generally the unintentional capture of organisms while fishing for (a) target species but it also includes discards of the target species (Crowder and Murawski 1998). Bycatch can be composed not only by fish, crustaceans, and mollusks but also of large air breathing vertebrates like seabirds, sea turtles, and cetaceans. Also, juveniles of the target species are usually considered bycatch. Some fishing gears have small amounts of bycatch, but others like trawls have large amounts of bycatch because of its lack of selectivity for target species.

Sea turtles are long lived species with slow growth and slow maturation that had been able to adapt to a changing world for 10s of millions of years. Nowadays all extant species of sea turtles are taken as bycatch in one or many fishing gears (Frazier et al. 2007). Bycatch is a recent threat for these organisms and it increased in intensity in a short period of time is leaving sea turtles with little time to adapt and many populations became endangered because of interactions with fisheries (Eckert and Sarti 1997, Crowder and Heppell 2011). For this reason, it is important to study bycatch of sea turtles in order to identify the capture and mortality hotspots and to concentrate mitigation efforts in these areas.

Despite many local and national efforts to study the incidental capture of sea turtles in the Eastern Pacific (EP), a comprehensive regional study is lacking. In order to fill in this gap and to understand the impacts of bycatch on the EP populations, we began this study. Our aim was to obtain a comprehensive view of sea turtle bycatch in the region and determine the fisheries that are having the biggest impacts on sea turtle populations. We compiled all available bycatch information (total bycatch numbers, bycatch rates, mortality rates, developmental stages captured, use of mitigation measures) for various species and fisheries within the region, so our conclusions reflect only the accessible data. The fishing gears included in the review are: trawls, longlines, and gill nets/entanglement nets/trammel nets. No purse seines, traps, or other gears are included.

1.2 The study area

The Eastern Pacific for this review was defined as the ocean that extends to the west of the coastlines of the eleven Latin-American countries in the Pacific basin until the meridian 120° West. These countries are Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, and Chile (Figure 1). The study area includes 4 large marine ecosystems: California Current, Gulf of California, Pacific Central American Coastal, and Humboldt Current; whose oceanographic characteristics are different and particular.

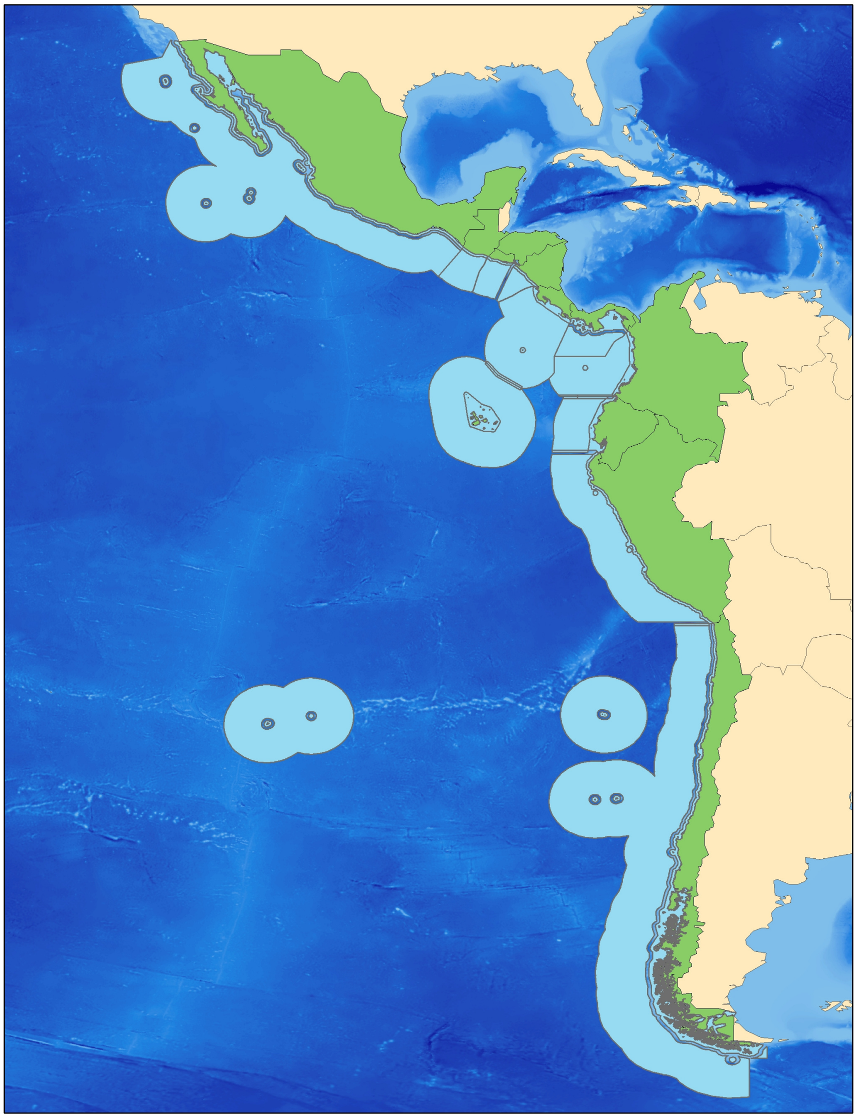

Figure 1: Map of the study area showing the countries included in the review (in green), and their Exclusive Economic Zones or Territorial Seas (in skyblue).

1.3 Sea turtles in the Eastern Pacific

In the Eastern Pacific, five species of sea turtles occur: Green turtle *Chelonia mydas*, Loggerhead turtle *Caretta caretta*, Hawksbill turtle *Eretmochelys imbricata*, Olive ridley *Lepidochelys olivacea* and Leatherback turtle *Dermochelys coriacea*. These species have different distributions with some encompassing the entire study area and others only half of it. The specific ecology and biology of each species is particularly important in determining the fishing gears with which they most often interact.

The green turtle has the widest distribution in the Eastern Pacific, from California (outside of the study area) in the north to the latitude of Punta Arenas, 53.15°S, in Chile (McDonald and Dutton 1990, Troncoso and Urbina 2007). Green turtles in the EP seem to belong to the same population as evidenced by genetic analysis conducted in several nesting beaches and marine habitats (Chassin-Noria et al. 2004, Velez-Zuazo and Kelez 2010) although there are occasionally wanderers that have been found in the central north Pacific (Dutton et al. 2008). The trend of this EP population has been determined as declining based in the last data available for the two most important rookeries in the region, the Galapagos Islands in Ecuador and Michoacán in Mexico (Seminoff 2004).

The leatherback turtle is also widely distributed in the Eastern Pacific ranging from California in the north to Chiloe Island (42.36°S) in the south of Chile (Pritchard 1980, Frazier and Brito 1990, Starbird et al. 1993, Sarti et al. 2007). There is evidence from satellite tags and genetic analysis to support that leatherbacks distributed from Mexico to Chile belong to the same population (Eckert and Sarti 1997, Dutton et al.

1999, Shillinger et al. 2008) while the ones found off California belong to the Western Pacific population (Dutton et al. 2000). However, there seems to be some population mixing because around 16.3% of individuals found in South America seem to come from Western Pacific origin and there are also some turtles from EP origin around Hawaiian Islands (Dutton in Sarti et al. 2000). The EP leatherback population is in a very critical situation as observed in the nesting records of the most important rockeries in Mexico and Costa Rica which have been declining for at least two decades (Spotila et al. 1996, Spotila et al. 2000, Reina et al. 2002, Santidrian Tomillo et al. 2007, Sarti et al. 2007).

Olive ridley turtles seem to be the most abundant species in the Eastern Pacific ranging from Mexico to Punta Lavapie (37.09°S) in Chile (Cliffton et al. 1982, Troncoso and Urbina 2007). Genetic analysis of turtles in nesting beaches and also of aggregations of turtles in foraging areas suggest all turtles in the EP belong to the same population (Bowen et al. 1998, Briseño-Dueñas 1998, Camacho-Mosquera et al. 2008, Velez-Zuazo and Kelez 2010). However, there seems to be some demographic independence in a short-time span among rookeries like Nancite and Ostional in Costa Rica, Baja California, and mainland Mexico - Escobilla and the other arribada beaches in Jalisco and Guerrero, Mexico (Lopez-Castro and Rocha-Olivares 2005, Bernardo and Plotkin 2007). Nevertheless, from Mexico to Chile all olive ridleys are considered one population (Wallace et al. 2010). In spite of being very abundant, its population seems to be declining in the Eastern Pacific based on nesting records analyzed during the last IUCN

Marine Turtle Specialist Group global assessment of this species (Abreu-Grobois and Plotkin 2007).

The hawksbill turtle in the Eastern Pacific is critically endangered (Mortimer and Donnelly 2008). It ranges from Mexico to Peru (Hays-Brown and Brown 1982, Seminoff et al. 2003). Genetic studies show that the EP hawksbill turtles belong to the same population (Zuniga et al. 2010). Higher abundances are found in Mexico and Central America with highest nesting records in El Salvador (Gaos et al. 2010, Liles et al. 2011).

The fifth sea turtle species in the EP is the loggerhead. This species is markedly different from the rest in three ways. First, there is no loggerhead nesting beaches along the entire Pacific coast of South America, Central America, or North America. Second, the individuals that occur in the EP are generally juveniles or subadults that were born in the other side of the Pacific Ocean. And third, there are two distinct populations, the north Pacific with rookeries in Japan and juvenile foraging sites extending to Hawaii and Baja California and the south Pacific population with rookeries in Australia and New Caledonia and juvenile foraging sites that reach Peru and northern Chile (Bowen et al. 1995, Kelez et al. 2003, Seminoff et al. 2004, Boyle et al. 2009). The loggerhead populations were severely declining during the 1980s and 1990s (Kamezaki et al. 2003, Limpus and Limpus 2003). Since 2000 the north pacific rookeries in Japan were showing an increasing trend until 2006 when a deep drop occurred. However in 2007 the population increased again but they are still far from past levels (Conant et al. 2009). The south Pacific populations in Australia also started showing an increase in the number of females nesters since 2000 but data has not been made public after 2003 so the current trend is not known (Limpus 2008, Conant et al. 2009). Therefore, considering the most updated information the two Pacific populations are still considered at risk of extinction.

1.4 Results

1.4.1 The sources

Our review includes 97 sources that are journal articles, reports, book chapters or symposium abstracts. Most of the studies focus on a quantitative measure of bycatch, but some that only mentioned bycatch were included when the interaction mentioned (among a specific species and a specific gear in a specific country) that was not reported elsewhere. Data from sources were added to a database specifically design for the bycatch review by Project GloBAL and were separated in different entries for each species and gear depending on the degree of detail of the bycatch report. When data from one source was included in a more recent source, we used the more recent source. Honduras was mentioned only once in the literature reviewed and this may be due to its small marine territory in the Pacific and the lack of bycatch information even though the Gulf of Fonseca seems to be an important area for hawksbills. As a consequence, we focus mainly on data from 10 countries rather than 11 as initially planned.

1.4.2 Legal protection of sea turtles

To put bycatch into perspective, we reviewed the history of protection by the countries in the region, including the prohibition of capture, killing, and sale of turtles (but not their eggs). This information is particularly important when reviewing information about captures and landings of turtles. Protection to sea turtles started to occur in the EP in the 1980s (Table 1). In this decade Guatemala protected all sea turtles, eight other countries joined them in the 1990s, and Costa Rica was the last one to do it in 2002. Nicaragua is a special case in the region because they only fully protect leatherbacks, hawksbills, loggerheads, and Pacific greens while olive ridleys and Caribbean greens are still captured legally following open and closed seasons. As a comparison, US gave legal protection to all sea turtle species in 1973 with the Endangered Species Act, around nineteen years earlier than most EP countries.

Table 1: Years when Pacific Latin-American countries gave full protection to sea turtles (does not includes protection to eggs)

Prohibition to capture turtles	*year*
Guatemala	1981
Ecuador	1990
El Salvador	1990
Mexico	1990
Colombia	1991
Chile	1992
Panama	1995
Peru	1995
Nicaragua	1999*
Costa Rica	2002

*Nicaragua only protects leatherbacks, hawksbill, loggerhead and Pacific greens

1.4.3 Trawl fisheries

1.4.3.1 Fishery description and fishing area

Trawling fisheries in the EP generally target shrimps, but also some fishes. Targeted shrimps can be divided in two groups depending on fishing depths: shallow and deep. Shallow species like white shrimp *Litopenaeus* spp, brown shrimp *Farfantepenaeus californiensis*, pink shrimp Farfantepenaeus brevirostris, and titi shrimp *Xiphopenaeus rivetti* are targeted generally at depths from 9 to 85 m and deep species like nylon shrimps *Heterocarpus* spp and the titi shrimps *Solenocera agassizii*, *Rimapenaeus byrdi* from 100 to 1000 m (INP 2000b, Ulloa 2003, Gutiérrez 2004, Bolaños 2005).

Industrial trawling for shrimp in the EP started in the 1950's and grew rapidly during the 1980s and 1990s. Trawling for shrimp extends mainly from Mexico to Ecuador. In Peru, this fishery is very small and constrained to the northernmost areas with higher efforts occurring during El Nino years. In Chile, trawling is important but they only target deep shrimp species like the squat lobster *Cervimunida johni* and the pelagic red crab *Pleuroncodes monodon* in depths that range from 150 – 300 m (Palma 1994). Peru and Chile also trawl for South Pacific hake *Merluccius gayi* and other fish species at depths ranging from 50 to 500 m (Wosnitza-Mendo and Guevara-Carrasco 2000).

Spatially, the extents of bathymetric ranges ideal for shallow and deep shrimping are shown in the map in Figure 2, where the areas in orange for shallow shrimps and the areas in red for deep shrimp. These areas with exception of the offshore areas (e.g. around Galapagos, Cocos ridge or Carnegie ridge) are indeed the areas most trawled. This is also evidenced by the presence of the most important trawling ports, which are located close to areas for shallow shrimping (Figure 2). Due to the proximity of the Middle America and the Peru-Chile trench to the coastline of the Americas, the areas ideal for shrimping are not as extensive as for example the ones in the Gulf of Mexico and are concentrated very close to the coast. This limited extension will create a higher density of neritic turtles and trawler vessels which will overlap a higher degree.

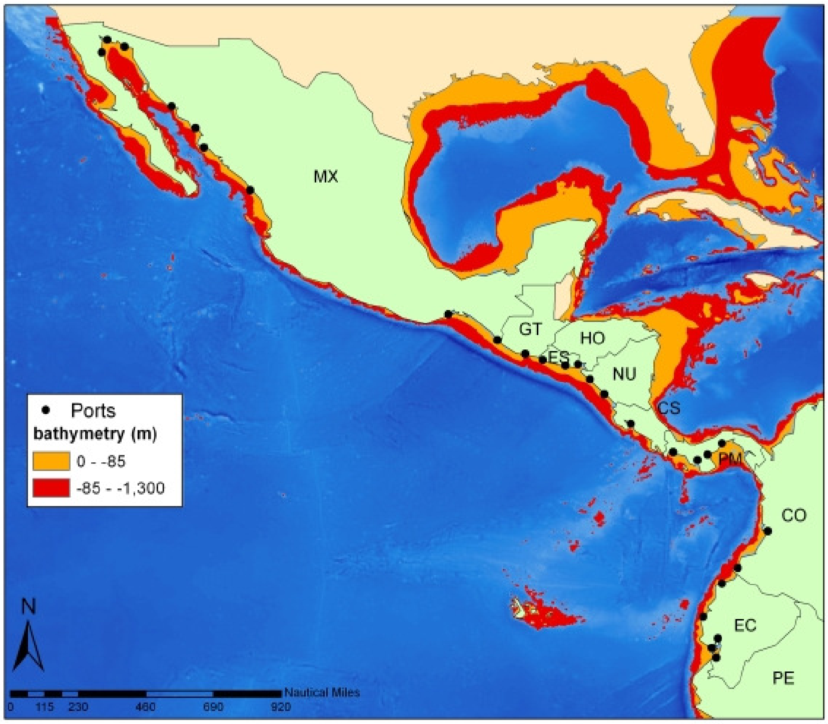

Figure 2: Areas bathymetrically ideal for shallow (orange) and deep (red) shrimp trawling. Black dots are the most important shrimp trawling ports.

1.4.3.2 Bycatch numbers, rates and mortality

The total number of sources that included some data related to sea turtle bycatch by trawlers was 32. From this total, two sources refer to strandings attributed to bycatch in trawls (Juarez and Muccio 1997, Alava et al. 2005), and seven sources do not give any numerical data about the incidental capture (Cliffton et al. 1982, Green and Ortiz-Crespo 1982, Hays-Brown and Brown 1982, Araya 2006, Zarate 2006, Ordonez and Duchez 2007, Gaos et al. 2010). The remaining sources were used to tally observed bycatch events and to summarize bycatch rates and estimations. Unfortunately, most of the information containing bycatch rates from the EP is from the 1990s, before mitigation measures were required. The sources were published between 1982 and 2009 and include data collected from 1973 to 2009.

In Table 2, there is a summary of the abundance in the records for each species of sea turtle and each country. Olive ridley is by far the species with the highest quantity of records which is not surprising giving the abundance of this species in the EP (Eguchi et al. 2007). On the contrary, loggerheads and leatherbacks are rarely mentioned as bycatch in trawl fisheries. The low abundance of loggerheads and leatherbacks must be related to their pelagic nature given the fact that all loggerheads in the EP are juveniles or subadults and rarely come to neritic areas (but see Seminoff et al. 2004, Peckham et al. 2007) and that leatherbacks only come close to the coast on rare occasions when strong currents push gelatinous plankton towards coastal areas (Shillinger et al. 2008). The countries with fewer records are Panama with none, Peru with only one mention of bycatch in the north of the country (Hays-Brown and Brown 1982), Chile with one record of leatherbacks captured in a South Pacific hake trawl (Brito 2001) and Ecuador with two records that only mention that the interaction occurs (Green and Ortiz-Crespo 1982, Zarate 2006). In general, the species with the highest capture records in the EP is olive ridley, followed by a lesser degree by green turtle and hawksbill.

A total of 767 turtles have been reported as incidentally captured in trawl fisheries in the EP (Table 3). From this, at least the 39% (n = 299) died. The precise number of mortalities was not able to be calculated because some sources did not report the fate of the turtles captured. As in the abundance of records, olive ridleys are the majority of the total identified individuals representing the 87.9%, while green, hawksbill, and leatherback are the 11.1%, 0.9% and 0.1% respectively (Table 3). The low capture of hawksbills (Table 3) is explained by the low numbers of this EP population which is why this species has been considered rare in the region since the 1980s (Gaos et al. 2010). In the case of Ecuador, if we consider all the strandings reported in Alava et al (2005) as trawl bycatch, then Ecuador will add 1686 olive ridleys, 76 greens, 11 hawksbills, 1 leatherback and 87 unidentified turtles to the count. All but three turtles included in Table 3 were captured by industrial shrimp trawlers. Those three turtle records were captured by artisanal trawlers in Colombia (Gomez-Cubillos and Amorocho 2008). Also, 17 hauls of artisanal trawlers in Peru were observed but resulted in no capture of sea turtles (Caceres-Bueno et al. 2010).

Table 2: Abundance of records of bycatch in trawls per country

Country	*Olive ridley*	*Green*	*Hawksbill*	*Loggerhead*	*Leatherback*
Mexico	**high**	low	low	low	
Guatemala	**high**	low			low
El Salvador	**high**	low	low		
Nicaragua	**high**				
Costa Rica	**high**	low	low		
Panama	low[2]				
Colombia	**high**	low	low		
Ecuador	low[1]	low[1]	low[1]		low[1]
Peru		low[2]			
Chile					low[3]

[1] Two sources mention the interaction without more data, [2] only one source mentioning this interaction, [3] only one source with 1 record in hake trawling.

Table 3: Total numbers of turtles captured and mortalities recorded in the EP. Data by country and species. Mortalities are between parentheses. Question mark denote that at least one source did not report mortality information. No data for loggerheads.

Country	*Olive ridley*	*Green*	*Hawksbill*	*Leatherback*	*nn*
Mexico	165 (107)	15 (5)	3 (2)		45 (1)
Guatemala	27 (22?)	2 (?)			
El	29 (4?)	15 (5?)	1 (1)		
Nicaragua	1 (?)				15 (12)[1]
Costa Rica	317 (94?)	34 (16)	1 (0)		26 (?)
Panama					
Colombia	57 (25?)	9 (3)	1 (1)		3 (?)
Ecuador					
Peru					
Chile				1 (1)	
totals	**596 (252?)**	**75 (29?)**	**6 (4)**	**1 (1)**	**89 (13?)**

[1] The mortality number is from turtles butchered on board, bycatch mortality was not mentioned.

BPUEs

Bycatch per unit effort (BPUE) was obtained for five countries (Duque-Goodman 1988, Stromme 1988, Arauz 1996, Arauz et al. 1998b, Rico-Mejia and Rueda 2007, Santana 2008, M Jolon 2010 pers. comm.) The rate was calculated as the number of individuals captured per hour of trawling in a vessel pulling two nets. The BPUEs are from fishing hauls that did not use any mitigation measure. The results show that the highest BPUEs for all turtles combined occur in Costa Rica (0.0999 turtles/hour) and Guatemala (0.0775 turtles/hour) and the lowest in Colombia (0.0225 turtles/hour) and Mexico (0.0264 turtles/hour) (Figure 3).

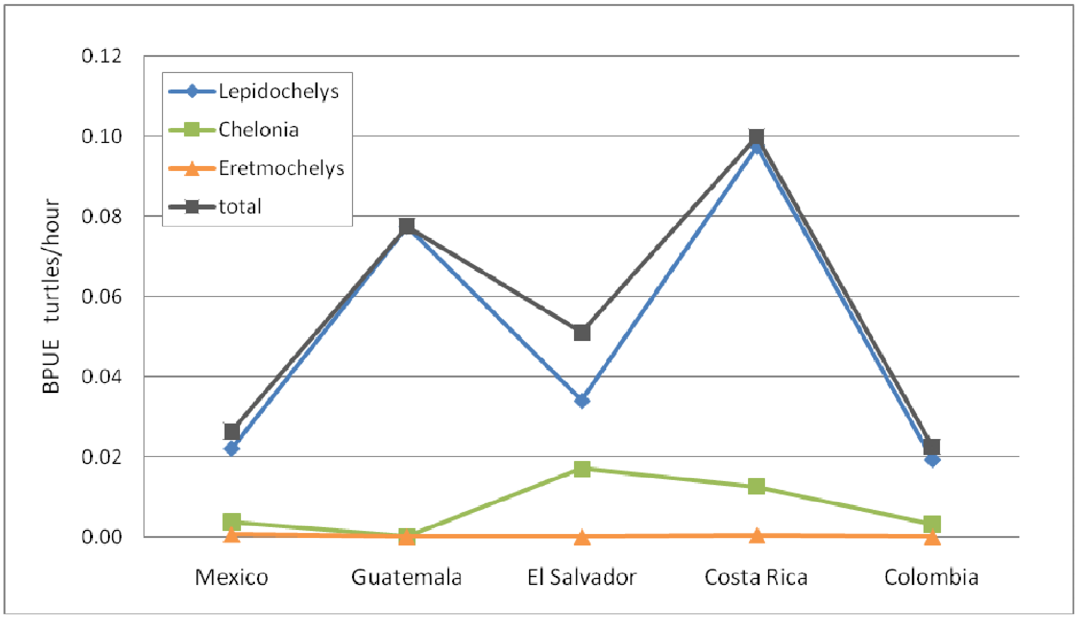

Figure 3: Bycatch per unit effort (BPUE) of sea turtles in trawl sets (turtles/ trawl hour in the EP. Total rates and per species rates in 5 countries (from north to south).

The total BPUE is driven almost entirely by the BPUE values for olive ridley. This species has the highest BPUEs in all the countries ranging from 0.0221 to 0974 turtles/hour. Hawksbills on the other hand, show the lowest bycatch rates from 0 to 0.0005 turtles/hour. Greens also have low BPUEs but with higher values in El Salvador and Costa Rica (0.0170 and 0.0125 respectively). Bycatch rates seem to be consistent with the abundances of these three species in the region. Moreover, the higher values for olive ridley BPUE from Guatemala to Costa Rica could be related to the proximity to the most important arribada beaches in the EP: Escobilla in the South of Mexico, Ostional in Costa Rica and La Flor in Nicaragua (Abreu-Grobois and Plotkin 2007). The data in Figure 3 are a combination of several studies per country and is not divided by trawl fishery. But there seems to be a lower bycatch rate when trawling at deeper fishing depths as observed in studies conducted in the Caribbean, the Southern North Atlantic, and the Mediterranean (Henwood and Stuntz 1987, Laurent et al. 2001, Alio et al. 2010).

To compare BPUEs in the EP region with other regions, we standardize catch rates from literature to hours and 2 nets per haul and summarize this information in Table 4 and Figure 4. BPUEs in EP are low when compared with bycatch in the northern prawn trawl fishery in the Gulf of Carpentaria, Australia, whose BPUE is twice the BPUE in Costa Rica (Brewer et al. 2006). However, when compared to BPUEs in Venezuela, Greece, and the Gulf of Mexico they are higher (Table 4, Figure 4). Therefore, we consider BPUEs in the EP as of a high magnitude especially in Costa Rica.

Table 4. Bycatch rates from this review and other regions. BPUEs are standardized to individuals/trawl hour in a vessel pulling 2 nets.

Region	*Fishery*	*BPUE*	*Species*	*Reference*
Venezuela, CAR	Fish, shrimp	0.0022	Ei Cm Cc Dc	Alio et al. 2010
Greece, Med.	fish	0.0037	Cc Cm	Laurent et al 2001
Gulf of Mexico	shrimp	0.0062	Cc Lk Cm	Henwood & Stuntz 1987
Colombia, EP	shrimp	0.0225	Lo Cm	this review
Mexico, EP	shrimp	0.0264	Lo Cm Ei	this review
Italy, Med.	fish, shrimp	0.0429	Cc	Laurent et al 2001
El Salvador, EP	shrimp	0.0510	Lo Cm	this review
Guatemala, EP	shrimp	0.0775	Lo	this review
Southern NA	shrimp	0.0974	Cc Lk Cm	Henwood & Stuntz 1987
Costa Rica, EP	shrimp	0.0999	Lo Cm Ei	this review
Queensland	prawn	0.2011	Nd Cc Lo	Brewer 1998

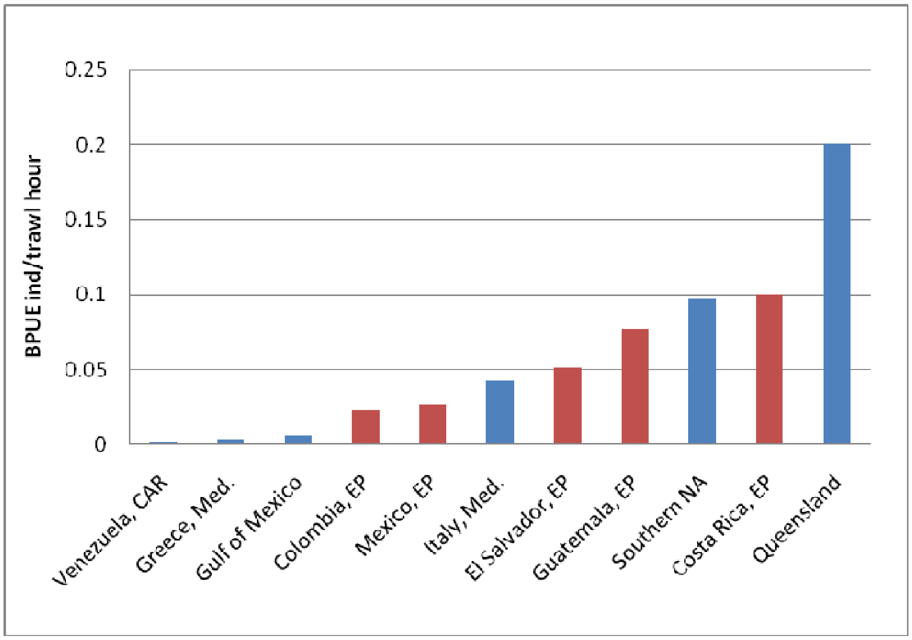

Figure 4: Bycatch rates from this review (in red) and other regions (in blue). BPUEs are standardized to individuals/trawl hour in a vessel pulling 2 nets.

Mortality rates

Mortality rates were calculated for all turtles combined and also for each species per country from the sources that included this information (Duque-Goodman 1988, Arauz 1996, Arauz et al. 1998b). Overall mortality rates per country ranged from 37% to 58%, with overall mortality following the behavior of the mortality rates for olive ridleys because of the large frequency of its capture (Figure 5). Green turtles show higher mortality rates in El Salvador and Costa Rica but not Colombia. Also, when we combined all the data together, the mortality rate for greens is 47% while the one for olive ridley is 40% and the one for hawksbill is 0% (based on the observation of 309 olive ridleys, 47 greens and 1 hawksbill). Although there are not demographic data associated with the mortality rates included in this review, data from some of the other sources show that olive ridleys captured are adults while greens are juveniles or subadults (Cornelius and Robinson-Clark 1986, Alava et al. 2005). This difference in life stage could be responsible for the higher mortality rates of green because younger sea turtles are less resistant to involuntary submergence than older turtles (Lutcavage and Lutz 1991, Lutcavage and Lutz 1997).

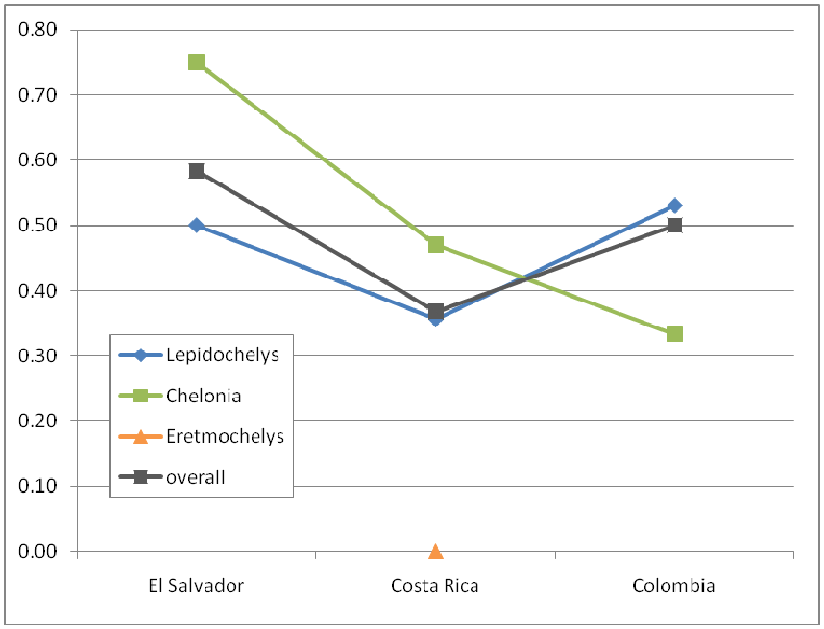

Figure 5: Mortality proportions of sea turtles captured during trawl fisheries in the EP. Data is shown for three countries, for each species and all turtles combined.

1.4.3.3 Bycatch mitigation – TEDs

Mitigation methods for trawl fisheries include the use of several bycatch reduction devices as well as modification of the trawl duration and areas. For sea turtles, the most common device used is the TED (Turtle Excluder Device) which was developed by the National Marine Fisheries Service in collaboration with commercial fishermen in 1980 (Epperly 2003). TEDs became mandatory in some states and for some seasons but they finally became mandatory in all inshore and offshore US waters in 1994 after studies found that it will help stop the decline and promote the recovery of the Kemp's ridley and the Northwest Atlantic loggerhead population (Crouse et al. 1987, Crowder et al. 1994, Watson and Smith 1998, Epperly 2003, Crowder and Heppell 2011). In 1988, while the U.S. shrimp industry was fighting against TEDs, the U.S. passed the Public Law 101-162 which prohibited the importation of shrimp or shrimp products from foreign countries if those countries were not certified for using TEDs in their trawl fisheries. This law was not interpreted as mandatory until a court decision was made in May of 1996 (Epperly 2003).

In the EP, all countries with large shrimp trawl fisheries (i.e. except Peru and Chile), have made the use of TEDs mandatory. Mexico, Guatemala, El Salvador, Costa Rica, Panama, Colombia, and Ecuador enacted their national TED's regulations in 1996 and Nicaragua did it the following year. The reason for this similarity seems to be the fulfillment of the requirements that the U.S. imposed to the importation of shrimp in 1996. And, to the best of our knowledge, only three (i.e. Mexico, Costa Rica and El Salvador) of all these countries conducted TED trials before making mandatory its use while Guatemala did it the same year, 1996 (Arauz 1996, Arauz et al. 1998a, Salaverría Reyes 1998, Santana 2008). Only five other studies about TED efficacy have been conducted in three of all these countries (i.e. Araya 1999 cited in Arauz 2000, 2006, Rico-Mejia and Rueda 2007, Lopez 2009) after the use of TED was mandatory.

Results from the TED trials against the overall country BPUEs can be seen in Figure 6, the BPUEs for Mexico, Costa Rica, and Guatemala are for both nets using TEDs, but the rates from El Salvador were reported as a combination of one net with TED and the other without and that is why it is the highest BPUE. However, in all cases the sea turtle bycatch reduction is more than 75% and up to 92% in the case of Costa Rica with a mean of 86%. These studies show that TEDs work for reducing sea turtle bycatch in these EP countries as it has been shown in other fisheries around the world (Crowder et al. 1995, Brewer et al. 2006). Usually, when a trawl net with a TED catches a turtle is either because the turtle was smaller than the TED bar separation or the TED got obstructed with logs and other debris resulting in the capture of turtles in the anterior portion of the net (in front of the TED). Moreover, this obstruction of the TED and the loss of catch are the main reasons why fishermen oppose the use of TEDs (Herrera 2001). As a consequence and despite the legislation, many fishermen in the EP are not using TEDs or are not using them properly being the most common modification to the TED to sew shut the opening (Arauz 2000, 2006, Ruiz-Slater and Acevedo 2006, PRETOMA 2009, Martinez 2010, UNIVISION 2010).

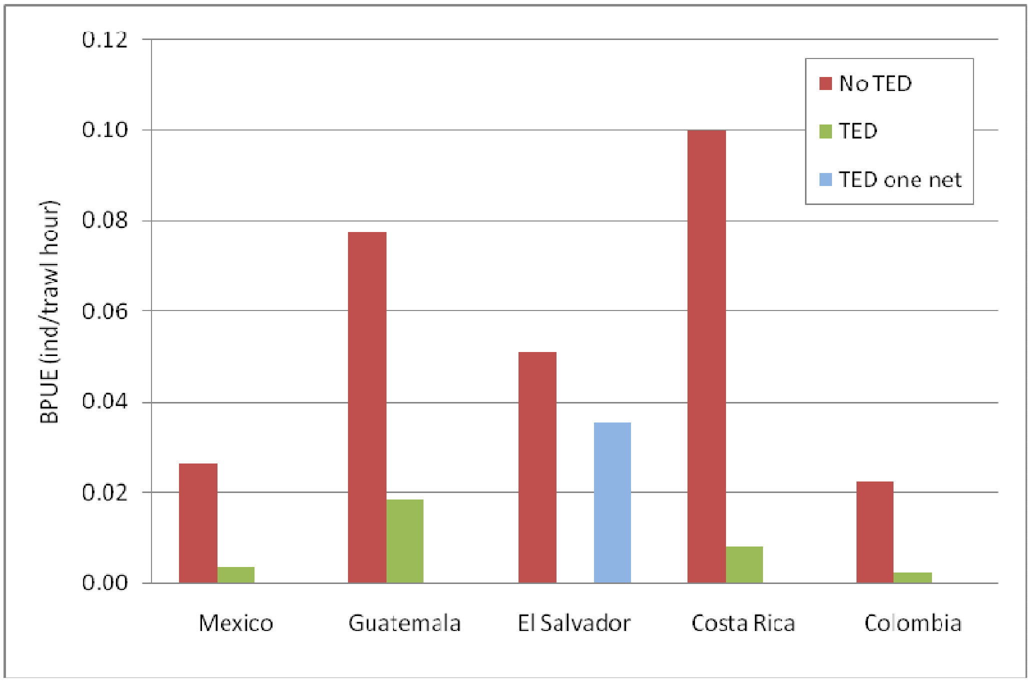

Figure 6: Sea turtle BPUEs in trawl fisheries without the use of a TED, with a TED in one net and in both nets. Data shown per country.

To enforce the use of TEDs, inspections are supposed to be conducted in all EP countries from Mexico to Ecuador. However, these inspections are basically conducted in ports before the fishing trips. At-sea inspections are not very common or sometimes are not conducted at all (Arauz 2000, SERMANAT 2005, Arauz 2006, Giron 2006, MARENA 2007). In Guatemala for example, 125 at sea inspections were conducted from 2001 to 2005, which represent only around 8% of the total fishing effort (Jolon, M. pers. comm.). Country certifications are conducted by NMFS officers who do an on-site visit once a year. Usually these visits are announced so when officers arrive all trawlers have TEDs. However some unannounced inspections and investigations had resulted in shrimp trade embargos of Costa Rica in 1999, 2003, and 2009 and Mexico in 2010 and an improvement in the use of TEDs. Nonetheless, the reality is that TEDs are not being properly used in the EP, and there is an urgent need to work collaboratively with fishermen to improve the compliance of TED use as well as to conduct more research to find the best TED model for specific fishery realities in each country in the region.

1.4.3.4 Fishery size and sea turtle impact

Current shrimp trawl fleet sizes in the Eastern Pacific are shown in Table 5. As a way to compare the fleets among countries, vessel density was calculated by dividing the fleet size by kilometers of coastline and multiplying by ten. These values show us that countries like Guatemala, Mexico, El Salvador, and Panama have high densities of fishing vessels and might be likely to have higher total bycatch of sea turtles per area (Table 5).

Table 5: Industrial shrimp trawl fleet size and density of vessels (v) per 10 km of coastline in each EP country with shrimp trawl fisheries.

Country	*fleet size*	*density (v/10km)*	*year*
Guatemala	65	2.6	2007
Mexico	1371	1.9	2010
El Salvador	57	1.9	2009
Panama	218	1.3	2008
Ecuador	159	0.7	2011
Colombia	93	0.6	2006
Costa Rica	55	0.5	2010
Nicaragua	16	0.5	2006

Since 1990 the shrimp resource has been overexploited and many countries have been limiting or downsizing the fleets to maximize yield per vessel or establishing closed seasons. For example in Nicaragua, due to the high but fluctuating yields during the 1990s the fleet size experienced continuous growth until 1999 when the fishery collapsed (Figure 7). Since then the fleet had been reduced in size but the fishery has not recovered (Figure 7). As a consequence, the Nicaraguan government declared a permanent closure of the shrimp fishery in their Pacific waters in April 2007. Up to 2009 the shrimp resource has not recovered and therefore the closure is still in effect (Gutiérrez 2009).

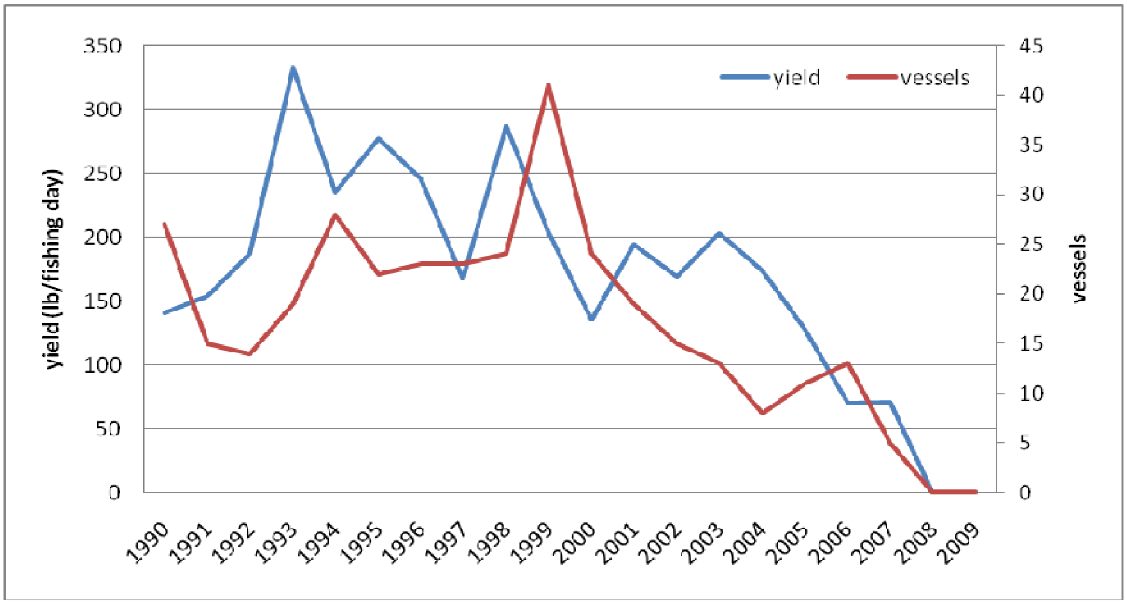

Figure 7: Time series of Nicaraguan shrimp trawl active fleet size and yield (pounds per fishing day). Data from INPESCA (2009).

To understand the magnitude of the threat that trawl fisheries represent for sea turtle populations in the EP, we need to estimate total bycatch numbers. The total impact of a country's trawl fishery had been calculated in some studies as seen in Table 6 and Figure 8 (Cornelius 1982, Duque-Goodman 1988, Arauz 1990, 1996, PRETOMA 2009). In 1979, the annual bycatch estimate for Costa Rica was based on a fishing fleet of 61 vessels and a small fishing effort that increased dramatically since the late 1980s and 1990s as in the Nicaraguan example (Figure 7). In 1993, Arauz (1996) estimated a total of 60,043 sea turtles captured only by four Central American countries due to the increased fishing effort (Table 6, Figure 8).

Estimates of total annual bycatch (TAB) for the period 2008-2010 were elaborated using the following equations:

$TAB = AV * FD/V * Ha/D * H/Ha * BPUE$

or

$TAB = AV * Ha/V * H/Ha * BPUE$ (used for Nicaragua only)

were:

AV: most updated number of active vessels

FD/V: average of annual fishing days per vessel (based on the most updated information for some countries and on the average from 2002 to 2006 for Nicaragua)

Ha/D: average hauls per day

H/Ha: average hours per haul

BPUE: bycatch per unit effort (turtles/hour)

Ha/V: average from 2002 to 2006 of annual hauls per vessel for Nicaragua only

We calculated two quantities of total annual bycatch; one assuming that all the fishing effort was conducted using TEDs and one assuming TEDs were not in use. The BPUEs used are shown in Table 4 and BPUEs with TEDs are from Figure 6. When information about fishing effort for a specific country was not found, we used the following regional averages: 199 for annual fishing days, 4.5 hauls per day, and 3.5 hours per haul. For countries with no BPUE information, the lowest regional value was used to be conservative in the estimates (i.e. 0.0226) and for countries with no BPUE with TEDs, we used the BPUE value without TED with a reduction of 86%, the regional reduction average. In the case of Costa Rica, the total annual bycatch number was taken from PRETOMA (2009) and in the case of Nicaragua no calculations were made due to the fishing closure in place since 2006.

Our estimates result in an annual bycatch of sea turtles in the EP ranging from 14,300 when using TEDs and 103,300 without TEDs (Table 6, Figure 8). Knowing that TED use is uncommon (section 1.4.3.3), we argue that the total number must be closer to 103,300 than to 14,300. The country which most likely contributes with the highest total bycatch is Mexico due to its large fleet size, followed by Costa Rica due to its high bycatch rate. Olive ridleys are the most impacted species because they represent the 89% of the captures and include adults or large subadults which have a high per capita reproductive value for the population. A total number between 12,500 and 90,400 olive ridleys could be getting captured in trawlers, which will result in between 5,000 – 36,200 mortalities annually. In the case of greens, bycatch impacts are of a lesser extend with capture and mortality numbers between 1,600 – 11,800 and 800 – 5,500 individuals annually. Moreover, demographic information shows that greens captured in shrimp trawls are juveniles; therefore the impact on the population would be smaller than in the case of olive ridleys because juveniles generally have lower reproductive values than adults. For hawksbill, even though the numbers can be very low, from 100 to 900, due to the small size of the population it could have a high overall impact.

Table 6: Estimates of total annual bycatch of turtles in trawl fisheries per country. Numbers for the 2008-2010 (no TED and TED) period was calculated in this review except the estimate for Costa Rica with no TED.

Country	*1979*	*1987*	*1993*	*2008-2010 no TED*	*2008-2010 TED*
Mexico				47,954	6,185
Guatemala			10,000	9,756	2,322
El Salvador			21,280	5,825	816
Nicaragua			8,000	closure	closure
Costa Rica	1,300	20,000	20,762	15,000	1,463
Panama				11,212	1,570
Colombia		8,231		8,460	1,269
Ecuador				5,100	714
total	1,300	28,231	60,042	103,307	14,339

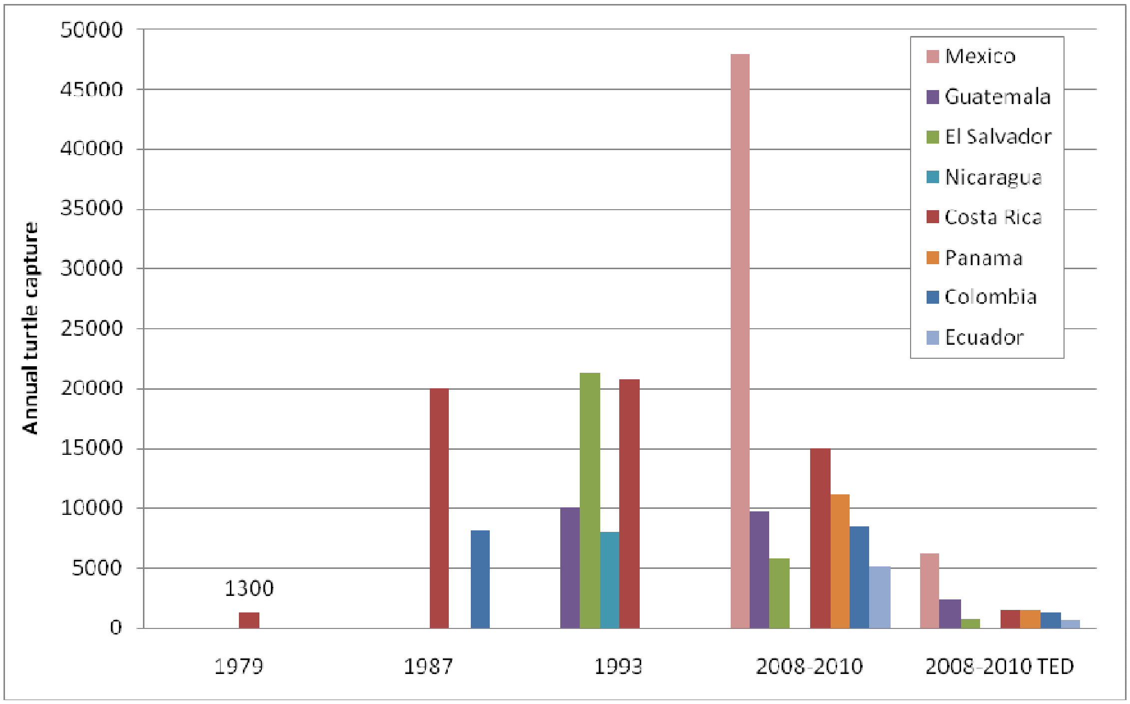

Figure 8: Estimations of total annual bycatch of turtles in trawl fisheries per country. Numbers for the 2008-2010 (no TED and TED) period was calculated in this review except the estimate for Costa Rica with no TED.

1.4.4 Longline fisheries

1.4.4.1 Fishery description and fishing area

In the EP region, longline fisheries are divided in pelagic and bottom longlines. Pelagic longline fisheries generally target tunas like yellowfin *Thunnus albacores*, bigeye *T. obesus,* and skipjack *Katsuwonus pelamis*, sharks like shortfin mako *Isurus oxyrinchus*, blue shark *Prionacea glauca*, hammerheads *Sphyrna* spp, silky shark *Carcharhinus falciformes*, bull shark *C. leucas*, and pelagic thresher *Alopias pelagicus*, mahi mahi *Coryphaena hippurus*, and billfishes like swordfish *Xiphias gladius*, and Indo-

Pacific blue marlin *Makaira mazara*. Also, bottom longlines target sharks like silky shark, bull shark, hammerheads, and fish species like snappers. Pelagic fisheries are conducted generally in an area that goes from 20 nautical miles from the coast as far as international waters (>200 miles offshore). Besides national fisheries, international fleets also operate in the region; most of this fleet is Japanese, Korean, Taiwanese, and Chinese, with 294, 193, 152, and 123 authorized vessels respectively (IATTC 2011). The EP is also used as fishing grounds by Illegal, Unregulated, and Unreported fleets (IUU). The international fleets moved into the Eastern Pacific in the 1960s targeting mainly bigeye tuna *Thunnus obesus,* but current catches are composed of large proportions of yellowfin tuna and albacore *Thunnus alalunga* in addition to bigeye. The fishing effort of these fisheries changes intensity and areas from year to year. For example, effort in 1990 (Figure 9, panel A) was high along the entire Peruvian coast, however in 2002 (Figure 9, panel B) the effort was higher in the western Pacific.

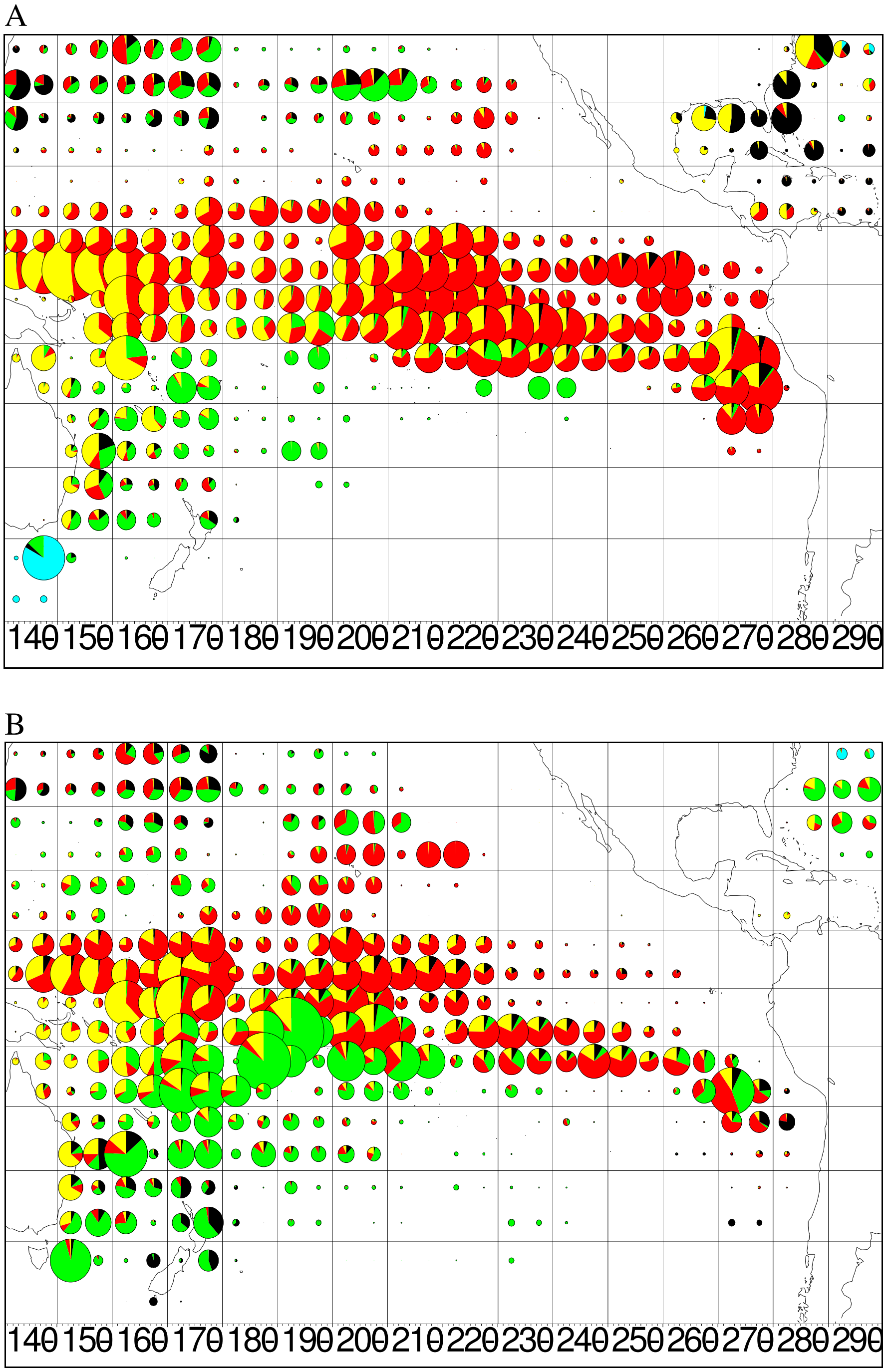

Figure 9: Fishing effort in the Pacific Ocean by international fleets. Circles represent catch and vary accordingly to catch magnitude. A) 1990, B) 2002. Green = albacore, red = bigeye tuna, yellow = yellowfin tuna, black = swordfish. Maps by the Secretariat of the Pacific Communities.

1.4.4.2 Bycatch numbers, rates and mortality

A total of 44 sources were useful for sea turtle bycatch in longline fisheries. The majority of sources had a quantitative component and most of them included information on fishing effort which greatly helped in the bycatch analysis. References included information from 1986 to 2010 and were published between 1992 and 2011. Three of the sources did not include specific quantitative information but were important in the review because of reported interactions or sizes of turtles captured that were not included in the other sources (Ordonez and Duchez 2007, Barreto et al. 2008a, de Paz et al. 2008). Overall, a total of 5,217 sea turtles have been reported as incidentally captured in longlines (pelagic and bottom) in the EP with at least the 3% (n = 168) reported as mortalities (Table 8). Also, 3 dead green turtles and 1 live olive ridley were recorded as captures in hook and line fishing in Michoacan, Mexico (Ruiz-Slater and Acevedo 2006).

Olive ridley

As in trawl fisheries, olive ridley is the most frequent turtle captured in the EP (Table 7) with 3,341 capture records and 54 mortalities, representing the 68% of all identified records (Table 8). The capture of olive ridley shows spatial differences in its frequency. From Mexico to Costa Rica olive ridleys are the most common species captured with a peak of records in Costa Rica, but from Colombia south to Chile other species become more frequent than olive ridleys (Tables 7 and 8). Bycatch rates of olive ridleys in pelagic longlines also show the same patterns of the records (Table 9 and

Figure 10). BPUE is low in Mexico (0.3058), increasing to the south until it reaches a maximum of 9.5641 turtles/1000 hooks in Costa Rica and subsequently decreasing to values of 0.0343 in Peru and 0.0011 in international waters off Peru and Chile (Table 9 and Figure 10). This capture frequency and rates seem to be related to the olive ridley distribution and abundance in the warmer waters of tropical countries like the ones in Central America and the northern part of South America.

Green turtle

Overall, 561 green turtles, 11% of identified records, were documented as captured by longlines in the EP, with a mortality rate of at least 1% (Table 8). This species had been recorded in a low frequency in those countries where olive ridleys show high capture records (Table 7). In Colombia and Ecuador, records of greens in longlines are as frequent as olive ridleys (Table 8). However in Peru, greens become even more frequent in longlines as 43% of all records come from this country. Nevertheless, bycatch rates vary from low values in the northern and southern areas of the EP (i.e. Mexico with 0.0503 and Chile with 0.0005 turtles/1000 hooks), and high values in the central area having a peak in Ecuador with 2.3226 turtles/1000 hooks (Table 9 and Figure 10). The bycatch of green turtles in longlines seems to be a particular characteristic of this species in the Eastern Pacific as the majority of worldwide records of bycatch in longline either don't include green turtles or its catch is very low (Witzell 1999, Ferreira et al. 2001, Lewison et al. 2004, Carranza et al. 2006, Gilman et al. 2007, Brazner and McMillan

2008, Petersen et al. 2009, Echwikhi et al. 2010, Sales et al. 2010). The reasons for this high interaction between green turtles and longlines is likely to be related with the fact that this species is the very common in Ecuador and Peru and that greens in the southeast Pacific seem to have a more carnivorous diet when compared with other populations which is further evidenced by high proportions of greens biting longline hooks (Hays-Brown and Brown 1982, Aranda and Chandler 1989, Bjorndal 1997, Kelez et al. 2010).

Leatherback

Leatherbacks represent the 8% of the identified turtle records and are the most common species captured in Chile, as they have the 70% of all leatherback capture records in the EP (287 out of 411), but have low records in other countries (Tables 7 and 8). BPUEs available from Chile, Peru, and foreign fleets fishing off these countries show general low bycatch rates, 0.0268, 0.0064, and 0.0225 turtles/1000 hooks respectively, when compared to BPUEs for olive ridley and green turtle in the region (Table 9 and Figure 10). In the Eastern Pacific leatherbacks use oceanic waters off Peru and Chile as foraging grounds (Eckert and Sarti 1997, Shillinger et al. 2008) and the overlapping of those foraging areas with longline fishing activities seems to be responsible for the interaction.

Loggerhead

Loggerhead captures in longliners in the central area of the EP where warmer waters occur has not been reported as in the case of bycatch in trawlers (Table 7). In colder waters, a total of 537 individuals had been recorded off Mexico, Ecuador, Peru and Chile with 44 mortalities (Table 8). Records from Mexico are from bottom longline fisheries in Baja California, areas that abundant juvenile loggerheads from the North Pacific population use as foraging habitats (Peckham et al. 2007, Peckham et al. 2008). Due to the abundance of loggerheads in that area, bycatch rates are of a high magnitude, 29.3 turtles/1000 hooks (Peckham et al. 2008). However, loggerheads had also been reported in the medium scale shark longline fishery off Mexico (Santana Hernandez and Valdez 2003); but due to the combined species reports, they bycatch numbers are included in the "nn" category of Table 8. In South America, records of loggerhead captures come from pelagic longline fisheries in Ecuador, Peru, and Chile (Tables 7 and 8) with the highest records in Peru (389 individuals). BPUEs were also obtained for Peru, Chile, and two international fleets fishing off Peru and Chile (Table 9 and Figure 10). The highest BPUE was recorded in Peru (0.0943 turtles/1000 hooks). Individuals captured off South America belong to the South Pacific population and the bycatch recorded shows an overlap among pelagic longline activities and loggerheads that use oceanic water as foraging grounds. Comparing bycatch rates for both populations, the bottom longline BPUE in Baja California is 20 times larger than the pelagic longline off Peru and Chile.

Table 7: Abundance of records of bycatch in longline fisheries (pelagic shallow, pelagic deep, and bottom) per country.

Country	*Olive ridley*	*Green*	*Leatherback*	*Loggerhead*	*Hawksbill*
Mexico	**medium**	low	low[1]	low	
Guatemala	**high**		low[1]		
El Salvador	low[1]	low[1]			
Nicaragua	**high**	low	low		
Costa Rica	**high**	low	low		low
Panama	low	low[1]			
Colombia	**medium**	**medium**			low[1]
Ecuador	**medium**	low	low	low	low
Peru	low	**medium**	low	**medium**	
Chile		low	**high**	low	

[1] Only one mention of the interaction.

Table 8: Total numbers of turtles captured in longlines and mortalities recorded in the EP. Data by country and species. Foreign fleets (Uruguayan and Spanish) fishing in internationals waters mainly off Peru and Chile are also included. Mortalities are between parentheses. Question mark denote that at least one source did not report mortality information.

Country	*Olive ridley*	*Green*	*Leatherback*	*Loggerhead*	*Hawksbill*	*nn*
Mexico	115 (16?)	16 (2?)		48 (43)		113 (?)
Guatemala	22 (22)					
El Salvador						
Nicaragua	673 (3?)	50 (?)	55 (?)			
Costa Rica	2,235 (9?)	98 (0?)	4 (0)		1 (0)	
Panama						
Colombia	25 (2?)	22 (1?)				
Ecuador	211 (2)	125 (1)	2 (0)	24 (0)	45 (0)	47 (42)
Peru	59 (0?)	244 (0?)	43 (0?)	389 (1?)		
Chile		7 (3)	288 (4)	59 (0)		15 (0)
Foreign fleets	1 (?)		20 (?)	17 (?)		
total	3,341 (54?)	561 (7?)	411 (4?)	537 (44?)	46 (0)	321 (59?)

Hawksbill

Hawksbill is the least frequent species recorded as being captured in longlines as there are only 46 records of this species, representing the 1% of all identified turtle records (Tables 7 and 8). Bycatch records come from pelagic longlines targeting dolphinfish or tuna/shark/billfishes mostly in Ecuador but also in Costa Rica (Table 8, Largacha et al. 2005, Solano 2010).

BPUEs

Overall per country bycatch rates in pelagic longlines show highest values in Costa Rica and Ecuador and lowest values in Chile (Table 9 and Figure 10). In the case of bottom longlines, two BPUEs were obtained showing low rates in Colombia (0.3 turtles/1000 hooks) but extremely high in Baja California (Gomez-Cubillos et al. 2008, Peckham et al. 2008). Comparing pelagic longline BPUEs in the EP with countries in other regions, it can be observed that the rates of EP countries fall either in the high extreme or the low extreme of the range (Tables 10 and Figure 11). The higher BPUEs were found in the most tropical countries (i.e. Costa Rica, Ecuador, and Nicaragua) and the lowest BPUEs in countries with comparatively more temperate waters (i.e. Chile, Mexico, and Peru, Tables 10, and Figures 10 and 11).

Bottom longlines

Published information from bottom longline fisheries is scarce in the EP but records show interaction principally with olive ridley, loggerhead, and green and in a lesser degree with leatherbacks (Brito 2001, Peckham and Nichols 2006, Ruiz-Slater and Acevedo 2006, Barreto et al. 2008b, Gomez-Cubillos et al. 2008, Peckham et al. 2008, INAPESCA/WWF 2009, WWF 2009). Bycatch rates show high variation having an extremely high BPUE in Baja California for loggerheads (29.3 turtles/1000 hooks), but a low olive ridley BPUE in that same fishery (0.8333 turtles/1000 hooks) (Peckham and Nichols 2006, Peckham et al. 2008).

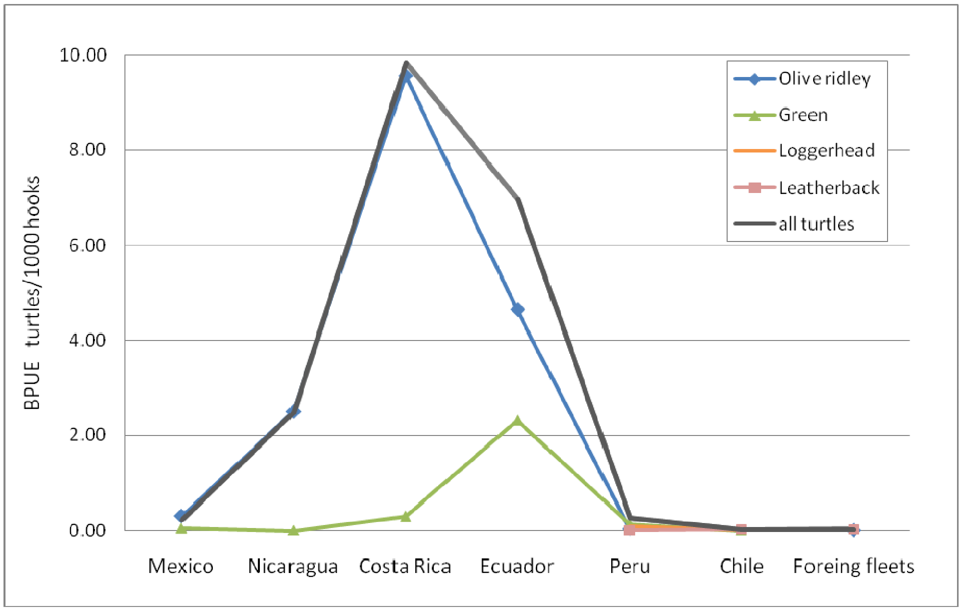

Figure 10: Bycatch per unit effort (BPUE) of sea turtles in pelagic longline fisheries (turtles/ 1000 hooks) in the EP. Rates of each species and for all sea turtles combined per country (from north to south) and international fleets from Uruguay and Spain fishing mainly off Peru and Chile.

Table 9: Bycatch per unit effort (BPUE) of sea turtles in pelagic longline fisheries (turtles/ 1000 hooks) in the EP. Rates of each species and for all sea turtles combined per country for 6 countries (from north to south) and international fleets from Uruguay and Spain fishing mainly off Peru and Chile. No data for hawksbill.

Country	*Olive ridley*	*Green*	*Loggerhead*	*Leatherback*	*all turtles*
Mexico	0.3058	0.0503	0	0	0.2465
Nicaragua	2.5037	0	0	0	2.5037
Costa Rica	9.5641	0.2981	0	0	9.8622
Ecuador	4.6452	2.3226	0	0	6.9677
Peru	0.0343	0.1420	0.0943	0.0064	0.2771
Chile	0	0.0005	0.0056	0.0268	0.0342
Foreign fleets	0.0011	0	0.0192	0.0225	0.0605

Table 10: Bycatch rates in pelagic longline fisheries from this review and countries from other regions. BPUE unit is turtles per 1000 hooks.

Region	*BPUE*	*Species*	*Reference*
Chile, EP	0.034	Dc, Cc, Cm	this review
South Africa, SEA	0.040	Cc, Dc, Ei, Cm	Petersen et al. (2009)
Mexico, EP	0.215	Lo, Cm	this review
Peru, EP	0.277	Cm, Cc, Lo, Dc	this review
US, NWA	0.291	Dc, Cc	Garrison (2005)
Guinea's gulf, ECA	0.480	Lo, Dc	Carranza et al. (2006)
Canada, NWA	0.750	Cc	Brazner & McMillan (2008)
Tunisia, Med	1.173	Cc	Echwikhi et al. (2010)
Brazil, SWA	1.500	Cc, Dc	Pinedo & Polacheck (2004)
Azores, NEA	1.700	Cc	Bolten et al.(2002)
Brazil, SWA	1.893	Cc, Dc, Cm	Sales et al. (2010)
Nicaragua, EP	2.504	Lo	this review
Ecuador, EP	6.968	Lo, Cm	this review
Costa Rica, EP	9.862	Lo, Cm	this review

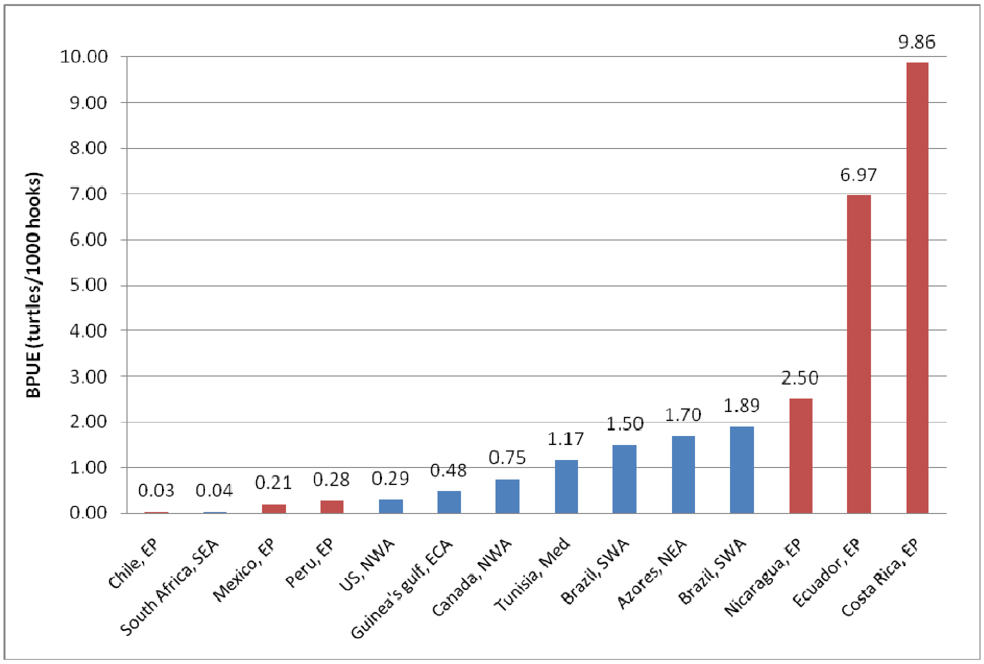

Figure 11: Bycatch rates in pelagic longline fisheries from this review (in red) and from countries other regions (in blue).

Mortality rates

Mortality rates in pelagic longline fisheries were calculated for all turtles combined and also for each species using all the sources that included mortality numbers (Segura and Arauz 1995, Arauz et al. 2000, Brito 2001, Santana Hernandez and Valdez 2003, Arauz 2004, Largacha et al. 2005, Swimmer et al. 2005, Mejuto et al. 2007, Alfaro et al. 2008, Rodríguez-Valencia et al. 2008, Donoso and Dutton 2010, Elias and Castro 2010, Kelez et al. 2010, Swimmer et al. 2010a, Swimmer et al. 2010b). The overall mortality rate for all turtles was calculated to be 1.1% (Table 11) and the low value is explained by the fact that most pelagic longline fisheries in the EP are shallow and turtles can reach the surface to breathe, especially when the target is dolphinfish. The high mortality rate of unidentified turtles is the result of the high mortality rate of the Spanish fleet fishing for swordfish off Peru and Chile. This higher rate could be because monofilament lines, which are used by commercial vessels like the Spanish fleet ones, sink as opposed to multifilament ones that are used by artisanal vessels.

Table 11: Mortality rates in pelagic longlines fisheries of the EP, all countries combined. Only sources with data on fate of turtles are included.

Species	*Bycatch*	*Mortality*	*Mortality rates (%)*
Olive ridley	1563	5	0.3
Green	269	1	0.4
Leatherback	290	3	1.0
Loggerhead	448	1	0.2
Hawksbill	18	0	0.0
unidentified	189	20	10.6[1]
All turtles	2777	30	1.1

[1] Includes records of unidentified turtles or of combined species (Arauz et al. 2000, Mejuto et al. 2007, Donoso and Dutton 2010).

Table 12: Mortality rates in bottom longline fisheries of the EP, all countries combined. Only sources with data on fate of turtles are included

Species	*Bycatch*	*Mortality*	*Mortality rates (%)*
Olive ridley	20	13	65.0
Green	8	5	62.5
Loggerhead	48	43	89.6
All turtles	76	61	80.3

In the case of bottom longline fisheries, mortalities were calculated also for all turtles combined and for each species using the best sources available (Brito 2001, Ruiz-

Slater and Acevedo 2006, Barreto et al. 2008b, Gomez-Cubillos et al. 2008, Peckham et al. 2008). Overall mortality rates were on average 80.3% (Table 12) but the highest rates were for loggerheads. Mortality rates in bottom longline fisheries are much higher than in pelagic longline fisheries. These mortality rates combined with high bycatch rates in the case of Baja California as well as mortalities due to gillnets seem to have been responsible for an exceptionally high mortality in the north Pacific loggerhead population (Peckham et al. 2008). If fishing effort is not considered, it is noticeable that bottom longlines are a larger threat for sea turtles because of the combination of medium or high bycatch rates and extremely high mortality rates while in the case of pelagic longlines even when bycatch rates are particularly high in some countries, mortality rates are so low that the resulting impact on sea turtles ends up becoming extremely small. However, post released mortalities and accumulated effects of subsequent recaptures still need to be considered. Calculating these mortality rates has not proven to be an easy task but some studies suggest a mortality proportion between 20% and 40% depending on the hooking location and others suggest no mortalities for lightly hooked turtles (Chaloupka et al. 2004, Parker et al. 2004, Swimmer et al. 2006). Current NOAA mortality criteria ranges from a mortality rate of 1% in the case of entanglement of a hard-shell turtle that is fully disentangled before release to a mortality rate of 95% in the case of a leatherback hooked in esophagus at or below level of the heart, released with hook and entangled (Ryder et al. 2006). Nevertheless, there is still a need for better mortality estimates by hooking location not only in pelagic longlines but also in bottom longlines.

Developmental stages

Information on sizes of turtles captured was available from some sources. This information let us deepen in the overall impacts of bycatch as the relative importance of individual turtles on a population depends on its reproductive value (Crouse et al. 1987, Heppell et al. 2005). In the case of loggerheads, individuals captured in pelagic longlines in the southeastern Pacific are juveniles of sizes that range from 33 to 93 cm of curved carapace length (CCL) but 1 adult size loggerhead (CCL 108 cm) was captured in international waters off Peru and Chile. In the northeast Pacific, loggerheads captured in bottom longlines are also juveniles of an average of 77.7 cm of CCL.

Olive ridleys captured in pelagic longlines varied in sizes with larger turtles captured in Costa Rica and Nicaragua as evidenced by the size averages of 64 cm of CCL in Nicaragua and the averages from various studies that ranged from 56.3 to 67.3 cm of CCL in Costa Rica which suggest that at least 50% of the turtles are adults. Moreover, in Guatemala olive ridleys captured had been identified as adults. In Peru, CCL ranges from 21 to 75.2 with an average of 54.9 cm and only 18% of adults. In bottom longlines, adults are the most common stage captured in Colombia and Mexico.

When considering that adult size for green turtles in the EP is at least 82 cm CCL in Michoacan nesting beaches and 86 cm of CCL in Galapagos Islands (NMFS and U.S. Fish and Wildlife Service 1998, Zarate et al. 2003), almost all green turtles captured in pelagic longline fisheries are juveniles or subadults (range 32 -86 cm of CCL). Only a few individuals captured in Peru could be considered adults based on their size. The same is true for turtles captured in bottom longlines that ranged from 63.9 to 75 cm of CCL. In the case of leatherbacks, one record from Peru is from a juvenile that measured 109 cm of CCL. In Chile, were the highest bycatch rate for leatherbacks occur, the majority of individuals captured are adults of a mean of 142 cm and a range of 80 -200 cm of CCL (Donoso and Dutton 2010).

Considering all species, olive ridley and leatherback are the species that have largest individuals being captured in longlines the ones that have highest relative reproductive values. In the case of leatherbacks they are captured by pelagic fisheries with very low mortality rates but in the case of olive ridleys they are not only being captured in pelagic longlines but also in bottom longlines which makes that fishery a higher threat for the olive ridley EP population.

1.4.4.3 Bycatch mitigation

Several techniques had been tested to reduce sea turtle bycatch in longline fisheries worldwide. The most common practice worldwide has been to test the efficiency of circle hooks to reduce sea turtle bycatch and reduce the proportion of swallowed hooks as it was demonstrated to be efficient in swordfish and tuna longline fisheries in the North Atlantic (Watson et al. 2005). In those experiments, larger and wider circle hooks compared to J hooks reduced turtle bycatch by 57% to 90% depending on the species and bait used while maintaining fishing efficiency for tuna and swordfish when using squid and mackerel bait respectively (Watson et al. 2005). In Brazil, an experiment of 18/0 circle hooks also reduced captured rates by 55% for loggerheads and 65% for leatherbacks when compared against 9/0 J hooks (Sales et al. 2010). However, other circle hook experiments have not been successful in demonstrating a reduction of sea turtle bycatch, but only a reduction in swallowed hooks (Bolten et al. 2002, Read 2007, Domingo et al. 2008). The size of the hook is an very important factor because a small circle hook will not be more effective in reducing turtle bycatch than a large J hook (reviewed by Gilman et al. 2005).

In longline fisheries of the Eastern Pacific, the first experiment conducted was the use of blue-dyed bait in pelagic longline fisheries targeting dolphinfish in Costa Rica in 2003, but results did not show a reduction in sea turtle bycatch (Swimmer et al. 2005). Fishermen in Costa Rica commonly use circle hooks and not J hooks as in the rest of the region. Therefore, experiments in Costa Rica did not involve a comparison between those types of hooks. From 2004 to 2006, experiments tested if offset circle hooks (14/0) will reduce bycatch rates but significant differences were not found (Swimmer et al. 2008). In 2004, several J vs. circle hook experiments started in Ecuador, Mexico, and Colombia. In Mexico, trials compared 9/0 J and 9/0 tuna hooks with 16/0 circle hooks in the shark pelagic longline fishery. Due to the low number of captures statistical comparisons were not made, but turtle bycatch was similar among the 3 types of hooks with 15, 16, and 11 turtles captured with 9/0 J hooks, 9/0 tuna hooks, and 16/0 circle hooks respectively (Santana and Valdez 2006). In Ecuador, from 2004 to 2005, experiments compared J hooks of several sizes to 18/0 and 16/0 circle hooks in the tuna fishery and to 14/0 and

15/0 circle hooks in the dolphinfish fishery. Results evidenced a reduction in turtle bycatch rates especially for 18/0 circle hooks in the tuna fishery where the reduction was 89% and was statistically significant (Largacha et al. 2005). Trials in Colombia were conducted in bottom longline fisheries but bycatch rate results of the experiment were not published (Barreto et al. 2008b).

After the trials in Ecuador and Colombia, the program expanded to other countries in the region. In 2005, Panama, Peru, Costa Rica, Guatemala, and El Salvador joined the Eastern Pacific Regional Sea Turtle program (aka circle hook program) that started in Ecuador and was mainly run by the Inter-American Tropical Tuna Commission (IATTC) and WWF (Hall et al. 2006, Valqui et al. 2006, Mug et al. 2007a, Mug et al. 2007b, Pacheco et al. 2007). In the second year of the program, the 16/0 hooks compared to the traditional J hooks in the tuna, billfish, and shark fisheries reduced sea turtle bycatch from 60% to 80% maintaining the catch efficiency. On the other hand, in the dolphinfish fishery the 14/0 and 15/0 circle hooks reduced target catch and were less accepted by fishermen than in the shark fishery. In Central American countries were fishermen were already using circle hooks, the program tested larger circle hooks with positive results (Hall et al. 2006). Hooks with wire appendages that were used in New Zealand were also tested in Peru and Ecuador, the experiment resulted in great bycatch reduction even for small circle hooks, from 53% to 80% reduction (Hall et al. 2006, Mituhasi et al. 2008). The program was not only testing circle hooks but also trying and providing tools for handling and dehooking of sea turtles like dipnets and dehookers. In

2005, Mexico also conducted trials of 14/0, 16/0 and 18/0 circle hooks in the coastal shark longline fishery. They got positive results for target catch specially with the 14/0 circle hook and sea turtle bycatch rates showed a reduction of 44% with circle hooks compared to J hooks (Rodríguez-Valencia et al. 2008).

By the third year of the circle hook program, Mexico and Nicaragua joined the program and turtle bycatch results were still positive in the shark and tuna fishery and dolphinfish fishery but the low catch of dolphinfish remains a problem only on some areas (Mug et al. 2008). Other components of the project are hooking location and entanglements. In the first case, the proportion of turtles that swallowed hooks also decreased with circle hooks in both fisheries. In the second case, it was observed that the majority of entanglements occurred in lines that are made by polypropylene and in the float lines more than in the branch lines (Mug et al. 2008). A possible solution could be to replace polypropylene lines with monofilament lines, but given the artisanal nature of the fleet that will be a great challenge.

Hooks with wire appendages were also tested in Costa Rica in 2007 with great bycatch reductions. The hooks used were 14/0 circle hooks with and without the wire appendage and the turtle bycatch reduction was 52% (Swimmer et al. 2010b). Even when there was also a reduction in the catch of marketable species, hooks with appendages seems to be a promising solution to bycatch in any type of hook. Other two sources reported the use of circle hooks in fisheries in small scale fisheries in Colombia and Mexico. In the case of Mexico only 13/0 circle hooks were used in pelagic and bottom artisanal fisheries resulting in hook efficiency to capture commercial species like sharks, rays, snappers among other fish species but also captured sea turtles with a bycatch rate of 0.5833 turtles/1000 hooks which is actually higher than the rate in pelagic commercial longline fisheries in Mexico (INAPESCA/WWF 2009). In Colombia, circle hooks were tested in the bottom longline fishery with good results for fish catch but data on the efficiency of the circle hook to reduce turtle bycatch was not included in the report (Gomez-Cubillos et al. 2008).

In general, circle hooks seem to be working for tuna, shark, and billfish fisheries, but for all fleets in the region to use those hooks would need to be made available to the fishermen given that usually there is a shortage of hooks. In the dolphinfish fishery, hooks with appendages seem to be the best solution and more trials should be encouraged. Also, in order to attend the other component of bycatch which is survival after release, fishermen need to participate in workshops to learn the best handling and release techniques. Moreover, handling tools need to be made available to fishermen, especially dipnets given that most of the injuries to sea turtles occur during the process of bringing the turtle on-board of the vessel (pers. observation).

1.4.4.4 Fishery size and sea turtle impact

The only fishing effort information available so far is for the swordfish and shark pelagic longline fishery of Chile. In this fishery, the annual fishing trips average (last 5 years: 2005-2009) is 36.6 and had an observer coverage of 85% (Azócar et al. 2009).

Considering that during each fishing trip an average of 22.7 sets are made with an average of 1338.9 hooks per set and that the BPUE is 0.0342 turtles/1000 hook (Donoso and Dutton 2010), we calculated an annual bycatch of 38 sea turtles which will be composed by 78% leatherbacks, 10% loggerheads, 8% olive ridleys and 4% green turtles. Due to the fishing effort and bycatch rates this country could have the lowest total annual captures in the region.

1.4.5 Gillnet fisheries

1.4.5.1 Fishery description and fishing area

Gillnets are the most common fishing gear used in the EP and largely varies in sizes and types depending on the target species. Also, fishing areas and methods vary greatly not only depending on the target species but also on the country. Unfortunately, this fishing gear had been the least evaluated in the region for sea turtle bycatch compared to trawls or longlines mainly due to the small-scale nature of gillnet fisheries and the rapid change of gear and target species that gillnet fisheries implement seasonally. Nevertheless, the limited information available shows that fisheries targeting sharks, rays, flounder, and swordfish are the ones that most commonly result in sea turtle bycatch.

The driftnet swordfish fishery in Chile had been recognized as a threat for sea turtles since 1990 (Frazier and Brito 1990). This fishery started around 1986 and operates all year round but with higher fishing effort between March and August. Swordfish is usually fished in water temperatures from 14°C to 20°C and operates from Chile's northern border to 40°S with higher catches at lower temperatures, higher latitudes, and higher chlorophyll concentrations (Yáñez et al. 1996, Yáñez et al. 2003, Yáñez et al. 2009). From 1987 to 1998, the swordfish stock experienced an 80% reduction due to overexploitation and by 2001 the driftnet fleet had diminished (Brito 2001, Yáñez et al. 2003). The driftnet swordfish fishery in Peru is extremely small as most fishermen target sharks instead (Arauz 1999). In Mexico, swordfish driftnets operated since 1986 in Baja California off the first 50 nm up to 2007 when their use was banned (DOF 2007, 2010). Nets for sharks and rays with mesh size of 20 cm are more widely spread in the EP than swordfish driftnet and seem to be highly associated with sea turtle bycatch. In addition, gillnets that target other species like flounder, guitarfish, and lobster also capture sea turtles in the EP.

One problem with evaluating gillnet bycatch is that direct capture is still going on in some places of the EP in spite of being illegal and it usually employs gillnets. In Mexico during Easter, sea turtles are captured for their meat due to the religious practice that prohibits eating "red meat" and the fact that in Mexico sea turtles are not considered to be "red meat". However, in Baja California, the consumption of turtle meat is a regular habit and it has been estimated that the annual total mortality of green turtles is 30,000 individuals (Nichols 2004). In Peru, in the area of Pisco-Paracas, the capture of turtles and commercialization of its meat is still common (Quinones pers. comm.). In both places, special turtle nets are used, usually with a mesh size between 20 and 60 cm (de Paz et al. 2002, Nichols 2004, Gilman et al. 2009).

1.4.5.2 Bycatch numbers, rates and mortality

The gillnet review includes 31 sources with information on interactions, bycatch numbers, bycatch rates, and/or mortality rates. The nature of the data is very specific to particular fisheries and countries; therefore, this part of the review will focus mainly on countries and particular fisheries instead of sea turtle species like in the case of trawls and longlines. Also, this part of the review is the only part to include Honduras due to the availably of one source referring to bycatch of sea turtles in gillnets (Sotelo 2010).

The abundance of records per species and countries are shown in Table 13 and the total numbers recorded of captured turtles and their mortalities are shown in Table 14. There was no information on interactions among gillnets and sea turtles for two countries in the region, El Salvador and Nicaragua, which can be attributed to the difficulty of recording the interactions and not the lack of interactions (Table 13). Moreover, records from Panama and Ecuador are limited to stating the interaction occurs (Zarate 2007, Abrego 2010, Gaos et al. 2010).

The summary of all the records show a total of 1,290 turtles reported as captured by gillnets in the region and at least 470 mortalities (36%). Olive ridley is the species most frequently captured with 38% of all records, followed by green and leatherback with 32% and 24% of the records respectively (Table 13). Loggerhead and hawksbill were the least frequent species in the records, with 25 reports for hawksbill in Mexico, El Salvador and Peru and 34 for loggerhead in Mexico, Peru, and Chile. The overall mortality rate calculated from studies that used observers in the entire region reaches 49%, which is the highest among all gears. Species specific mortality rates were 100%, 76%, 66%, 52%, and 40% for hawksbills, olive ridleys, loggerheads, leatherbacks and greens respectively. Also, as mentioned before, there is a lack of information on bycatch in gillnets in many countries of the region, and in the case of turtle reports only 6 out of 11 countries have available data. Moreover, the majority of the records come from Peru with the 70% of the total reports (Table 14).

Table 13: Abundance of records of bycatch in gillnet fisheries (bottom gillnets, driftnets, mid-water gillnets) per country.

Country	*Olive ridley*	*Green*	*Leatherback*	*Loggerhead*	*Hawksbill*
Mexico	**medium**	low		low	low
Guatemala	low				
El Salvador					**high**
Honduras	low				
Nicaragua					
Costa Rica	**high**	low[1]			
Panama	low[1]				
Colombia	low[1]	low[1]			
Ecuador		low[1]			low[1]
Peru	**medium**	**medium**	low	low	low
Chile	low	low	**high**	low	

Table 14: Total numbers of turtles captured in gillnets and mortalities recorded in the EP. Data by country and species. Mortalities are between parentheses. Question mark denote that at least one source did not report mortality information.

Country	*Olive ridley*	*Green*	*Leatherback*	*Loggerhead*	*Hawksbill*	*nn*
Mexico	92 (72)	11 (2)		40 (27?)	15 (15)	28 (?)
Guatemala						
El Salvador					8 (8)	
Honduras						
Nicaragua						
Costa Rica	4 (?)					
Panama						
Colombia						2 (?)
Ecuador						
Peru	385 (63?)	393 (167?)	113 (7?)	2 (0)	2 (1?)	4 (4)
Chile	1 (0)	4 (4)	183 (97?)	3 (3)		
total	482 (135?)	408 (173?)	296 (104?)	45 (30?)	25 (24)	34 (4?)

Mexico

In Mexico, the majority of sea turtle bycatch records (53%) are from gillnets of 20cm mesh size that targeted California flounder *Paralichthys californicus* in Baja California or snappers (Lutjanidae) and tripletails (Lobotidae) in Michoacan (Nichols 2004, Ruiz-Slater and Acevedo 2006, Peckham et al. 2008). Loggerhead bycatch rates in the California flounder fishery of Puerto Lopez Mateos were calculated for two fishing depths, no turtles were captured when fishing at depth up to 32 m, but 0.37 turtles/km of net (or 0.8 turtles/day) were captured at depths between 32 and 45 m. (Peckham et al. 2008). The mortality rate associated with the fishery at higher depths was found to be 68% and only large juvenile loggerheads were captured. Furthermore, a total of 830 ± 102 loggerhead had been estimated to being caught in 2007 by this fishery (Peckham et al. 2008). In addition, green turtles and olive ridleys also get captured in this flounder fishery but bycatch rates are very low, only 0.0137 turtles/set for each species (Peckham and Nichols 2006). In the Michoacan records, bycatch rates were not available but mortality rates were estimated to the 91% for all turtles captured by 20cm gillnets (i.e. olive ridleys, hawksbills and greens) (Ruiz-Slater and Acevedo 2006).

Gillnets of mesh size of 15cm targeting snappers, tripletails, and lobster in Michoacan were also observed resulting in 63 bycatch records, the 45% of all records for Mexico. Turtles captured were olive ridley, hawksbills, and greens and 76% of them resulted in mortalities (Ruiz-Slater and Acevedo 2006). In the same area, gillnets of 3.5" mesh size also captured one olive ridley and one green but no mortalities occurred. The study did not report bycatch rates for either of these fisheries. In addition, gillnets had also been reported to capture olive ridley and green turtles in Guerrero and Oaxaca and to capture sea turtles in driftnets for swordfish in offshore areas off Baja California, but no more information about the interaction was given (INP 2000a, WWF 2009).

Guatemala

In Guatemala, there is only one source citing the interaction with gillnets from 1980 and 1984, when adult olive ridleys tagged when nesting in Costa Rica were recaptured by fishermen in Guatemala. A total of 13 turtles were recaptured by fishermen in that country and many of them indicated that they captured the olive ridleys in gillnets but the exact number or the target species was not mentioned (Cornelius and Robinson-Clark 1986).

El Salvador, Honduras, Costa Rica, Colombia and Ecuador

Only one was source was obtained from El Salvador and it reported the mortality of 8 subadult hawksbills in lobster bottom gillnets in Los Cobanos (Liles et al. 2011). One source was found for Honduras as well which mentioned that olive ridleys get incidentally captured by gillnets in the Gulf of Fonseca but that the impact is low (Sotelo 2010). Similarly, only one source was obtained from Colombia the one that reports the interaction of two turtles (green and/or olive ridley) with gillnets targeting "corvina" (probably weakfish *Cynoscion squamipinnis*) in Gorgona (Rojas and Zapata 2006, Gomez-Cubillos and Amorocho 2008). Very few sources were found for Costa Rica and Ecuador, for the former country the sources cited interactions among olive ridleys and greens with gillnets and for the latter the interactions cited were among greens and hawksbills (Cornelius and Robinson-Clark 1986, Araya 2006, Zarate 2007, Gaos et al. 2010). The only quantitative data comes from Cornelius and Robinson-Clark (1986), who recorded four adult female olive ridleys captured in gillnets for sharks in Costa Rica. No more information is available from any of these four countries.

Peru

Peru is the country with the highest quantity of records, 70% of all records in the region, but also with the largest quantity of sea turtle bycatch studies (de Paz et al. 2002, Majluf et al. 2002, Alfaro-Shigueto et al. 2007, Alfaro-Shigueto et al. 2008, Alfaro et al. 2008, Beteta 2009, Caceres-Bueno et al. 2010, Castro et al. 2010, Gonzales 2010, Rosales et al. 2010). The most frequent species reported were green and olive ridley which represented the 44% and 43% of total records respectively (Table 14). Leatherback records were only the 13% and loggerhead and hawksbill were rarely recorded as bycatch in gillnets with only 2 individuals recorded for each species (Table 14). Most of the turtles were captured in gillnets of 20cm mesh size which is commonly used in Peru to capture many species of sharks and rays, Pacific guitarfish *Rhinobatos planiceps*, flounder, and green spiny lobster *Panulirus gracilis*. Even though it was not specified in most of the studies, we assumed most gillnets were set at the bottom due to the target species. A minority of turtles were also captured in driftnets and trammel nets.

Bycatch rates from Peru were available from three different studies from departments in the northern half of the country. Bycatch rates for all species combined range from 0.253 to 3.070 turtles/set and in all cases highest rates are for green turtles (Table 15). The high values of Constante could be related with the fact that the village is located in Sechura Bay, a shallow water bay with abundance of algae which has been identified as an important foraging area for green turtles (Hays-Brown and Brown 1982, de Paz and Alfaro 2008). Constante had been a place where fishermen specialized in fishing sea turtles and in the months of September and October it was easy to capture between 80 to 100 turtles per boat in a fishing day (Vargas et al. 1994). Therefore, green turtle density in the area is likely to be high and consequently bycatch rates would be high as well. Moreover, fishermen from Constante still consume green turtles that get entangled in their nets (Caceres-Bueno et al. 2010). In the case of olive ridleys, they show the second highest bycatch rate after green while leatherbacks, hawksbills, and loggerhead show the lowest bycatch rates (Table 15). Comparing these BPUEs with the only other one available for the region (0.8 turtles/set in Baja California, Mexico, Peckham et al. 2008), the values from Mexico fall inside the ranged of BPUEs from Peru. Moreover, the BPUE in Constante is more than three times higher than the one in Mexico, highlighting even more the problem that bottom gillnets represent for sea turtles in that area.

As many turtles captured in gillnets are sacrificed for consumption (de Paz et al. 2002), instant mortality rates were calculated from studies that used on-board observers and had that information available (Alfaro et al. 2008, Caceres-Bueno et al. 2010, Rosales et al. 2010). The overall mortality rate was found to be 25% from a total of 169 turtles observed. However, high variation was observed among studies as can be seen in Table 15. Different fishing practices in each area and for the variety of target species could be responsible for this high variation. In some cases fishermen leave the nets in the water and only check they once a day while in other cases fishermen make more than 1 set per day.

To identify the developmental stage of turtles captured, their size was compared to the average size of nesting females in the region. In the case of green turtles, CCLs ranged from 45.5 to 85.5 cm; all turtles captured were smaller than the mean size of nesting females recorded in Galapagos (86 cm CCL). Two of the three sources with olive ridleys size data show adult sizes (69.8cm and 75 cm), but the third source, which had the largest sample size, shows a size average[1] slightly smaller than the average size for nesting females at La Cuevita in Colombia (64.9 cm CCL). Therefore, adult and subadult sizes seem to be represented fairly equal among the turtles captured in gillnets in Peru. Leatherbacks are a mix of adults and juveniles presumably with a large proportion of juveniles while all loggerheads and hawksbills were juveniles.

Table 15: Bycatch rates (turtles/set) and mortality rates (%) in gillnet fisheries in Peru. Data presented by species and locality. Peruvian departments cited among parenthesis.

Species / locality	*Bonanza & Punta Picos (Tumbes)*	*Mancora & Constante (Piura), Salaverry (La Libertad), Supe (Lima)*	*Constante (Piura)*
Green	0.440	0.221	3.070
Olive ridley	0.133	0.016	
Leatherback	0.013	0.013	
Hawksbill	0.013		
Loggerhead		0.003	
all turtles	**0.600**	**0.253**	**3.070**
mortality	73%	6%	12%
sets	75	312	14
reference	Rosales et al. 2010	Alfaro-Shigueto et al. 2008	Caceres-Bueno et al. 2010

Chile

In Chile, 98% of all bycatch records in gillnets come from the swordfish driftnet fishery reported during the period 1982 – 1998 with a total mortality of 102 individuals, the 54% of all captured in driftnets (Frazier and Brito 1990, Chandler 1991, Brito 1998,

---

[1] Data from de Paz et al. 2000 was transformed from SCL to CCL using the formula CCL=1.0103SCL + 2.7104 which was calculated using data from ecOceanica's database.

Arauz 1999, Brito 2001). The majority of the 188 turtles captured in driftnets were leatherbacks (96%), while the rest were greens, loggerheads and olive ridleys with the 2%, 1%, and 1% respectively (Table 14). The available data on turtle sizes seems to indicate that the majority of the leatherbacks were adults and even one turtle with a tag from Costa Rica was encountered (Frazier and Brito 1990, Chandler 1991, Brito 1998, 2001). The rest of the records from bycatch in gillnets in Chile (n=3) are from gillnets for corvina drum *Cilus gilberti* and a beach net (Brito 2001).

Bycatch of sea turtles in the swordfish fishery in Chile was first cited by Frazier and Brito in 1990 and they estimated that only in San Antonio Port a total of 350 leatherbacks were taken annually and that mortality rates were around 80%. By 1997, Eckert and Sarti (1997) estimated that around 500 leatherbacks were taken only in that same port while the entire Chilean fleet could take around 1700 leatherbacks. The level of bycatch and mortality rates of around 86% led these authors to speculate that this fishery was the major reason for the reduction of the eastern pacific leatherback population in the 1990s. Around those same years, swordfish stocks diminished and the fleet also experimented a large reduction diminishing from more than 500 vessels in 1991 to 49 in 2003 (IFOP 2004). However, it seems that since 2007 the fleet has being growing again and a quick search on the Artisanal Fisheries Registry of Chile in May 2011 (http://www.sernapesca.cl) resulted in 727 vessels with license to fish swordfish with nets although the number of active vessels was not shown. Nonetheless, the fleet had grown since 2003 and therefore on-board observations and bycatch reduction studies must be conducted to conserve the east pacific leatherback population, as well as those of other sea turtle species.

1.4.5.3 Bycatch mitigation

Some mitigation methods that involve technical modifications to the fishing gear had been tested in some areas to try to reduce sea turtle bycatch in gillnets. Diminishing the gillnet profile has proven a good technique for reducing sea turtle bycatch for both bottom and surface gillnet fisheries. Low profile bottom gillnets reduced sea turtle bycatch and maintained acceptable levels of target catch in the southern flounder *Paralichthys lethostigma* fishery in Pamlico Sound, North Carolina (Price and van Salisbury 2007). Also, low profile surface drift gillnets reduced leatherback bycatch in the mackerel (king mackerel *Scomberomorus cavalla*, and serra Spanish mackerel *S. brasiliensis*) fishery in Trinidad and resulted in less damage to the nets (Eckert 2008, Eckert et al. 2008, Gearhart et al. 2009). However, fishing area and depth seems to affect the performance of the low profile net (Eckert and Gearhart 2009).

In the EP, some bycatch mitigation techniques had been tested. In the bottom gillnet California flounder fishery off Baja California, lower profile nets with shorter suspenders were tested but bycatch was too low to conduct statistical comparisons (Maldonado et al. 2006). Also, only shorter suspenders and shorter suspenders at three different depths were tested which resulted in no statistical significant bycatch reduction (Maldonado et al. 2006). Another technique tested in this same fishery was the use of light-emitting diode (LED) to illuminate gillnets which resulted in a sea turtle bycatch reduction of 54%, a very promising reduction that did not reduce target catch rates (Wang et al. 2009). However, these results seem case-based dependent due to the fact that white vs. red LED lights and lights vs. no lights were also tested in the mackerel gillnet fishery in Trinidad with no significantly results in either case (Eckert and Gearhart 2008). Shark silhouettes in the flounder gillnet fishery in Baja California were also tested with good sea turtle bycatch reduction proportions but the large target catch reduction found makes this technique highly unlikely to be adopted by fishermen (Wang et al. 2009). Buoy-less nets were also compared to control nets in this fishery an even with a reduction of sea turtle bycatch in the experimental nets, the reduction was not significantly different (Peckham et al. 2009).

Other mitigation methods for bycatch in gillnets different than gear modification had been proposed. Switching gears from gillnets to trolling seems to be promising in the mackerel fishery of Trinidad because earnings show acceptable levels and sea turtle bycatch gets eliminated (Eckert 2008, Eckert et al. 2008). In the EP, fishermen from Puerto Lopez Mateos had expressed interest in switching from bottom gillnets to hook and line and even trolling in the deeper fishing areas where the highest loggerhead bycatch rates occur (Peckham et al. 2009).

1.4.6 Relative impact of fisheries to sea turtle populations in EP

Bycatch rates and total annual captures of sea turtles need to be compared with population sizes estimate the impact of each fishery over each species. However, estimating the sea turtles population size is nearly impossible. Nevertheless, we can use data on portions of the population to at least have a number that will allow putting bycatch in context. These numbers are not intended to be used as a precise number but to be used as comparison indicators among different species populations.

Sea turtle nests and nesting females are used in management to assess population trends and categorize the level of threat of sea turtle population. Therefore I compiled information on the total number of nesting females or nest numbers per population in the Eastern Pacific. Nesting numbers from the most current years available were used averaging numbers of six years for green, loggerhead, and hawksbill, and three years for leatherback and olive ridley. When only nest numbers were available, they were transformed to nesting females dividing them by the average clutch per season parameter for that species population if available or the global average (Hirth 1997, Miller 1997, Abreu-Grobois and Plotkin 2007, Santidrian Tomillo et al. 2008) Despite the fact that not all nesting sites had the amount of years needed, I am confident that the compilation represents the best information available for the region.

The annual average of nesting females was used to calculate total adult females for each population by multiplying these annual averages by the remigration interval for each species (Miller 1997). Results from these calculations can be seen in Table 16. Note the reduced number of hawksbills and leatherbacks compared with olive ridleys.

Annual captures of sea turtles in trawls in the EP as proportions of total adult females are shown in Table 17. These values allow us to visualize how critical it is to minimize bycatch in trawls for populations like the EP hawksbill whose reduced numbers make this interaction critical. On the other hand, even though the amount of olive ridleys is significantly high, compared to its total adult female population, the interaction is low (Table 17). Nevertheless, bycatch mitigation in trawls for one sea turtle species usually brings benefits to the other species (unless size differences are high). Therefore, it should be a regional priority to mitigate bycatch in trawls to help recovery the population of hawksbills, especially in Mexico, Costa Rica, and Panama.

Table 16: Total adult females for each population in the eastern Pacific estimated from annual nesting averages and remigration interval. Letters after species names note population name. EP: Eastern Pacific, NP: North Pacific, SP: South Pacific. Minimum and maximum values were calculated for population whose raw included binned numbers.

Population	*Total adult females*	
	Min	Max
Olive ridley EP	1'490,247	
Green EP	13,268	
Loggerhead SP	1,334	1,722
Loggerhead NP	1,354	
Leatherback EP	611	
Hawksbill EP	284	554

Table 17: Annual bycatch in shrimp trawl relative to adult female population numbers. Data per country and regional. Minimum value is for all fishing effort using TEDs and maximum value for all fishing effort without TEDs.

Country	*Olive ridley*		*Green*		*Hawksbill*	
	min	max	min	max	min	max
Mexico	0.35	2.70	6.53	50.60	22.33	337.47
Guatemala	0.16	0.65	0	0	0	0
El Salvador	0.04	0.26	2.03	14.49	0	0
Costa Rica	0.09	0.89	1.26	12.89	0.79	15.83
Panama	0.09	0.66	1.50	10.73	0.43	5.92
Colombia	0.07	0.49	1.34	8.93	0	0
Ecuador	0.04	0.29	0.75	5.38	0	0
Regional	0.83	5.95	13.41	103.02	23.55	359.22

1.5 Regional priorities

Due to the large threat that bycatch in fishing activities represent for sea turtles, it is necessary to conduct mitigation activities. And in order to try to solve the most pressing issues, managers, financial agencies, policy makers and researchers need to have regional priorities. Therefore, we used the review information and the population size indexes to generate these priorities. Population size index, catch frequency per species and mortality rates per species were ranked for each gear to build a weighted table of ranking. Population size was weighted by two, catch frequency by one and mortality rates by half (0.5). Then all the weighted ranks were added to obtain overall rankings (Table 18). Priorities that obtain the higher ranks involved mostly hawksbills and leatherbacks which are the two critically endangered species in the region and whose population numbers are the smallest. Some of the priorities even though they are separated by species, will also benefit other species like in the case of priority number 1 that involves trawls. Solving bycatch of hawksbills in trawls will solve bycatch of greens and olive ridleys in trawls as well.

Table 18: Table of multiple criteria weighted ranks to obtain conservation priorities per species and gear in the EP.

Species	gear	population rank x 2	catch frequency rank x 1	mortality rank x 0.5	total rank	priority
Hawksbill	trawl	12	4	2	18	1
Hawksbill	gillnets	12	2	3	17	2
Leatherback	longline	10	3	3	16	3
Leatherback	gillnets	10	4	1	15	4
Hawksbill	longline	12	1	0.5	13.5	5
Green	trawl	4	5	3	12	6
Loggerhead SP	longline	6	4	1.5	11.5	7
Green	longline	4	5	2.5	11.5	8
Loggerhead NP	gillnets	6	3	2	11	9
Olive ridley	gillnets	2	6	2.5	10.5	10
Olive ridley	trawl	2	6	2.5	10.5	11
Olive ridley	longline	2	6	2	10	12
Green	gillnets	4	5	0.5	9.5	13
Loggerhead NP	longline	6	2	1.5	9.5	14
Loggerhead SP	gillnets	6	1	2	9	15
Leatherback	trawl	10	0	0	10	0
Loggerhead SP	trawl	6	0	0	6	0
Loggerhead NP	trawl	6	0	0	6	0

1.6 Conclusions

This regional bycatch review underlines the high bycatch rates in trawls for Costa Rica, Guatemala, and El Salvador and the detrimental impact that these captures could have specially for hawksbill due to its reduced population numbers and for green turtle due to its highest mortality rate. It also emphasizes the continuous lack of use of TEDs as a bycatch mitigation measure. In longline fisheries, the review identifies the high bycatch rates in pelagic longline fisheries of Costa Rica, Ecuador, and Nicaragua in a global context but given that olive ridley is the most common species captured in these countries, it highlights the capture of loggerhead and leatherback off Peru and Chile due to their small population numbers. Bottom longlines have high mortality rates compared with pelagic longlines in the region and the review identifies a need for further research in this area due to the scarce information but high mortality rates. The review also noted that some mitigation measures for pelagic longlines like circle hooks and hooks with appendages could bring improvements in the mitigation of bycatch in longline fisheries in the region, there is still considerable work to be done in technology transfer, sea turtle handling, and estimates of post-release mortality rates.

For gillnet fisheries, the most important highlight is how little information exists for the region given the high rates of bycatch for sea turtles in this gear. However, the difficulties of studying bycatch in highly dynamic and artisanal fisheries are recognized as the major impediment for this situation. Nevertheless, the high bycatch rates in areas where sea turtles congregate in high numbers like in foraging grounds for loggerhead in Baja California, Mexico and for greens in Paracas and Sechura, Peru, calls for either gear modifications (which has not been that successful), change of gear, or areas closed for gillnets.

2. Oceanic Isoscapes and the feeding ecology of sea turtles in the southeastern Pacific Ocean: a stable isotopic analysis

2.1 Introduction

Stable isotope analysis (SIA) is a technique used extensively in ecological studies. In marine ecosystems, SIA had been used to study migration between foraging and reproductive areas of several species of wild animals (Rubenstein and Hobson 2004, Phillips et al. 2009), to reconstruct diets, and to estimate trophic levels as well as trophic niches (Dalerum and Angerbjörn 2005, Estrada et al. 2005, Newsome et al. 2009, Jaeger et al. 2010). The most common elements used in SIA are Carbon and Nitrogen. The general consideration for both elements is that the signatures of the consumers would be a function of the signatures of their prey, the proportions of each prey item in the consumer's diet, the consumer diet-tissue fractionation (also known as discrimination), and the spatial variability in basal isotopic signatures (Steele and Daniel 1978, DeNiro and Epstein 1981, Tieszen et al. 1983). Carbon is used commonly as a food source indicator (e.g. C4 vs. C3 plants) or spatial indicator due to the inshore-offshore, benthic-pelagic and latitudinal gradients observed in its distribution in the world oceans (Rubenstein and Hobson 2004) and also because it only shows a small enrichment, only 1‰ $\delta^{13}C$, from prey to consumer tissues. In SIA, the ratio of carbon 13 to carbon 12 is used for this element.

For nitrogen, we use the ratio between nitrogen 15 and nitrogen 14 and this element is considered a trophic level indicator. The ratio value has proven to increase with trophic level due to enrichment in a consumer's tissue relative to its prey. This enrichment is a consequence of isotopic fractionation (i.e. different isotopic values of source and product after a metabolic reaction) during excretion, amino acid amination and transamination and the differential routing of isotopes to specific tissues (Steele and Daniel 1978, Macko et al. 1986, Hobson and Clark 1992). A stepwise increase in $\delta^{15}N$ from one trophic level to the next of about 2.5‰ to 5‰ has been observed (e.g. DeNiro and Epstein 1981, Hobson and Clark 1992, Bearhop et al. 2002) and the most current average is 2.75 ± 0.10‰ (Caut et al. 2009). Therefore, animals occupying higher trophic levels have higher proportions of nitrogen 15.

As mentioned before, carbon is commonly used as the spatial indictor and nitrogen as the trophic level indicator. However, certain processes occurring in marine environments like denitrification and nitrogen fixation can also generate different nitrogen signatures in space and time at the base of the food web (Cline and Richards 1972, Liu and Kaplan 1989, Voss et al. 2001). On an ocean basis scale, the effects of nitrogen fixation and denitrification had been shown to explain the large differences in $\delta^{15}N$ of loggerhead (*Caretta caretta*) and leatherback turtles (*Dermochelys coriacea*) from the North Atlantic Ocean (high nitrogen fixation area) and the Eastern Pacific Ocean (high denitrification area) (Wallace et al. 2006, Pajuelo et al. 2010). These effects have been also observed in smaller scales when studying zooplankton and several species of tunas in the Northeast Pacific Ocean and observing that the variation along a latitudinal gradient in zooplankton's isotopic signature for nitrogen was the same as in tunas (Popp et al. 2007, Allain et al. 2008). As a result, it is necessary to consider all the factors that can affect isotopic signatures of the animals being studied and their prey species not to mistake a trophic level change with isotopic changes at the base of the food web.

The southeastern Pacific is a unique and highly dynamic area. It encompasses three of the six ocean ecosystems as defined in Barber (2001): a coastal upwelling, an Eastern Boundary Current (EBC) and the equatorial upwelling. The first two ecosystems occur because of the presence of the Peru Current which runs northward parallel to the South America coast. One part of the equatorial upwelling occurs in the northern part of the southeastern Pacific from the coasts of South America to the west. The Peru Current coastal upwelling and EBC together form the most productive ecosystem in the world, as the upwelled waters bring great quantities of nutrients to the surface, which sustains large populations of phytoplankton. This productivity upholds great zooplankton and fish populations and generates the highest production of fish per unit area in the world oceans (Bakun and Weeks 2008, Chavez et al. 2008, Montecino and Lange 2009). This area experiences cyclical oceanographic changes generated by El Nino which reduces availability of nutrients and therefore fish productivity (Taylor et al. 2008).

In addition to the high plankton and fish abundance, this area is also rich in marine mega-vertebrates like cetaceans, seabirds, and sea turtles (Ballance et al. 2006, Eguchi et al. 2007). Five of the seven existing species of sea turtles inhabit the southeastern Pacific during one or more of their life stages. The olive ridley sea turtle, *Lepidochelys olivacea*, the smallest of the five, can nest in arribadas of tens of thousands females (Peñaflores 2007). This highly pelagic species is the most abundant sea turtle in the eastern Pacific; due to its preference for tropical waters, it inhabits the southeastern Pacific with higher abundances towards the equator (Olson et al. 2000, Olson et al. 2001a, Olson et al. 2001b, Eguchi et al. 2007). Another highly pelagic sea turtle, the leatherback, is currently one of the least abundant turtles in the eastern Pacific. It inhabits oceanic waters of the southeastern Pacific during non-nesting seasons as evidenced by satellite tracking of post-nesting females (Eckert and Sarti 1997, Shillinger et al. 2008).

Green turtles, *Chelonia mydas*, are one of the most common sea turtle species found in coastal areas in the eastern Pacific, as it lives in shallow bays and feeds on algae and associated species. However, subadult and adult green turtles are also found in foraging grounds in oceanic waters in the southeastern Pacific (Seminoff et al. 2008), a behavior uncommon for this neritic sea turtle species (but see Hatase et al. 2006). The rarest sea turtle in the eastern Pacific, the hawksbill turtle, *Eretmochelys imbricata*, is generally distributed in tropical and coastal waters; its southern limit occurs in northern Peru (Hays-Brown and Brown 1982). On the contrary, the loggerhead in the eastern Pacific is distributed in the temperate waters and is rare in tropical areas. Differently from the other turtle species whose distribution goes along the Pacific Coast of The Americas, loggerheads have a transoceanic distribution from the west to the east side of the Pacific Ocean and with one population in the north Pacific and another in the South Pacific.

Loggerheads in the southeastern Pacific are only juveniles whose rookeries are in Australia and New Caledonia (Boyle et al. 2009).

All but one of the species of sea turtles found in the southeastern Pacific are categorized worldwide as threatened (endangered or critically endangered), the exception, the olive ridley, is considered vulnerable (IUCN 2010). The conservation status of these turtles has motivated researchers to study many aspects of their life history and ecology to develop the best conservation strategies. Some of these studies focus on foraging ecology, which is one of the most important aspects of their ecology because it clarifies the role of sea turtles in the marine ecosystems as well as their links to other species and to environmental factors. In oceanic environments, understanding the factors that contribute to good foraging times or locations can aid management plans.

Sea turtles in the open ocean are extremely difficult to study and many aspects of their ecology remain unknown (e.g. what they eat?, how they find food?, do they conduct seasonal migrations?, etc). A few studies have given some insights on their oceanic lives but nearly all of them have focused on the loggerhead sea turtle *Caretta caretta* (but see Polovina et al. 2003). These studies have provided information on diet, diving behavior, and movements in the North Pacific Ocean (Polovina et al. 2000, Parker et al. 2005) and survival probabilities and somatic growth in the North Atlantic Ocean (Bjorndal and Bolten 2003, Bjorndal et al. 2003). However, oceanic sea turtles remain the least studied life stage (Bolten et al. 2010).

The feeding ecology of sea turtles living in oceanic environments has been rarely studied due to the difficulty in gaining access to individuals on the high seas. Most of the information on oceanic turtles (besides observations, i.e. without handling) comes from individuals incidentally captured during fishing operations, especially during longline fisheries targeting pelagic fishes (e.g. Polovina et al. 2000, Bjorndal and Bolten 2003, Bjorndal et al. 2003, Polovina et al. 2003, Polovina et al. 2004). However, the feeding ecology of sea turtles in the open ocean needs to be studied because it is necessary to know the food items sea turtles are depending on for growth and survival and also the habitat areas they are selecting in which to forage.

In Peru, research on longline bycatch has not only provided insights into the interaction among turtles and longline operations but also allowed researchers, as in other regions, to access individuals in oceanic environments. This research on longline bycatch allowed scientists to confirm the presence of the loggerhead turtle in Peru (Kelez et al. 2003, Alfaro-Shigueto et al. 2004), to determine via genetic analysis that the rookeries for this population are in Australia and New Caledonia (Boyle et al. 2009) and to provide insights into the genetic composition of turtle aggregations off Peru (Velez-Zuazo and Kelez in prep.). In this study, our fisheries bycatch research has enabled us to conduct foraging ecology studies loggerheads, greens, and olive ridleys in the southeastern Pacific.

A variety of SIA studies have also been conducted with sea turtles and results of these studies have given new insights on the ecology of sea turtles like the differences among co-occurring species and among tissues (Godley et al. 1998, Biasatti 2004, Revelles et al. 2007a, Bjorndal and Bolten 2010), the differences on foraging habitats and foraging strategies in females from the same rookery (Hatase et al. 2002, Hatase et al. 2006, Reich et al. 2010), the ontogenetic dietary changes in several green turtle populations (Reich et al. 2007, Arthur et al. 2008, Cardona et al. 2009), the foraging strategies of several loggerhead populations (Revelles et al. 2007b, Arthur et al. 2009, Wallace et al. 2009, McClellan et al. 2010, Vander Zanden et al. 2010) and that sea turtles can be indicators of isotopic differences between ocean basins (Wallace et al. 2006, Pajuelo et al. 2010). Also, stable isotope discrimination factors of sea turtle tissues with respect to diet have been determined for greens, loggerheads, and leatherbacks (Seminoff et al. 2006, Reich et al. 2007, Seminoff et al. 2009).

In this study we aimed to investigate if the oceanographic differences in the southeastern Pacific that could generate stable isotopes variability at the base of the food web were observed in sea turtles, so they could be indicators of these differences. We also aimed to study foraging ecology of sea turtles using stable isotopes by comparing trophic niche of oceanic greens, loggerheads, and olive ridleys. To our knowledge, this is the first study employing SIA to research the ecology of three species of sea turtle within the same time and space. The results will ideally shed light on the ecological variation between these species and generate information that will help develop appropriate conservation strategies for these taxa.

2.2 Hypothesis

2.2.1 Oceanic indicators

The study area spanned two different marine ecosystems: the equatorial upwelling in the north of Peru where the coastal upwelled waters collide with warmer and tropical waters coming from the north (Montecino and Lange 2009) and the Peru Current System from 4° South to the south, which is composed by an Eastern Boundary Current system and a Coastal upwelling system (Barber 2001). These two areas had also been classified in the large marine ecosystems (LME) division being the northern one inside the Pacific Central-America Coastal LME and the other one named Humboldt Current LME. The Humboldt Current LME is characterized by a narrow continental shelf, especially in the south; a strong eastern boundary upwelling which pushes large quantities of nutrient rich waters to the surface thus enhancing productivity. The Humboldt or Peru-Chile current which runs north is the major current in the LME. On the other hand, the portion of the study site inside the Pacific Central-America Coastal LME is characterized by warmer waters than the Humboldt Current LME and re-circulating coastal currents, being the most important one in the study site the Pacana Current.

The Humboldt Current system can be divided in two different zones at the latitude 15°S. In this study we will call the area from 5°S to 15°S central zone and the area south of 15°S south zone. These two zones have different characteristics and the three most important ones are continental shelf, productivity and Oxygen Minimum Zone (OMZ). The continental shelf is wider in the central zone as compared to the south zone where it is extremely narrow. The central zone is highly productive, having high chlorophyll a concentrations extending wider areas next to the coast and a year round upwelling system while the south zone has lower productivity that is also seasonal (Montecino and Lange 2009) (Figure 12). The OMZ is thicker and wider to about 1,000 km offshore in the central zone while in the south zone it extension decreases from 1,200 km at 20°S to 25 km at 30°S as well as it thickness decreases from 300 m to less than 50 m (Fuenzalida et al. 2009) (Figure 13). Considering all these characteristics our study area can be divided in three different zones: north (from the north to 5°S), central (from 5°S to 15°S), and south (from 15°S to the south).

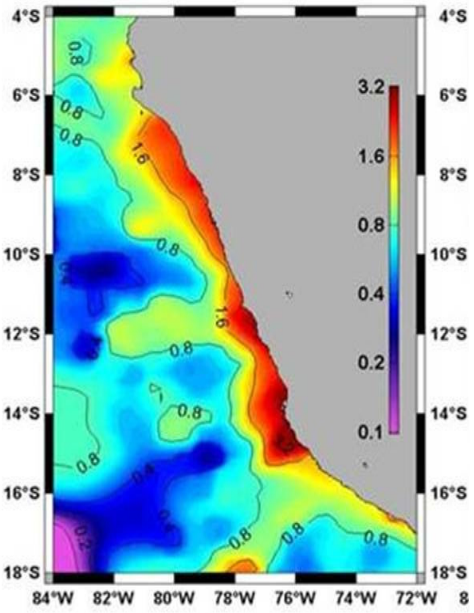

Figure 12: Annual average of chlorophyll a concentration for 1953 - 2001 along the coast of Peru. Figure shows that south of 15°S chl. a concentration is lower. Source: F. Chavez.

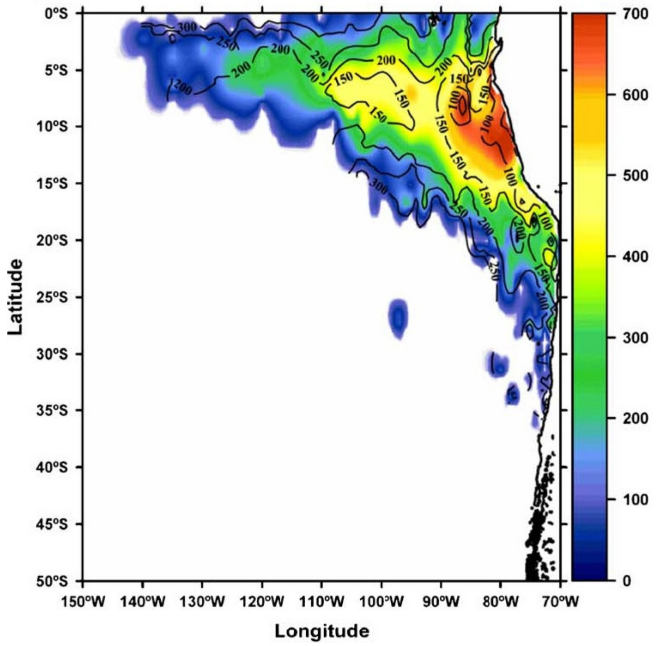

Figure 13: Oxygen minimum zone, extension and thickness color coded as in the bar (m). The upper layer is noted by black lines. Source: Fuenzalida et al. 2009.

Given the differences in oceanographic characteristics we expect stable isotopic signatures to also differ among these zones. In this regard, there is some evidence of differences in nitrogen isotopic signatures in a region in the southeast Pacific that encompasses our study area. Farrell et al. (1995) analyzed surface sediment and found a core of low δ^{15}N in an area that corresponds with our central zone, and δ^{15}N increasing sharply to the south and offshore (Figure 14). This pattern seems to be inversely correlated with nitrate concentration in the water (Wada and Hattori 1976, Farrell et al. 1995).

Our stable isotopic hypothesis for nitrogen and carbon are as follow: 1) Higher values of nitrogen in the south zone and lower values in the central and north zone, 2) Higher values of carbon in the north zone and lower values in the central and south zones.

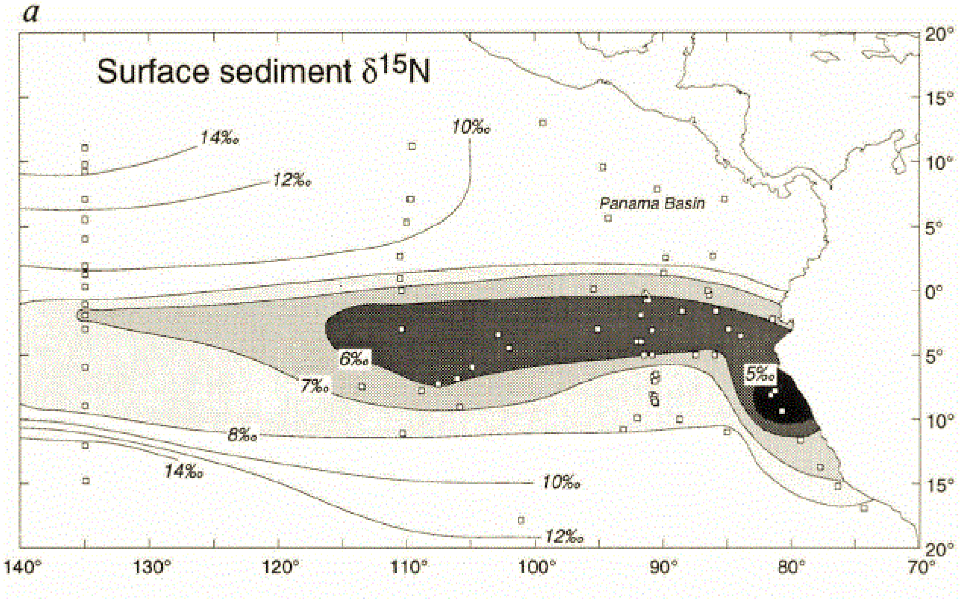

Figure 14. Spatial distribution of surface (Holocene) sediment $\delta^{15}N$ values from Farrell et al. (1995).

2.2.2 Trophic niches

Based on the foraging ecology of loggerheads, olive ridleys and greens in their subadult and adult stages and also on the wider distribution of green turtles in the study area compared with olive ridleys and greens our hypothesis for trophic niches are as follows: 1) Loggerheads and olive ridleys will have higher average nitrogen values than green turtles, and 2) Green turtles will show a wider distribution of nitrogen and carbon values compared with loggerheads and olive ridleys.

2.3 Methodology

2.3.1 Study area

This study was conducted in the Southeastern Pacific Ocean, offshore of the Peruvian coast but also extended to marine areas off Ecuador and Chile and international waters (Figure 15). All the fishing sets observed were conducted off the continental shelf up to 88.2°W and from latitudes 3°S to 23°S.

2.3.2 Sample collection

From 2003 to 2009, observers collected data from 512 longline fishing sets on board of Peruvian fishing vessels (Figure 15). The observed fishing sets targeted dolphinfish *Coryphaena hippurus* or sharks (mainly shortfin mako *Isurus oxyrinchus*, blue shark *Prionace glauca*, and hammerhead shark *Sphyrna* spp.) and spanned almost the entire Peruvian coast from the latitude 3°S to the 18°S, around 1600 km. We also observed some trips targeting swordfish *Xiphias gladius* further south (around latitude 23°S).

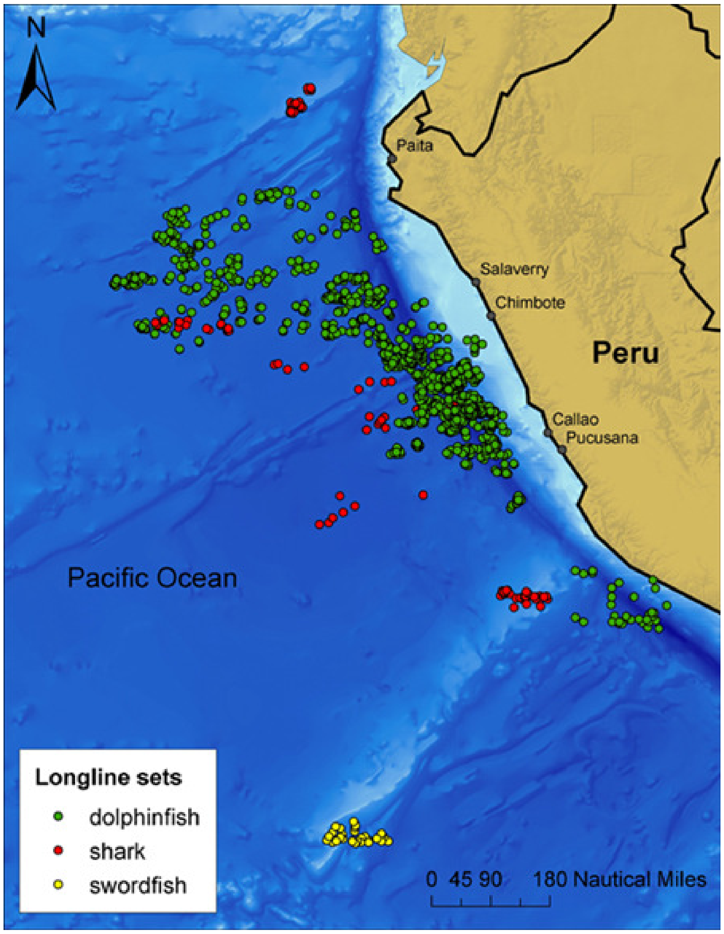

Figure 15: Study site showing the longline fishing sets observed off Peru.

Sea turtle skin samples were collected using a scalpel or a biopsy punch from the neck-shoulder area or from the rear flipper. The samples were preserved immediately after collection in either 70% EtOH (ethanol) or salt. After each fishing trip, the observer sent the samples to Lima and after a re-labeling they were refrigerated. Besides the skin sample collection, each turtle was identified to species, the curved carapace length notch to tip (CCLn-t) and minimum curved carapace length (CCLmin), the total tail length and the post-cloacal tail length was measured with a flexible tape measure as specified by Bolten (1999). Each turtle's weight was determined with a spring scale, and the interaction type was recorded (e.g. hooked in the mouth, hook swallowed, entangled with mainline, etc.). Pictures were taken of all individuals although some pictures were lost due to malfunction of the cameras. These pictures were used to confirm the species identification.

2.3.3 Laboratory analysis

Sea turtle tissue samples were prepared at the Southwest Fisheries Science Center facilities in La Jolla, California. We used paper towels to dry remains of ethanol or a scalpel to remove the salt from the samples. All samples were subsequently diced into the smallest possible pieces with a scalpel and then dried either in an oven at 60°C for 2.5 hours or freeze dried for 2 hours. The dry samples were ground to a fine powder. Lipids were extracted with an ethyl ether and petroleum ether solution (1:1) using a Soxhlet apparatus for ca. 10 hours. After the lipid extraction, samples were air-dried for one hour and oven-dried at 60°C for one hour to eliminate any remaining ether. Finally, samples were ground again (if needed) and a portion of the sample weighting between 0.8 – 1 mg was placed in tin cups for analysis.

Stable isotope analyses were conducted at the Stable Isotope Laboratory at the Department of Geosciences, University of Florida. We used a Costech ECS 4010 elemental combustion system interfaced via a ConFlo III device (Finnigan MAT, Bremen, Germany) to a DeltaPlusXL gas isotope-ratio mass spectrometer (Finnigan MAT). The international standard, USGS40 L-glutamic acid (δ^{13}C‰ -26.39, δ^{15} N - 4.52‰) was used to check the calibration of the spectrometer. Five USGS40 samples were run with each 44 unknowns to standardize the results and avoid potential drift. Hundreds of replicate assays of standard materials indicated measurement errors of 0.05% and 0.095%for carbon and nitrogen, respectively.

To express the isotope values of the samples, we used the δ notation. This notation expresses in parts per thousands (‰) the difference between ratios of the heavier to the lighter isotope compared to a standard. For carbon, the standard is PeeDee Belemnite (Ratio, 13C/12C = 0.011180) and for nitrogen the standard is Air (Ratio, 15N/14N = 0.0036765) (Fry 2006). The calculation of the δ values is as follows:

$$\delta^{\text{element}} = [(\text{Ratio}_{\text{sample}} / \text{Ratio}_{\text{standard}} - 1)] * 1000$$

2.3.4 Statistical analysis

We used the R program (R Development Core Team 2010) to conduct all the data exploration and statistical tests. We obtained histograms, densities, boxplots, and QQplots to observe the distribution of the values of δ^{15}N and δ^{13}C per species, to compare distributions among species and to examine the data for normality. To compare means of δ^{15}N and δ^{13}C among the three species, we used the Kruskal-Wallis test and the Mann–Whitney U test for post-hoc comparison tests. To explore spatial patterns we conducted correlation tests among $\delta^{15}N$ and $\delta^{13}C$ values with latitude, using Spearman Rank Correlation or Pearson's correlation test (two tails). Also, to observe spatial patterns of the stable isotope values, we used the Inverse Distance Weighted Interpolation technique (IDW) in ArcGIS. To specify the interpolation area, we created buffers of 2 degrees around each turtle location and dissolved the buffers borders to obtain only one polygon and used it as a mask to run the IDW.

Due to the correlations encountered between the isotope data and latitude, we conducted a focal analysis of means in a smaller area to factor out spatial patterns in carbon and nitrogen and observe if the difference among species will persist in this scenario. We used Kruskal-Wallis tests to compare means among species. The area selected was off the central coast of Peru and it was chosen because it included the highest density of individuals.

2.4 Results

2.4.1 Turtles captured

During the fishing sets, we observed a total of 266 turtles that were incidentally captured. Some turtles were not evaluated (n=26) because they either got free when they were pulled up, were not brought on-board, or were sent back by fishermen crew. We evaluated 240 individuals and 141 skin samples were collected to conduct stable isotope analysis. A total of 139 stable isotope signatures were obtained from 76 green turtles, 36 loggerheads, and 27 olive ridleys.

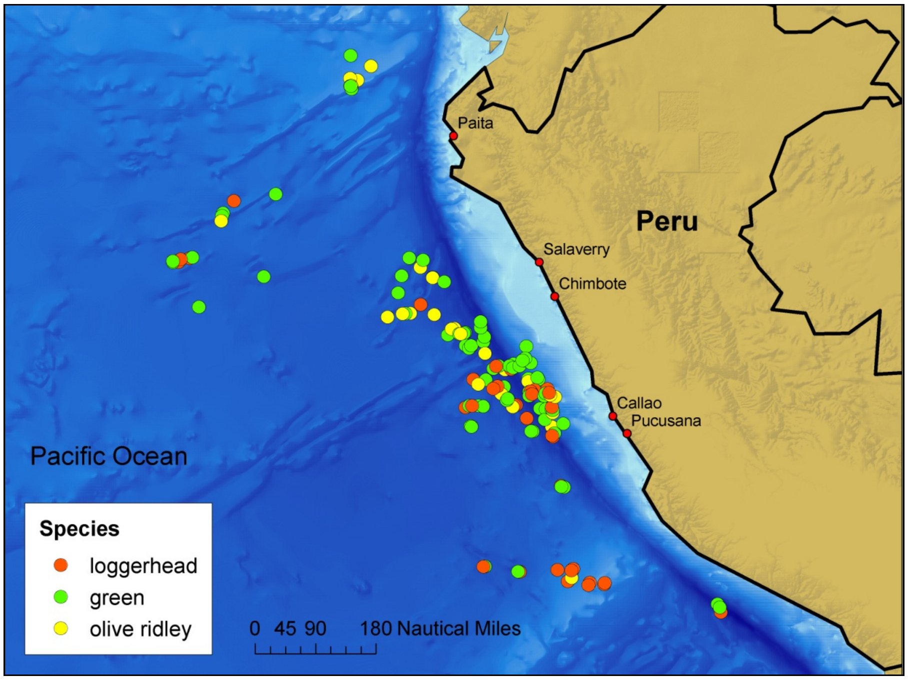

Figure 16: Capture location of 139 sea turtles whose skin was collected for stable isotope analysis.

The 139 turtles included in the analysis (Figure 16) were captured from January 2003 to November 2004 and from May 2007 to February 2009 mostly during the dolphinfish fishing season (85%, n=118) but also during the shark fishing season (15%, n=21). The majority of the interactions among sea turtles and the longline gear was a result of turtles trying to ingest the bait with 49% hooked in the mouth (including maxillas and tongue) and 23% in the esophagus (swallowed) but turtles were also hooked in the fins (15%) and entangled with the branch lines (9%). A minority where hooked in other places like neck, eyes, and shoulders (4%). The hooks were removed from the majority of individuals, but from all the turtles hooked in the mouth and esophagus, a 17% (n=17) were liberated without removing the hook to avoid further injuries to the turtles. All turtles were sent back to the water alive.

Individuals in the study varied in size (Table 19). Based on the CCLn-t, loggerheads were on average the biggest turtles followed by greens and then olive ridleys. Based on the mean size of nesting females in the closest major rookeries for each population (95.76 cm for loggerhead in Mon Repos, Australia, Limpus 1985, 86.7 cm for green turtles in Galapagos Islands, Zarate et al. 2003, 64.9 cm for olive ridley in La Cuevita, Colombia, Barrientos and Ramirez 2008) all loggerheads, all greens and 96% of olive ridleys will be considered juveniles or subadults. However, the 15% of the olive ridleys and 20% of the green fall between the minimum and the mean size of nesting females in the before mentioned rookeries, which means that the proportion of adults for these species could be higher. Due to the life stages of the individuals captured, gender was difficult to determine, but at least two olive ridleys were categorized as males because they showed secondary sex characteristics.

Table 19: Mean size (CCLn-t), standard deviation (SD), and size range of individuals included in the SIA. Note that the δ^{15}N axis units are double the units of the δ^{13}C axis

Species	CCLn-t cm	SD	Range	n
Caretta caretta	54.5	8.5	34 - 69	36
Chelonia mydas	53.0	8.6	27 - 71.2	75
Lepidochelys olivacea	52.8	9.5	25 - 65	26

2.4.2 Stable isotope data

We obtained stable isotope signatures from 139 of the samples (Figure 17). The δ^{15}N data show a higher spread of values compared to δ^{13}C and there appear to be significant differences among species. Comparing the means, loggerheads showed the lowest mean value for carbon (-16.53) while olive ridley showed the highest, -15.80 (Table 20, Figures 18 and 19). In contrast, the mean of the nitrogen isotope for loggerheads was the highest, 13.69, and was 2 ppt higher than the mean values for greens and olive ridleys which were 11.58 and 11.71 respectively (Table 20, Figures 18 and 19). The means for carbon were more similar to each other than the means for nitrogen.

Table 20: Stable isotope values for *C. mydas*, *C. caretta*, and *L. olivacea* (mean, SD, and range)

Species	*d^{15} N*			*d^{13} C*			*n*
	Mean	SD	Range	Mean	SD	Range	
C. mydas	11.58	1.43	7.68 - 16.26	-16.12	0.71	-18.02 - -14.5	76
C. caretta	13.69	2.48	8.42 - 17.87	-16.53	0.76	-19.10 - -15.39	36
L. olivacea	11.71	1.57	8.76 - 15.42	-15.80	0.90	-19.01 - -14.47	27

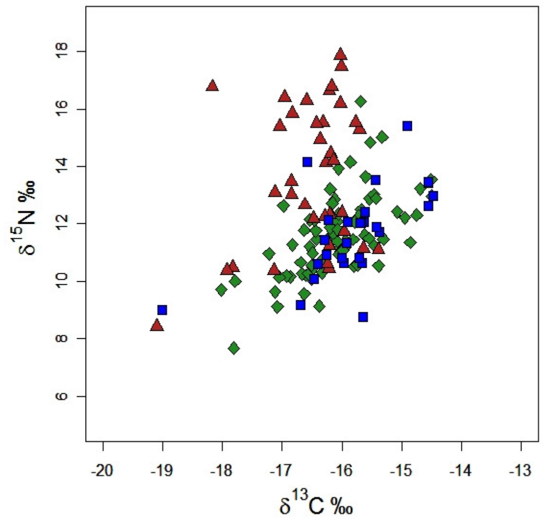

Figure 17: Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values. *C. mydas* in green, *C. caretta* in red and *L. olivacea* in blue.

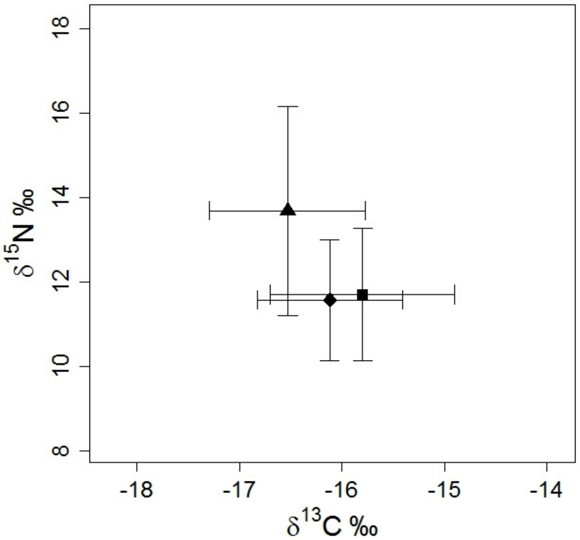

Figure 18: $\delta^{13}C$ and $\delta^{15}N$ mean values and standard deviations for each sea turtle species. Rhombus for *C. mydas*, triangle for *C. caretta* and square for *L. olivacea*.

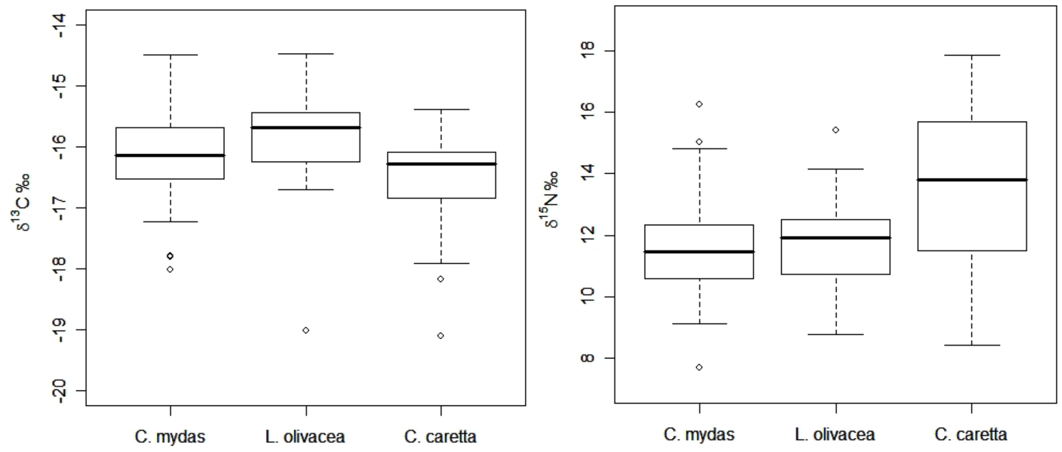

Figure 19: Boxplots of δ^{13}C (left panel) and δ^{15}N (right panel) for *C. mydas*, *L. olivacea* and *C. caretta*.

2.4.3 Oceanic indicators

To observe if sea turtles could be oceanic indicators of isotopic differences in a wide oceanic region, we explored if there were spatial patterns in the stable isotope signatures of their skin tissue and the 3 zones in our study area. We created maps of interpolated values derived from each species *(C. mydas, C. caretta* and *L. olivacea*) and isotope (carbon and nitrogen). The maps in Figure 20 are for carbon and there seems to be a zone with higher values in the north for both olive ridleys and greens but not for loggerheads for which values of carbon do not seem to show any pattern. This high carbon zone agrees with our hypothesis. The maps in Figure 21 are for nitrogen and it can be observed that nitrogen tends to be higher in the northern and southern portion of the study area. Also, it appears that there is a major hotspot of high nitrogen signatures for loggerheads in the south (Figure 21, left map). The results of high values of nitrogen in the south zone and low values in the central zone agrees with our hypothesis. Moreover, results from statistical analysis show a significant negative correlation between nitrogen and latitude for loggerhead and green turtle but not for olive ridley (Table 21). For carbon, significant positive correlations were observed for olive ridley but not for green turtle or loggerhead (Table 21).

Table 21: P-value and correlation coefficients of correlation tests among latitude and stable isotopes for *C. mydas, C. caretta* and *L. olivacea*.

	C. mydas	*C. caretta*	*L. olivacea*
Carbon			
p-value	0.1593	0.7519	**0.005339**
correlation coefficient	cor = 0.1630764	rho = 0.05457588	cor = 0.5208916
Test	Pearson	Spearman Rank	Pearson
Nitrogen			
p-value	**0.04541**	**0.0003037**	0.4628
correlation coefficient	cor = -0.2302292	rho = -0.5760618	cor = 0.1475100
Test	Pearson	Spearman Rank	Pearson

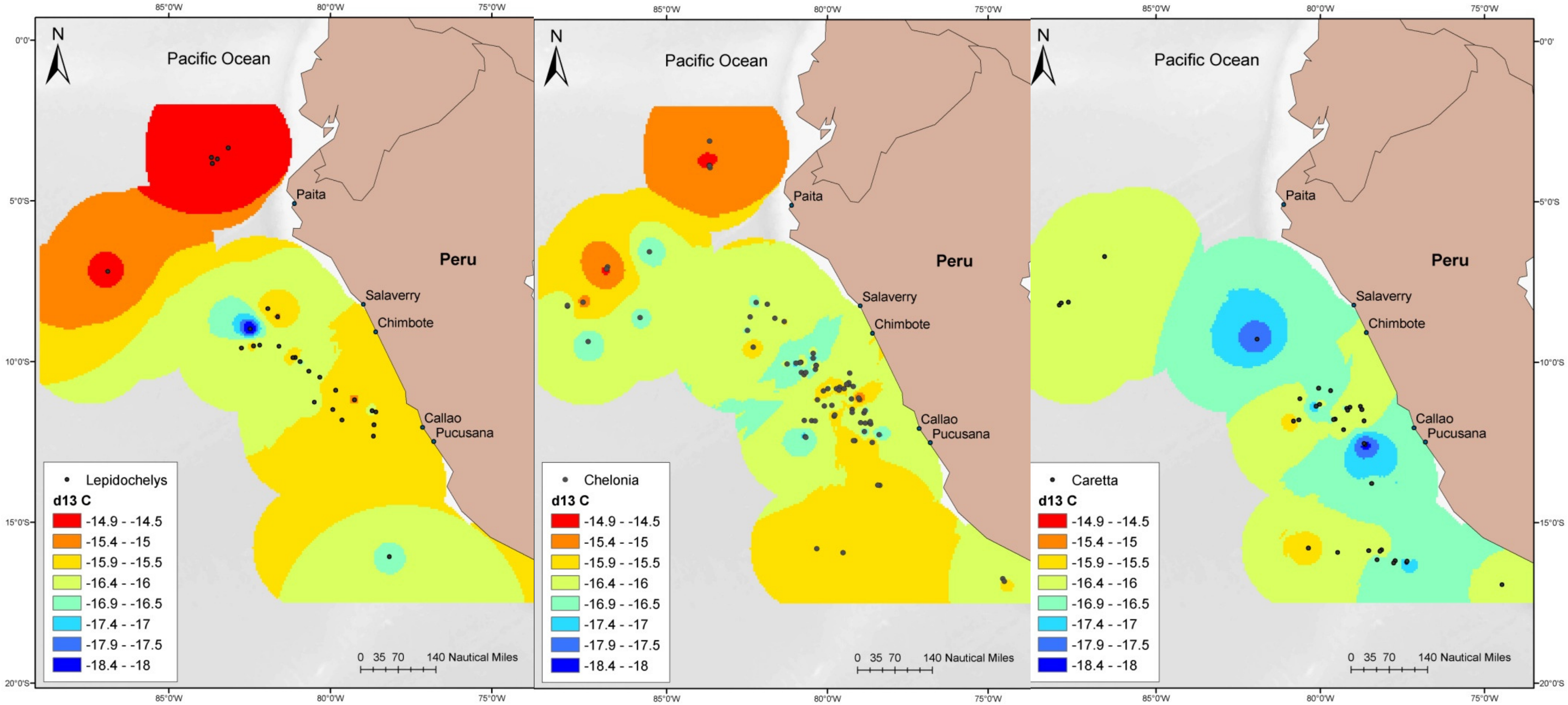

Figure 20: Maps of interpolated zones of δ^{13}C values derived from *L. olivacea* (left), *C. mydas* (center) and *C. caretta* (right). All maps were created using the same scale. Black dots are sea turtle capture locations.

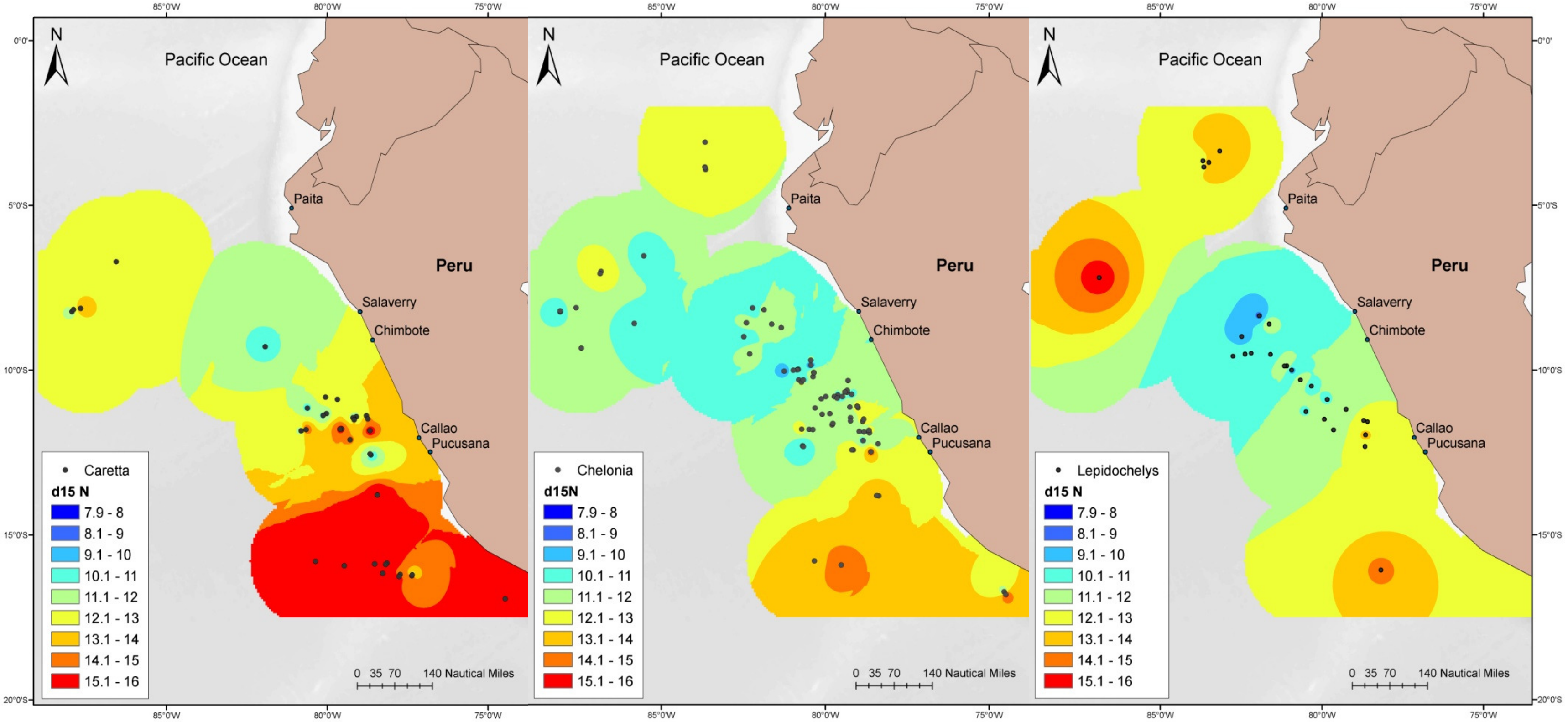

Figure 21: Maps of interpolated zones of δ^{15}N values derived from *C. caretta* (left), *C. mydas* (center) and *L. olivacea* (right). All maps were created using the same scale. Black dots are sea turtle capture locations.

2.4.3 Trophic niches

The trophic niches of each sea turtle species are defined, in this case, by the distribution of the $\delta^{13}C$ and $\delta^{15}N$ values. The distributions can be observed in the histograms and frequency lines in Figures 22 and 23. For carbon, contrary to our hypothesis, olive ridleys show a slightly wider distribution (4.54 units), than the others (3.52 for greens and 3.71 for loggerheads) but all show comparably narrow distributions. Also, loggerheads have more negative values (curve expanded to the left) than greens and olive ridleys (Figure 22). In the case of nitrogen, olive ridleys show the narrowest distribution (6.66 units) of all three species and the loggerheads have the widest distribution (9.45) with a clear bimodal distribution (Figure 23). To observe better the distributions they were plotted in the same panel in Figure 24. This figure shows clearly the large differences in nitrogen values among loggerheads and the other two species. These findings did not agree with our hypothesis that expected greens to have the wider nitrogen distribution as it is the one with the widest distribution in the study area.

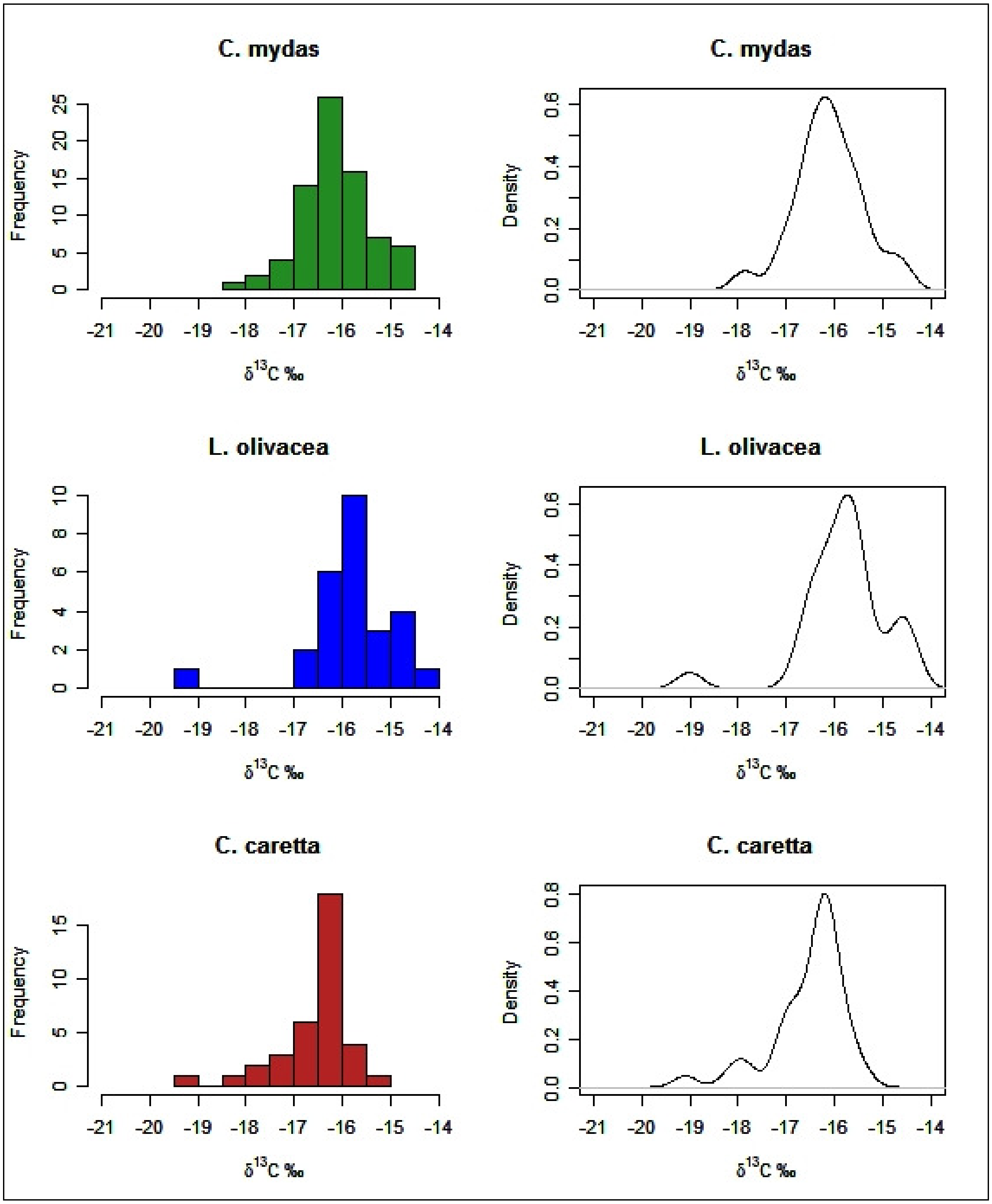

Figure 22: Histogram and density plots of $\delta^{13}C$ for *C. mydas*, *L. olivacea* and *C. caretta*.

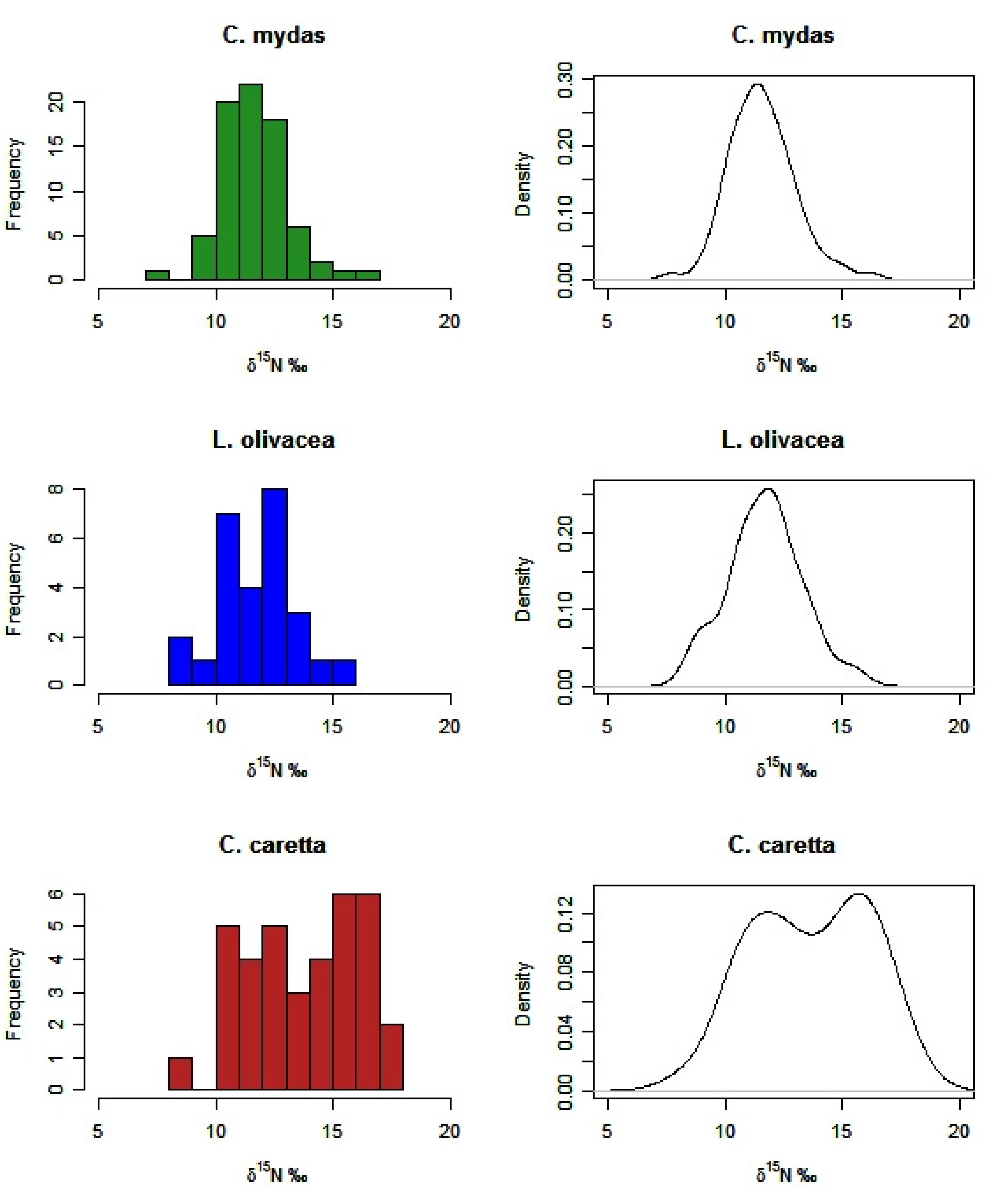

Figure 23: Histogram and density plots of δ^{13}C for *C. mydas*, *L. olivacea* and *C. caretta*.

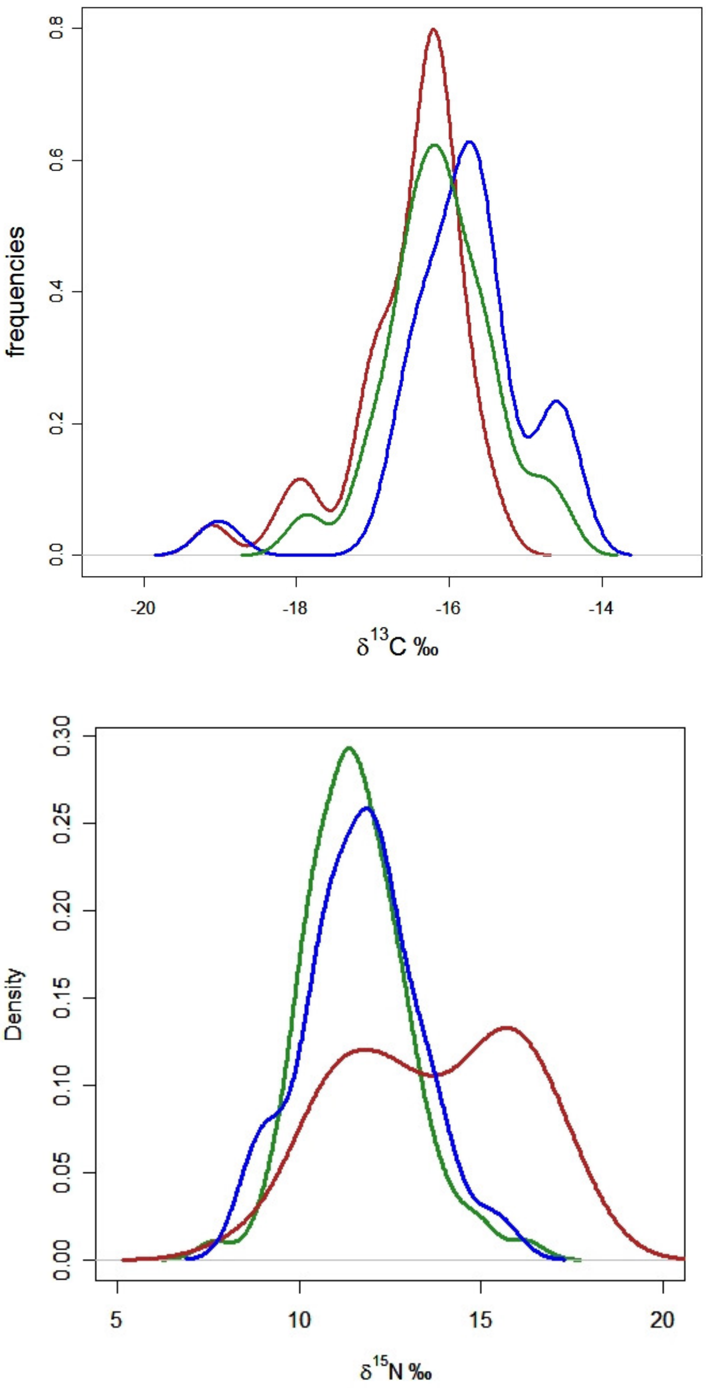

Figure 24: Density lines of the distribution of δ^{13}C (top panel) and δ^{15}N (bottom panel) for *C. mydas* (green), *C. caretta* (red) and *L. olivacea* (blue).

Without diminishing importance to the shapes of the distributions, we compare means per species due to the importance of means to represent a population in foraging ecology studies. For example, to calculate the trophic level of a species in a food web, only the mean of the nitrogen signature is used. Likewise, to calculate the importance of food items in the diet of a consumer using mixing model analysis, only the isotope means are used as inputs to represent the consumer as well as the species identified as food items. The nonparametric test to evaluate for differences in the means resulted in significant differences of means both for carbon and nitrogen (Carbon: Kruskal-Wallis chi-squared = 15.0406, p-value = 0.000542, Nitrogen: Kruskal-Wallis chi-squared = 19.0273, p-value = $7.384e^{-05}$). Further paired analysis showed that all means for carbon were statistically different among each other and olive ridley and loggerheads were highly significantly different (Table 22). In the case of nitrogen, greens and olive ridleys were not different but they were both highly significantly different from loggerheads (Table 22). The high values of nitrogen for loggerheads and low values for green agree with our hypothesis but the low values for olive ridleys were not expected.

Table 22: Significance of p-values of the Mann-Whitney U-test per pair of species for $\delta^{13}C$ and $\delta^{15}N$

	C. mydas	*C. caretta*	*L. olivacea*
C. mydas		**	ns
C. caretta	*		**
L. olivacea	*	**	

$\delta^{15}N$

$\delta^{13}C$

ns: no significant, *: significant, **: highly significant

2.4.4 Focal analysis

The focal analysis included a total of 39 green turtles, 19 loggerheads and 10 olive ridleys that were captured in the selected area (Figure 25). Results from the analysis showed no differences among the mean nitrogen values for the 3 species (Kruskal-Wallis chi-squared = 4.5097, p-value = 0.10490) but still encounter significant differences in carbon (Kruskal-Wallis chi-squared = 9.0885, p-value = 0.01063).

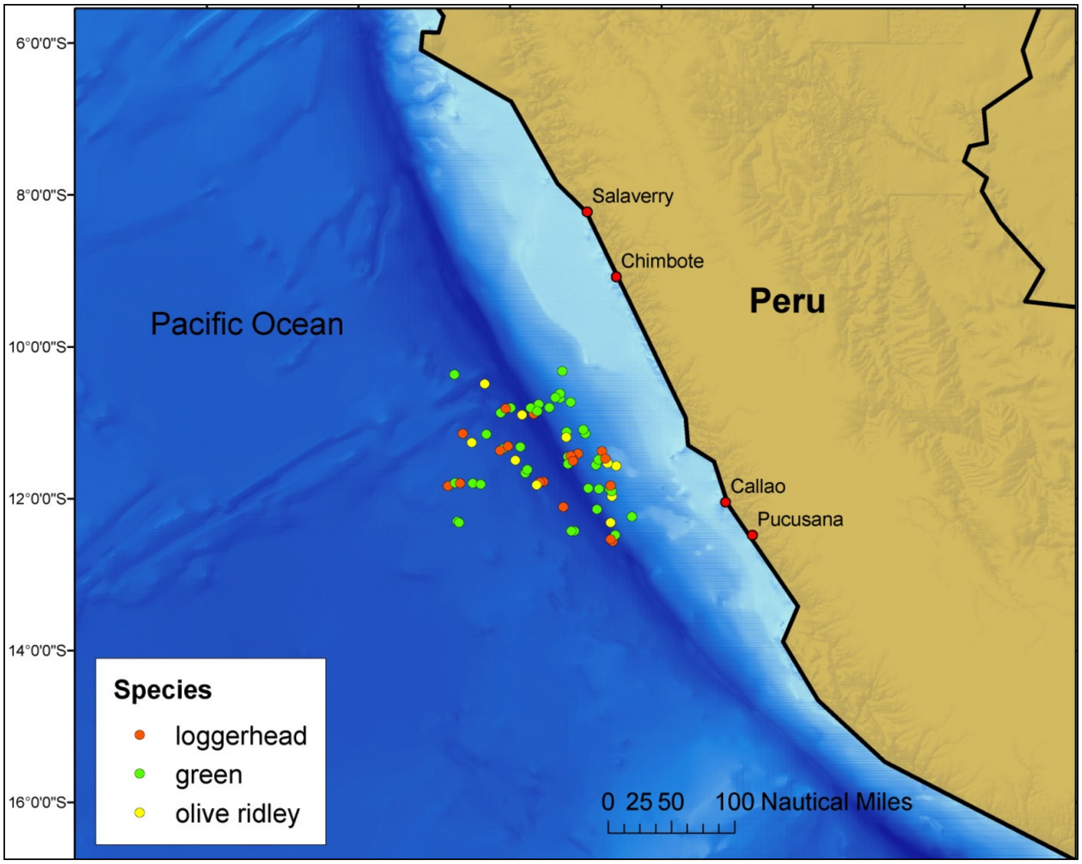

Figure 25: Capture locations of sea turtles included in the focal area analysis. Different dot colors are different species.

2.5 Discussion

In marine environments off Peru, several processes will modify the signature of the nitrogen 15 in the water. The Peru Upwelling Ecosystem is the most productive marine ecosystem in the world, due to the great amount of nutrients that enter the system via upwelling. These nutrients get consumed by organisms that use oxygen. The high use of oxygen and the poor ventilation of the region create a large area of low oxygen or oxygen minimum zone – OMZ (Helly and Levin 2004). In these hypoxic conditions denitrification occurs rapidly. Denitrification is a process in which organisms like bacteria, in the absence of oxygen, use NO_3- (nitrate) as an electron receptor for their reactions with N_2 as a sub-product (Montoya 2007). Because denitrification reactions favor $^{14}NO_3$ over $^{15}NO_3$ these OMZ waters will be highly $\delta^{15}N$ enriched (Saino and Hattori 1987, Liu and Kaplan 1989) with an enrichment factor of 30 ± 7.5 ‰ (Voss et al. 2001). Waters enriched due to denitrification will get transported to surface layers by vertical transport like upwelling but they will also be transported horizontally by advection (Voss et al. 2001). In the euphotic zone, the phytoplankton assimilates the lighter nitrate (14) at a higher rate than the heavier one (15), resulting again in an enrichment, with a discrimination factor around 5%, of the surrounding waters which will also generate spatial trends (Montoya 2007).

We believe that these processes are generating spatial variation in the $\delta^{15}N$ of surface waters in our study area off Peru. Moreover, these processes will generate different effects depending on the particular oceanographic features present. These features are particularly different in the three zones identified along the marine environments of Peru. The north zone, where the coastal upwelled waters collide with warmer and tropical waters coming from the north (Montecino and Lange 2009), and the central and south zone, which are part of the Peru Current System (PCS), show different characteristics. The central zone has a year-round upwelling system, higher concentration of chlorophyll a, higher productivity, and a thicker, larger, and closer to the surface OMZ. On the other hand, the south zone has a weaker upwelling, lower productivity, higher presence of eddies and thinner and smaller OMZ (Chaigneau et al. 2008, Fuenzalida et al. 2009, Montecino and Lange 2009). The weaker upwelling in the southern part generates a longer transport time to the surface, so surface waters are comparatively older than the waters in the central area of Peru. The older the waters the more nitrogen 15 enriched they get due to denitrification and phytoplankton consumption. Therefore, isotopic signatures of nitrogen will be different in the central and south zones of the study area having the south zone higher values than the central one. The north zone will also have higher values than the central one due to the enriched that continuously occur while water are moving from upwelling cores to adjacent areas.

Our results for loggerheads and green turtles support these ideas. In the case of olive ridley the lack of more than one data point in the south zone might have prevented the detection of a spatial correlation for nitrogen. Our findings are also supported by the spatial variability found in other studies. For example, yellowfin tuna and omnivorous copepods sampled in the Eastern Pacific show an increase in δ^{15}N values from latitude 10°S to 25°N. In the case of tunas the increase was around 5 ‰ (Popp et al. 2007). In the same region, the δ^{15}N of samples of sinking particles (pellets formed by algae, bacteria and zooplankton) at 130 m depth ranged from 9 ‰ at 14°N to 11.2‰ at 24°N (Voss et al. 2001). Moreover, studies conducted on yellowfin, skipjack and bigeye tunas in the Pacific Ocean show spatial patterns of $\delta^{15}N$, with the three species having higher values concentrated around the same areas (Graham et al. 2008).

Our data also show spatial variation of $\delta^{13}C$ for olive ridleys with a negative correlation with latitude. These findings agree with our hypothesis and other studies that had also find this spatial correlation with high values observed closer to the equator and a negative gradient towards the poles (Takai et al. 2000, Phillips et al. 2009, Jaeger et al. 2010). The reason for this relationship may be related to water temperature, CO_2 concentration, and phytoplankton growth rates. As temperatures diminish towards the poles, the amount of CO_2 in the water increases and it seems that the size of the CO_2 pool in the water is negatively correlated with $\delta^{13}C$ (Rau et al. 1990 in Michener and Kaufman 2007). In the case of green turtles, there was a high $\delta^{13}C$ center in the northern area (Figure 23) but a correlation was not found. The lack of correlation could be due to the possibility that green turtles are not only using oceanic areas but also neritic areas close to the coast. If this is the case, the inshore – offshore pattern of $\delta^{13}C$ will be also affecting the carbon signatures as $\delta^{13}C$ is highly enriched in coastal areas compared to oceanic ones (Hobson et al. 1994).

Loggerheads seem to be showing the inshore – offshore pattern of $\delta^{13}C$ when compared to greens and olive ridley. Their $\delta^{13}C$ is significantly lower than the ones for greens and olive ridleys not only when comparing all sea turtles in the study site but also in the focal area analysis. Loggerheads off Peru are all considered oceanic juveniles and have not been observed in neritic areas. Moreover, due to this habitat selection, a live animal of this species was not recorded in Peru until on-board observers were placed in pelagic longliners for the project that includes this study (Kelez et al. 2003).

The values of $\delta^{15}N$ observed in all oceanic sea turtles off Peru varied among species. Loggerhead mean value was around 2 units higher than greens and olive ridleys. Knowing the preference of loggerheads for animal prey over plants and algae the high values of nitrogen were expected. However, loggerheads and olive ridleys, which also are supposed to favor animal prey, were significantly different in their nitrogen values. Moreover, olive ridleys' nitrogen values were not different from green turtles which could mean that these two species are foraging very similarly in oceanic waters (i.e. same preys and/or same areas). On the other hand, being food sources so scarce in the open ocean it is interesting to observe the differences in the values if they indeed reflect prey in different trophic levels. If this is the case, searching and targeting different prey in oceanic waters will require differential behaviors to increase their foraging efficiency.

Multispecies studies in the same oceanic area would be ideal to elucidate differential behaviors, but they are lacking in the literature with the exception of Polovina et al. (2004). His study, conducted in the north Pacific, satellite tagged loggerheads and olive ridleys that were caught during longline fishing sets. Tagged individuals separated spatially by species and loggerheads were observed using more northerly and colder waters when compared to olive ridleys. Besides the spatial separation they also showed differential diving behaviors. Loggerheads conducted shallower dives than olive ridleys (Polovina et al. 2003, Polovina et al. 2004). If these two species are foraging at different depths in our study site off Peru and consequently foraging on different species, this could potentially be responsible for their isotope signature differences.

Besides prey selection, another factor that affects diet is the foraging area. In the case of sea turtles in the open ocean, it is known that in general, different species don't have the same distribution. This is also the case for the sea turtle aggregations off Peru in this study. Green turtles occurred along the entire study site which corresponds with this population's distribution (Figures 24 and 26). Greens are known to commonly occur from Mexico to Chile (Marquez 1990) and they are the most common species in Peru (Hays-Brown and Brown 1982). Moreover, this species occurrence coincided very closely with the fishing effort distribution with the exception of the southernmost areas (south of 20.5°S) were no sea turtles were captured (Figure 26). The high density of fishing effort and sea turtles in the central zone might be related with the chlorophyll concentration which in the Peruvian coast is richest between 9°S and 12°S (Echevin et al. 2008). Regarding green turtle's oceanic habitats, studies have investigated mostly their migration from nesting beaches or from a liberation point after captivity to neritic foraging areas crossing oceanic areas (Hays et al. 2001, Godley et al. 2002, Pelletier et al. 2003, Rice and Balazs 2008). Only one study found evidence of foraging in the open ocean. These turtles were adult females that nested at Galapagos Islands and moved south from these islands in the southeastern Pacific. They seem to be associated with SST fronts and 0.2 mg m^{-3} surface chl. a concentration (Seminoff et al. 2008). In our study, considering the data constraints (longline bycatch), green turtles did not show oceanic spatial preferences and were the most common species captured which highlights the importance of oceanic habitats for green turtles in the southeast Pacific.

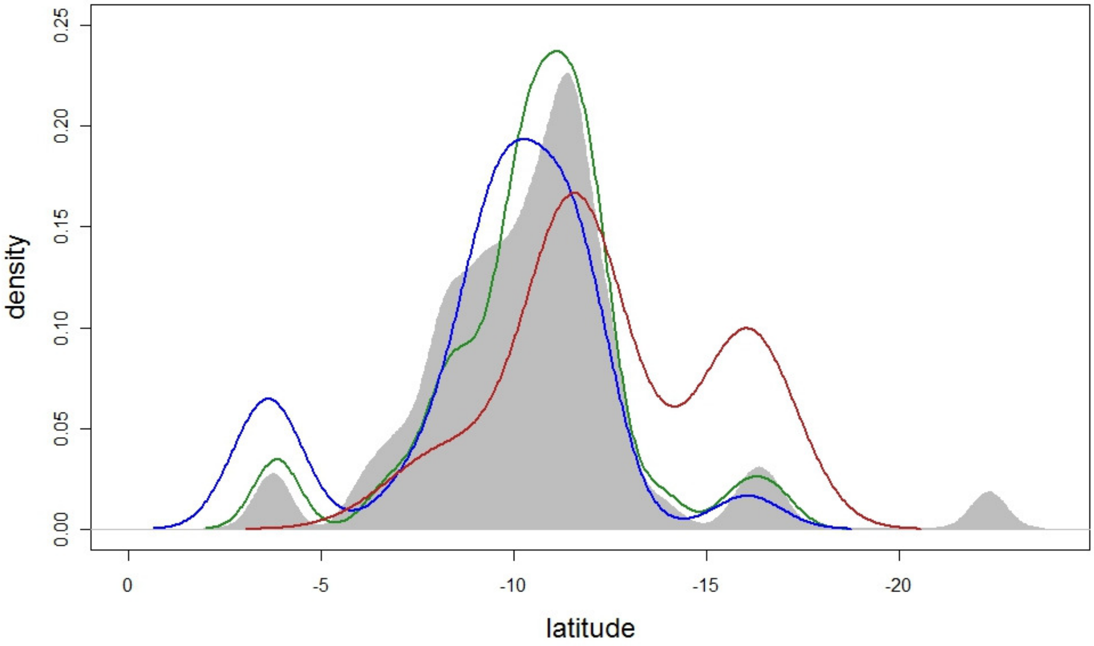

Figure 26: Frequencies of turtles captures along a latitudinal gradient. Green line for green turtle, red for loggerhead and blue for olive ridley. Grey area is the fishing effort.

Olive ridley occurred more commonly in the north and central zone of the study area (Figures 24 and 26) being highly more frequent in the north zone than expected based on fishing effort (Figure 26). This is also consistent with the distribution of the Eastern Pacific olive ridley population and their preference for more tropical waters. Olive ridleys are not very common in the south of Peru or Chile (Hays-Brown and Brown 1982, Chandler 1991). Habitat preferences for olive ridleys in the open ocean had been studied in some regions. Adult olive ridleys in the Bay of Bengal, Indian Ocean, migrated through oceanic areas using pathways between cold core and warm core eddies which are areas that concentrate floating prey (Ram et al. 2009). However, in Australia, adult females did not forage in oceanic areas but traveled straight to neritic feeding grounds (Whiting et al. 2007). In the north Pacific, olive ridleys were found in the center of the Subtropical Gyre, occupying waters with SST ranging from 23°C to 28°C, a deep thermocline at 100 m. but were not associated with strong surface chlorophyll gradients (Polovina et al. 2004). The preference of olive ridleys for warmer SSTs will result in the consumption of prey that are more abundant in such oceanic waters and could result in differential isotopic signatures.

In the case of loggerheads, they were not encountered in the north zone of the study area but occurred commonly in the central and south zones (Figures 24 and 26). However, based on the fishing effort distribution, they were highly more frequent in the south than expected (Figure 26). Once more, this distribution is not surprising because loggerheads are not as common in tropical waters as other turtles (Marquez 1990, Pritchard 1997). Also, the northernmost part of the study site, were loggerheads were not found, is not under the influence of the Peru current but superficial tropical waters coming from Ecuador (Zuta and Guillen 1970). Juvenile/subadult loggerhead’s oceanic foraging areas had been the most studied ones. In the north Pacific, this species had been associated with convergence fronts (temperature and chlorophyll) where floating organisms accumulate (Polovina et al. 2000, Polovina et al. 2004) and seem to move latitudinally following the chlorophyll front’s movements (Polovina et al. 2004).

Distinctively, in the north Atlantic, loggerheads were not associated to a specific oceanographic region but limited by cold sea surface temperatures (SST) with the hypothesis that turtles could be taking advantage of the spring blooms during warmer months but retreating to the warm waters of the Gulf Stream during colder months (Mansfield et al. 2009). Moreover, another study in the Atlantic found that loggerhead distribution in the open ocean seemed to be associated with topographic features (Santos et al. 2006). Some juvenile individuals of this population seem to use both oceanic and neritic foraging areas (McClellan and Read 2007, Mansfield et al. 2009, McClellan et al. 2010). In the Mediterranean Sea, juvenile loggerheads tagged in the Alboran Sea remained in this area, avoided the coastal shelf, were not associated with eddies, and did not show seasonal migrations (Cardona et al. 2005, Revelles et al. 2007c, Revelles et al. 2007d). The lack of seasonal movement patterns was explained by the fact that SST in the Alboran Sea is always warmer than 10°C (Revelles et al. 2007c). A similar pattern of fidelity to oceanic areas had been observed in other parts of the Meditarrean Sea with the exception of larger oceanic loggerhead presumed to belong to Atlantic stocks (Casale et al. 2007).

In our study site off Peru, the preference for the southern area could be related to the origin of loggerheads in the southeast Pacific. While greens and olive ridley's sources of hatchlings are in countries north of Peru, the source for loggerheads is the southwest Pacific (Australia and New Caledonia) and their migration to the coasts of South America seems to be facilitated by the Tasman Front and the South Pacific Current (Stramma et al. 1995, Boyle et al. 2009). Another explanation is that loggerheads could be associating with the high frequency of eddies that occur south of 15°S (Chaigneau et al. 2008) and exploiting the convergence areas that tend to accumulate floating organic material (Dandonneau et al. 2003). Their preference for less tropical waters could be giving them the advantage to exploit these eddies over greens or olive ridleys that are more thermally constraint.

As the literature shows, some species seem to be associated with similar oceanographic features (e.g. SST fronts, chlorophyll fronts) but there seems to be regional (e.g. loggerheads in north Pacific and north Atlantic) as well as interspecific differences. These interspecific differences in distributions in the oceanic environment could be responsible for the differences in isotopic values not only due to different prey availability but also because nitrogen and carbon can vary spatially which will result in isotopic differences at the base of the food web that will transmit up the food web.

The interspecific differences in nitrogen observed among loggerheads and the other two sea turtle species seem to be principally related not with a trophic level difference but with the spatial location were turtles were found. We base our conclusions in the correlation among nitrogen signatures and latitude as well as the focal analysis which show no difference in nitrogen signatures when latitude was accounted for. δ^{15} Nitrogen, which typically has been considered to be the trophic level isotope indicator due to its low spatial variation (mainly in terrestrial studies), can actually have great variability in marine environments. The most important sources of variability for this element in the marine realm are processes like denitrification, nitrogen fixation, and nitrification and the nitrogen source, which refers to where is the nitrogen in the system coming from (i.e. atmospheric nitrogen, runoff, upwelled nitrate, etc) that will change the baseline values in the ocean waters (Montoya 2007).

In conclusion, our analyses are showing that sea turtles seem to be oceanic indicators of stable isotope signatures that are particularly related to water masses and oceanographic characteristics. This had been shown previously with sea turtles from different ocean basis but in our study the differences are observed in a comparatively smaller area in the Eastern Pacific. Moreover, our results give further evidence that in areas where different oceanographic processes are occurring, we need to consider how these processes affect elemental isotopic values before interpreting data and making trophic ecology conclusions. Our findings of spatial correlations for nitrogen and carbon were likely influenced in the case of nitrogen signatures by cycling processes like denitrification and phytoplankton consumption resulting in low values in the central zone of the study site and high values in the south zone. Carbon values were higher in the north zone and loggerheads showed significant depleted values of carbon which corresponds with their juvenile oceanic behavior typical of this area. This result opens the question as whether greens and olive ridleys are not only foraging in oceanic areas but also in coastal ones as observed in some turtles in other regions In our study off Peru, in terms of foraging, loggerheads were particularly distinct from greens and olive ridleys because they showed a considerable wider trophic niche in terms of nitrogen and also higher mean values. To observe if these differences are related with diet preferences further mixing model of diet preferences will be conducted. We believe that there is a need for additional trophic ecology information on oceanic sea turtles in order to start to understand better their life history in the open ocean. Only this information will allow us to properly elaborate management plans for their conservation.

3. Sea turtle diet in oceanic environments off Peru: stable isotope mixing models results for green, loggerhead and olive ridley sea turtles

3.1. Introduction

The foraging ecology of sea turtles in the open ocean remains a poorly researched subject. Most studies have been conducted with loggerhead sea turtles *Caretta caretta* in the North Pacific (Parker et al. 2005), North Atlantic (Brongersma 1972, Frick et al. 2009), and Mediterranean Ocean (Tomas et al. 2001, Revelles et al. 2007b) and only a few have been conducted with green turtles *Chelonia mydas* and olive ridleys *Lepidochelys olivacea* (Kopitsky 2002). Moreover, there are no studies involving multiple species in the same oceanic region. In this light, we studied the foraging ecology of three sea turtle species: loggerheads, greens, and olive ridleys captured in oceanic environments off Peru, in the southeastern Pacific Ocean.

One way to study food webs and a consumer diet is by analyzing stable isotope signatures of consumer tissues because they integrate the isotopic signature of their prey. Moreover, an added benefit of this technique is that isotopic signatures reflect a longer term foraging history, on the order of weeks to months depending on the tissue as opposed to a snapshot of the diet. The most common elements used in ecology studies are carbon and nitrogen.

The objectives of our research were to increase our knowledge on diet preferences in oceanic environments for three species of sea turtles (green, olive ridley, and loggerhead) in the southeast Pacific Ocean. We also wanted to investigate if longline bait had any contribution in the diet of these oceanic turtles.

3.2. Methodology

We used stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis to investigate trophic ecology of sea turtles because this technique can provide a comprehensive view of a consumer’s diet. Stable isotope values were determined for all turtle and prey tissue samples.

3.2.1 Study area

This study was conducted in the Southeastern Pacific Ocean, offshore of the Peruvian coast but also extended to marine areas off Ecuador and Chile and international waters. The study area spanned two different marine ecosystems: the equatorial upwelling in the north of Peru where the coastal upwelled waters collide with warmer and tropical waters coming from the north (Montecino and Lange 2009) and the Peru Current System from 4° South to the south, which is composed by an Eastern Boundary Current system and a Coastal upwelling system (Barber 2001). These two areas had also been classified in the large marine ecosystems (LME) division being the northern one inside the Pacific Central-America Coastal LME and the other one named Humboldt Current LME. The Humboldt Current LME is characterized by a narrow continental shelf, especially in the south; a strong eastern boundary upwelling which pushes large quantities of nutrient rich waters to the surface thus enhancing productivity. The

Humboldt or Peru-Chile current which runs north is the major current in the LME. On the other hand, the portion of the study site inside the Pacific Central-America Coastal LME is characterized by warmer waters than the Humboldt Current LME and re-circulating coastal currents, being the most important one in the study site the Pacana Current.

As a consequence of different oceanographic characteristics and processes, stable nitrogen and carbon concentration will vary spatially so we conducted our analysis considering the three zones described in chapter 2 (section 2.2.1) to minimize spatial variability to be included in our mixing models.

3.2.2 Sample collection

From 2003 to 2009, observers collected data from 512 longline fishing sets on board of Peruvian fishing vessels (Figure 15 in section 2). The observed fishing sets targeted dolphinfish *Coryphaena hippurus* or sharks (shortfin mako *Isurus oxyrinchus*, blue shark *Prionace glauca*, and hammerhead shark *Sphyrna* spp.) and spanned almost the entire Peruvian coast from the latitude 3°S to the 18°S, around 1600 km. We also observed some trips targeting swordfish *Xiphias gladius* further south (around latitude 23°S). All the fishing sets and collection of potential prey items were conducted off the continental shelf.

The collection and preservation of skin samples from sea turtles captured are detailed in section 2.2.2. Potential prey items were collected in 2008 and 2009 using a plankton net that was towed from a fishing vessel for approximately 5 minutes each time during the day or at night hours (n = 20). The organisms collected were classified on board of the vessel and preserved in 70% or 96% EtOH (ethanol). The entire organism was preserved for small organisms while only a portion of large organisms was preserved (i.e. jellyfish, giant kelp). We also included samples from the two species most commonly used as bait in pelagic longline fisheries off Peru; Humboldt squid *Dosidicus gigas* and chub mackerel *Scomber japonicus*. These samples were collected from baits during the retrieval of longline hauls.

3.2.3 Laboratory analysis

Sea turtle tissue and potential prey item samples were prepared at the Chemistry Lab at the Southwest Fisheries Science Center facilities in La Jolla, California. Samples were dried, grounded, lipid extracted and dried again (detailed explanation in section 2.2.3). The whole sample from potential prey items was used with three exceptions: the calcareous plates from the gooseneck barnacles were removed, the shell of a pelagic octopus was removed from the sample and for some of the pelagic crabs the exoskeleton was removed. Also, for very small organisms like copepods, many individuals were combined to have enough quantity for stable isotope analysis as one sample. In the case of the bait species, only the body parts used as bait were analyzed, therefore in the case of the Humboldt squid only the mantle was used and in the case of mackerel pieces of muscle were used. Fine ground samples were weighed and between 0.8 – 1 mg of the sea turtle samples and 1 – 1.4 mg of the potential prey item samples was placed in tin cups for stable isotope analysis. These analyses were conducted at the Stable Isotope

Laboratory at the Department of Geosciences, University of Florida and a detailed explanation of the methodology can be seen in section 2.2.3.

To express the isotope values of the samples, we used the δ notation. This notation expresses in parts per thousands (‰) the difference between ratios of the heavier to the lighter isotope compared to a standard. For carbon, the standard is PeeDee Belemnite (Ratio, $^{13}C/^{12}C = 0.011180$) and for nitrogen the standard is Air (Ratio, $^{15}N/^{14}N = 0.0036765$) (Fry 2006). The calculation of the δ values is as follows:

$$\delta^{\text{element}} = [(\text{Ratio}_{\text{sample}} / \text{Ratio}_{\text{standard}} - 1)] * 1000$$

3.2.4 Statistical analysis

We used the R program (R Development Core Team 2010) to conduct all the data exploration and statistical analysis. To investigate prey contribution to the diet of each sea turtle, we used mixing models because they allow calculations of proportional source contributions to a mixture when the number of sources is larger than the number of elements used to analyze the mixture. In this case, the diet (the mixture) is investigated by analyzing the stable isotope signatures for carbon and nitrogen from skin tissue of sea turtles. The sources (i.e. potential prey items) selected for the analysis were organisms that had already been reported as prey of oceanic sea turtles based on stomach content and/or esophageal lavage analysis and the two most common species used as bait in pelagic longline fisheries off Peru. Due to the high number of different prey taxa and to maximize the performance of our mixing models (that used only two stable isotopes), we conducted an a priori aggregation and created groups based on taxonomic similarities. In addition to these three groups, we included each bait species as a separate source due to their anthropogenic origin. To properly solve the mass balance equations in the mixing model, it is necessary to have a mixing polygon, formed by the sources' signatures, that includes the mixtures inside its area (Phillips and Gregg 2003).

The Bayesian isotopic mixing model available as an open source R package, SIAR (Stable Isotope Analysis in R; Parnell et al. 2010) was used because it allows for uncertainty and natural variation to be incorporated in the model. The Bayesian inference model uses Markov Chain Monte Carlo (MCMC) as the fitting algorithm and a dirichlet distribution as the prior which treats each source input as independent but requires they sum to unity (Parnell et al. 2010). Moreover, besides the posterior distributions of the sources, SIAR results include an overall residual error term.

One of the inputs that mixing models use is the enrichment factor of a consumer with regards to its diet. This factor, also known as fractionation or discrimination factor, varies depending on the species, tissues, developmental stage of the organism, nutritional stress, and the diet type from around 0.2 to 7‰ for δ^{15} nitrogen (DeNiro and Epstein 1981, Minagawa and Wada 1984, Peterson and Fry 1987, Wada et al. 1987, Hobson and Clark 1992, Bearhop et al. 2002) but the general and most current average is 2.75 ± 0.10‰ (Caut et al. 2009). In the case of δ^{13} carbon, the discrimination factor among diet and tissue varies also depending on species, tissues and diet type and the range is between -0.6‰ and 2.7‰ with an average of 0.8‰ (DeNiro and Epstein 1978, Peterson and Fry 1987). Discrimination factors of epidermal tissue used for the mixing models in the present study were 2.18‰ for δ^{15} nitrogen and 0.17‰ for δ^{13} carbon for *Chelonia mydas* (Seminoff et al. 2006) and 1.6‰ for δ^{15} nitrogen and 1.11‰ for δ^{13} carbon for *Caretta caretta* (Reich et al. 2008). In the case of *Lepidochelys olivacea*, there are no specific discrimination factors available therefore we used the *Caretta caretta* ones based on the foraging ecology similarities, both are omnivorous, of these two species during their entire life cycle.

The mixing models also included the concentrations of carbon and nitrogen in the sources. These values were obtained during the stable isotopes analysis in the laboratory. Therefore, the model inputs for each species specific model were: δ^{13} carbon and δ^{15} nitrogen of each turtle sample of the same species, fractionation factors for δ^{13} carbon and δ^{15} nitrogen and their standard deviations for the specific sea turtle species, the average δ^{13} carbon and δ^{15} nitrogen and standard deviations of each source (either one species or group) and the concentration of carbon and nitrogen of each source.

Due to correlations among δ^{15} nitrogen and δ^{13} carbon of sea turtle tissues and latitude in our study site (section 2), and the three different oceanographic regions off the Peruvian coast that were included in our study site (section 2), all sea turtle data was divided accordingly with the regions resulting in three groups: the northern group which included turtles captured from the equator to 5°S, the central group with turtles captured from 5°S to 15°S and the south group that included turtles obtained from 15°S to 17°S.

3.3. Results

3.3.1. Sea turtles

We collected skin samples of 139 sea turtles that were incidentally captured by longline vessels mostly during dolphinfish sets but alto during shark sets. The total number of samples for green turtle, loggerhead and olive ridley was 76, 36 and 27 respectively and based on their sizes, all turtles were classified as juveniles or subadults with a higher proportion of subadults among olive ridleys (Table 23). The amount of turtles captured varied per zone being the largest central zone the one from where higher number of turtles was collected (Figure 27). The total number of turtles captured per zone can be observed in Table 24. Due to the small sample size in the zones north and south, and the fact that all our prey samples were collected in the central zone, the diet analysis were conducted only for the central zone. The size distribution of turtles captured in the central zone is shown in Table 25.

Table 23: Mean size (CCLn-t), standard deviation (SD), and size range of captured individuals.

Species	CCLn-t cm	SD	Range	n
Caretta caretta	54.5	8.5	34 - 69	36
Chelonia mydas	53.0	8.6	27 - 71.2	75
Lepidochelys olivacea	52.8	9.5	25 - 65	26

Table 24: Number of turtles captured per species in each of the three different oceanographic zones in the study site.

Species	North	Central	South
Chelonia mydas	4	68	4
Caretta caretta	0	25	11
Lepidochelys olivacea	4	22	1
total	8	115	16

Table 25: Mean size (CCLn-t), standard deviation (SD), and size range of individuals captured in the central zone.

Species	CCLn-t cm	SD	Range	n
Caretta caretta	53.4	8.9	34 – 68.2	25
Chelonia mydas	53.7	7.9	27 - 71.2	67
Lepidochelys olivacea	56.7	4.7	48 - 65	22

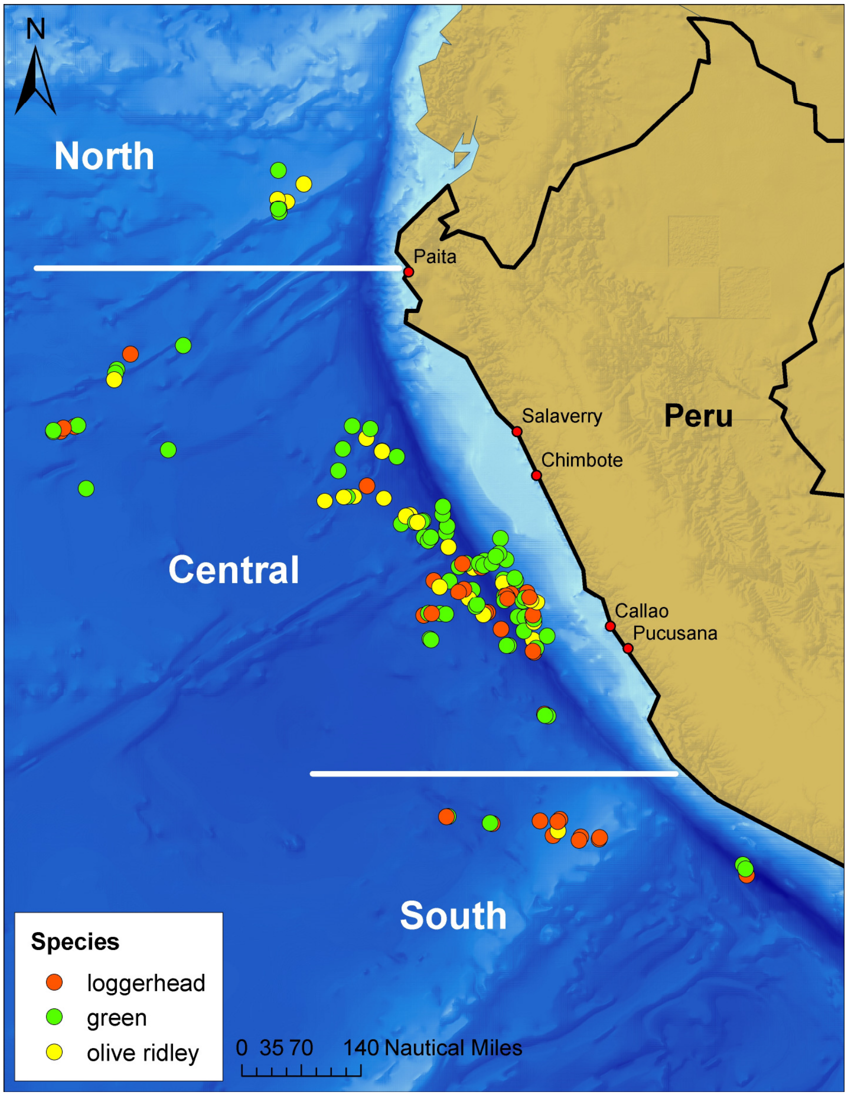

Figure 27: Map of capture locations for all turtles in the study showing the three different oceanographic zones. Symbols are color coded by species.

From the plankton trawls, many samples were collected and organisms were classified and separated in vials. The identification of most species were conducted in the Peruvian Sea Institute – IMARPE (Instituto del Mar del Peru) but for some samples experts opinion were requested by e-mail (e.g. for pelagic octopus). In the case of small organisms like copepods and water striders, several individuals were combined to make one sample whose stable isotope signatures could be analyzed. A total of 57 samples of potential prey and two species used as bait were obtained after the classification and combination process. These samples belonged to 19 different organisms (Table 26). Also, we analyzed samples from a mixture of microscopic floating organic material that was usually composed by eggs, fish larvae, algae, copepods, snails, and blue sea slug larvae to obtain micro-plankton isotopic values. Three of the samples that were sent to UF for laboratory analysis did not correctly run so our sample size was reduced to 54 samples (Table 26).

Values of δ^{15} nitrogen and δ^{13} carbon of prey samples showed great variability. In the case of nitrogen, the lowest value was from the pelagic gooseneck barnacle *Lepas anatifera* which average was 5.03‰ while the higher value was 19‰ for the Humboldt squid *Dosidicus gigas* (used as bait). This range encompasses 14 units δ^{15} nitrogen which could be translated to five trophic levels if we used the most updated enrichment factor of 2.75‰ (Caut et al. 2009). However, due to the processes originated by strong upwelling and a large oxygen minimum zone (OMZ) in the central study area, the actual quantity of trophic levels will vary (Montoya 2007). In the case of δ^{13} carbon, the range of values was narrower than with nitrogen. The lowest and higher average values were observed in the same species as in the case of δ^{15} nitrogen. On one end, the pelagic gooseneck barnacle with -19.30‰; while in the other end, the Humboldt squid with -15.62‰.

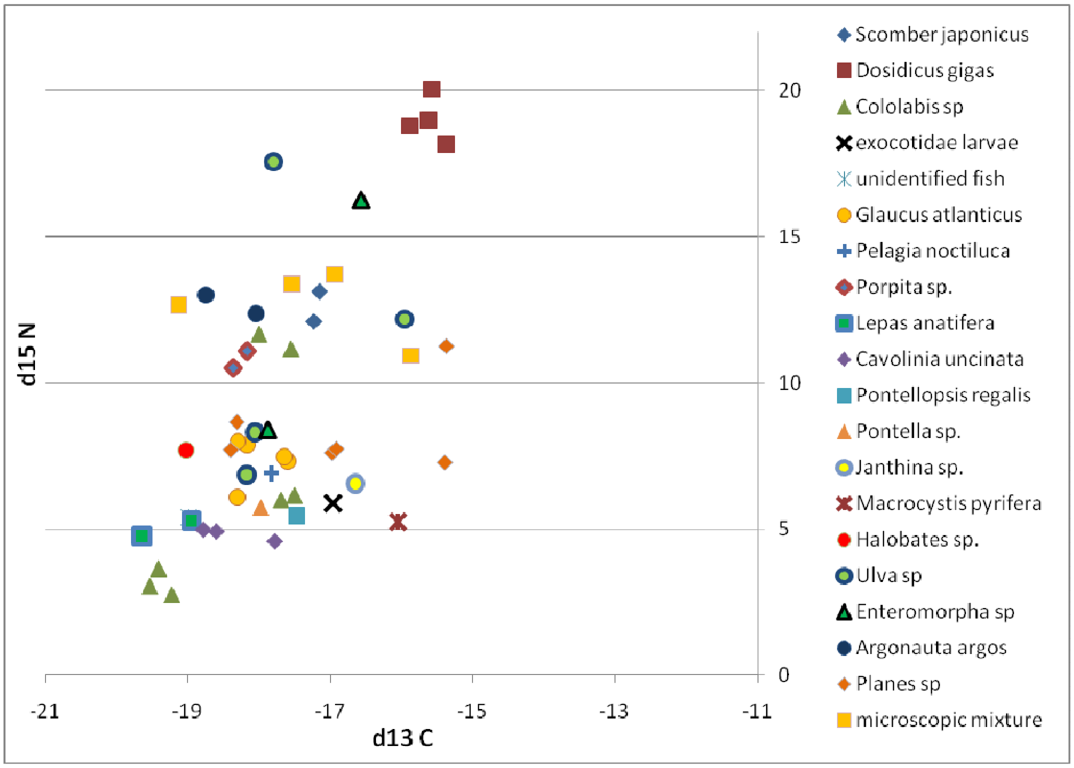

Figure 28: Stable δ^{15} Nitrogen and δ^{13} Carbon for the 56 samples that belongs to 20 categories of potential preys.

Table 26: Nitrogen and carbon isotope values for potential preys collected.

Common name	Scientific name	Phylum	$\delta^{15}N$	SD	$\delta^{13}C$	SD	n
water strider	Halobates sp.	Arthropoda	7.69		-19.03		1*
pelagic goosneck barnacle	Lepas anatifera	Arthropoda	5.03	0.37	-19.30	0.49	2
oceanic crab	Planes sp.	Arthropoda	8.37	1.479	-16.90	1.338	6
copepod	Pontella sp.	Arthropoda	5.74		-17.98		1*
copepod	Pontellopsis regalis	Arthropoda	5.46		-17.47		1*
chub mackerel	Scomber japonicus	Chordata	12.6	0.73	-17.2	0.06	2
flying fish larvae	Fam. Exocoetidae	Chordata	5.88		-16.97		1
sauri larvae	Cololabis sp	Chordata	6.36	3.71	-18.42	0.93	7
unidentified fish larvae		Chordata	5.4		-18.99		1
purple striped jelly	Pelagia noctiluca	Cnidaria	6.90		-17.83		1
blue bottom	Porpita sp.	Cnidaria	10.81	0.41	-18.27	0.15	2
uncinate cavoline	Cavolinia uncinata	Mollusca	4.84	0.22	-18.40	0.53	3
Humboldt squid	Dosidicus gigas	Mollusca	19	0.785	-15.62	0.205	4
blue sea slug	Glaucus atlanticus	Mollusca	7.50	0.772	-18.02	0.318	6
violet snail	Janthina sp.	Mollusca	6.55		-16.65		1*
pelagic octopus	Argonauta nouryi	Mollusca	12.68	0.44	-18.40	0.49	2□
green algae	Enteromorpha sp.	Chlorophyta	12.32	5.57	-17.23	0.93	2
green algae	Ulva sp.	Chlorophyta	11.23	4.79	-17.23	1.04	4
giant kelp	Macrocystis pyrifera	Heterokontophyta	5.25		-16.05		1
microscopic mixture	na	na	12.67	1.24	-17.37	1.36	4[b]

*combination of many individuals, [a]eggs + body, [b]combination of eggs, larvae fish, algae, copepods, blue sea slug larvae, violet snails

Some potential prey organisms showed very similar isotopic values like the Humbodlt squid, chub mackerel *Scomber japonicus* and blue bottom *Porpita sp* (Figure 28). However, other organisms have very high variability especially in δ^{15} nitrogen values. For example, *Cololabis* sp larvae (a fish species in the Scomberesocidae family) had samples ranging from 2.77‰ to 11.68‰ δ15 nitrogen (Figure 28). Moreover, three *Cololabis* sp. samples collected in October 2008 had values around 3‰ while two samples collected in February 2009 had the high values around 11‰. Such high variation in fish larvae that depends on plankton must be related to changes at the base of the food chain.

All but five of the potential prey samples collected, excluding the species used as bait, had been cited in the literature as diet items for loggerhead, olive ridley and/or green turtle (Table 27). These five items are: kelp *Macrocystis pyrifera*, two species of green algae *Ulva* sp. and *Enteromorpha* sp., the only unidentified fish species, and *Cololabis* sp. (Table 26). In the case of *Cololabis* sp., this species itself has not being cited in the literature but eggs of other Beloniformes have been recorded as part of the diet of oceanic loggerheads in the north Pacific and Azores (Parker et al. 2005, Frick et al. 2009) and of oceanic green turtles off Ecuador (Fritts 1981). However, these species were not selected to be included in the diet analysis.

Due to the limitations of working with only two elements for the stable isotopes analysis (carbon and nitrogen), and the fact that if the model contains n isotope elements and n+1 sources the calculations become mathematically undetermined and the solution is not unique but a group of possible combinations (Phillips and Gregg 2003); we needed to reduce the number of samples to be included in the mixing models as sources. To do this, we selected from Table 27 the species that seemed more important taking into consideration information from literature about the relevance of these items in the diet of oceanic turtles as well as the abundance of the species during our sampling tows and the size of the organisms. Our selection resulted in six species: pelagic gooseneck barnacle, oceanic crab, purple striped jelly, blue bottom, blue sea slug and pelagic octopus (Figure 29). These six species were further grouped by taxonomic similarities resulting in three groups: crustaceans (pelagic gooseneck barnacle and oceanic crab), cnidarians (purple striped jelly and blue bottom) and mollusks (blue sea slug and pelagic octopus).

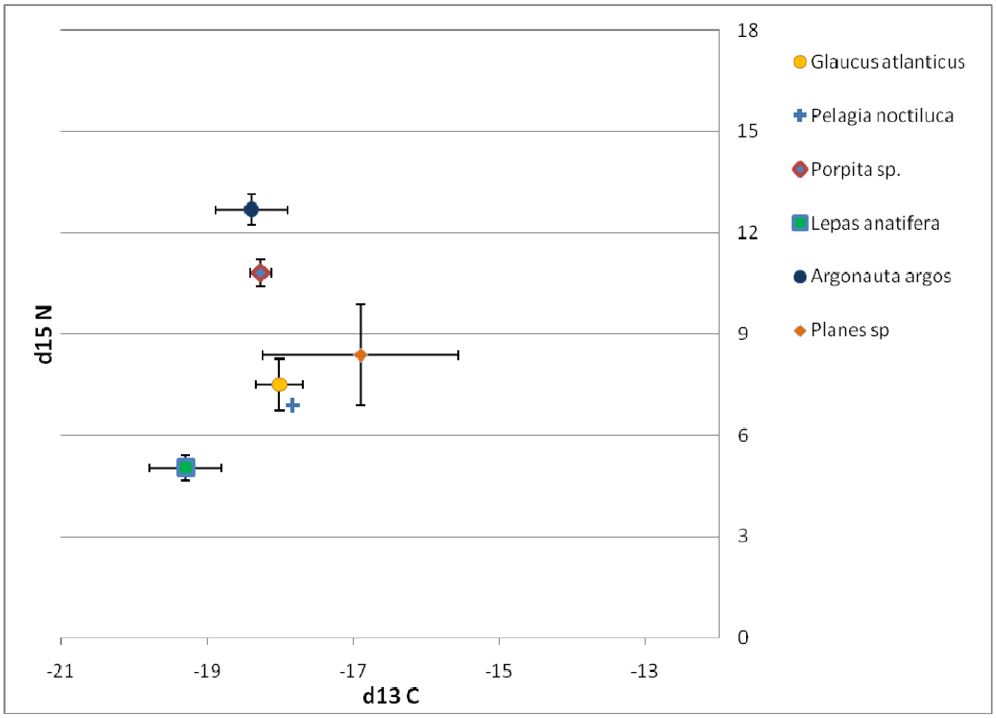

Figure 29: Average values of δ^{15} nitrogen and δ^{13} carbon for the six species selected as sources for the mixing model analysis. Error bars are standard deviations.

Table 27: List of preys collected during this study and the closest taxonomic species found in literature as diet item for oceanic sea turtles. Species of sea turtle and location of the studies in literature is shown.

Common name	Scientific name	species in literature	turtles	location	Ref.
water strider	*Halobates* sp.	*Halobates micans*	Cc	Azores	1
		Halobates sp.	Cc	Florida	2
pelagic gooseneck barnacle	*Lepas anatifera*	*Lepas anatifera*	Cc	Azores & Madeira	3, 1
			Cc	North Pacific	4
oceanic crab	*Planes* sp.	*Planes minutus*	Cc	Azores & Madeira	3, 1
		Planes sp.	Cc	North Pacific	4
copepod	*Pontella* sp.	Calanoida copepods	Cm	Australia	5
copepod	*Pontellopsis regalis*	Calanoida copepods	Cm	Australia	5
flying fish larvae	Fam. Exocoetidae	Exocotidae eggs	Cc	North Pacific	4
purple striped jelly	*Pelagia noctiluca*	*Pelagia* sp.	Cc	Florida	2
		Pelagia noctiluca	Cc	North Atlantic	6
			Cc	Azores	1
blue bottom	*Porpita* sp.	*Porpita* sp.	Cm	Australia	5
			Cc	Florida	2
		Porpita porpita	Cc	Azores	1
uncinate cavoline	*Cavolinia uncinata*	*Cavolinia* sp.	Cc, Cm	Australia	5
		Cavolinia globosa	Cc	North Pacific	4
		Cavolinia tridentata	Cc	Azores	1
blue sea slug	*Glaucus atlanticus*	*Glaucus atlanticus*	Cc	Azores	1
violet snail	*Janthina* sp.	*Janthina* sp.	Cc	Florida & Texas	2, 7
		Janthina sp., *J. janthina*	Cc	Azores & Madeira	3, 1
		Janthina janthina, *J. globosa*	Cc	North Pacific	4
		Janthina janthina	Cm	South Africa	8
pelagic octopus	*Argonauta nouryi*	*Argonauta argo*	Cc	Azores	1

References: 1) Frick et al. 2009, 2) Witherington 2000, 3) Brongerma 1972, 4) Parker et al. 2005, 5) Boyle & Limpus 2008, 6) Bolten & Balazs 1995, 7) Plotkin 1996, and 8) Hughes 1974

To the three groups created, we added the two bait species, chub mackerel and Humboldt squid but, interestingly, all our oceanic samples were not as rich in carbon as some of the turtles' samples so we added an organism from coastal origin to complete our mixing polygon. The coastal organism was the green algae *Ulva* sp. and stable isotope raw data from it (n=6) was obtained from A. Catenazzi from samples collected washed ashore in Paracas Bay, Peru in 2003 (Catenazzi and Donnelly 2007). Paracas is also located inside of what we are calling the central zone in our study site. Coastal Ulva in this case was use as an indicator of coastal food sources due to its carbon values and not to be interpreted as that turtles were directly consuming this green algae. The six sources averages and standard deviations together with the sea turtle data for each species (after correcting for the trophic enrichment factors) can be observed in Figure 30. The three species of sea turtles show different distributions, greens have higher values of δ^{13} carbon but low values of δ^{15} nitrogen when compared to olive ridleys and loggerheads. In the case of loggerheads, the values of δ^{15} nitrogen are the highest among all the species.

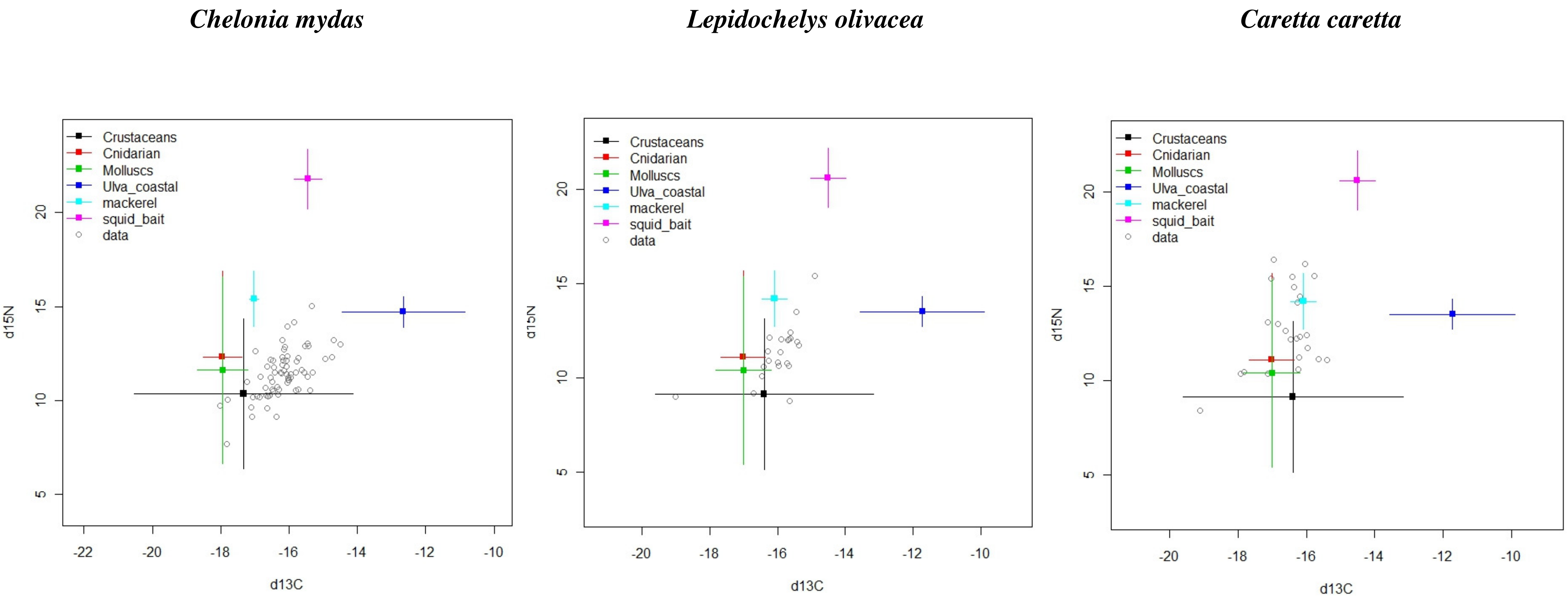

Figure 30: Stable isotope values for each sea turtle and the averages and standard deviations of the six sources used in the mixing model analysis.

3.3.3. Mixing models

Proportional contributions of the six sources in the diet of our oceanic sea turtles for the central zone show variability per species (Figure 31). In terms of the sources selected as important diet items, green and olive ridley have similar results but both were different from loggerhead sources. Figure 31 shows the results of the model as posterior distributions for each source and each turtle species. Each posterior distribution shows the proportional contribution of a dietary item in the mixture (the skin sample in this case). Therefore, if a posterior source distribution straddle zero, then that source is not a necessary source for the specific mixture. On the contrary, the farther away from zero the distribution of the source is, the greater contribution that source has in the mixture. Also, the narrower the distribution the more precision about the estimate of the proportional contribution.

Greens had three sources whose distributions were higher than 0%, meaning that they were always selected in the model, these are crustaceans, coastal *Ulva* and mollusks (Figure 31) and a summary of the specific data can be seen in Table 28. The model shows a narrow and far from zero distribution for crustaceans which make them the most important item in the mixture, with a mode of 40% proportional contribution. The coastal *Ulva* also shows a narrow distribution that is away from zero and makes it another important source with a contribution mode of 35.2%. The third important source for greens was mollusks with a proportional contribution mode of 20% but in this case the distribution is wider and closer to zero which shows more uncertainty in the precision of the contribution estimate of this source (Figure 31).

Results for olive ridley are similar to greens but there is more uncertainty as it can be seen in the wider distributions of the posteriors compared with the source distributions for green turtles (Figure 31). The sources that resulted in important contributors to the mixture were mollusks, crustaceans, and coastal *Ulva* with a mode of 25.3%, 23.7% and 17% respectively (Table 28). In the case of loggerhead, four sources had the distribution minimum value higher than zero but only one source was similar to green and olive ridley and that is the group mollusks with a proportional contribution mode of 25.7%. The other three sources were cnidarians, mackerel (bait) and squid (bait). Cnidarians was the group with the distribution farther away from zero and a mode of 24.8% while the two species use as longline baits, mackerel and squid, had proportional contribution modes of 21.2% and 8.7% respectively.

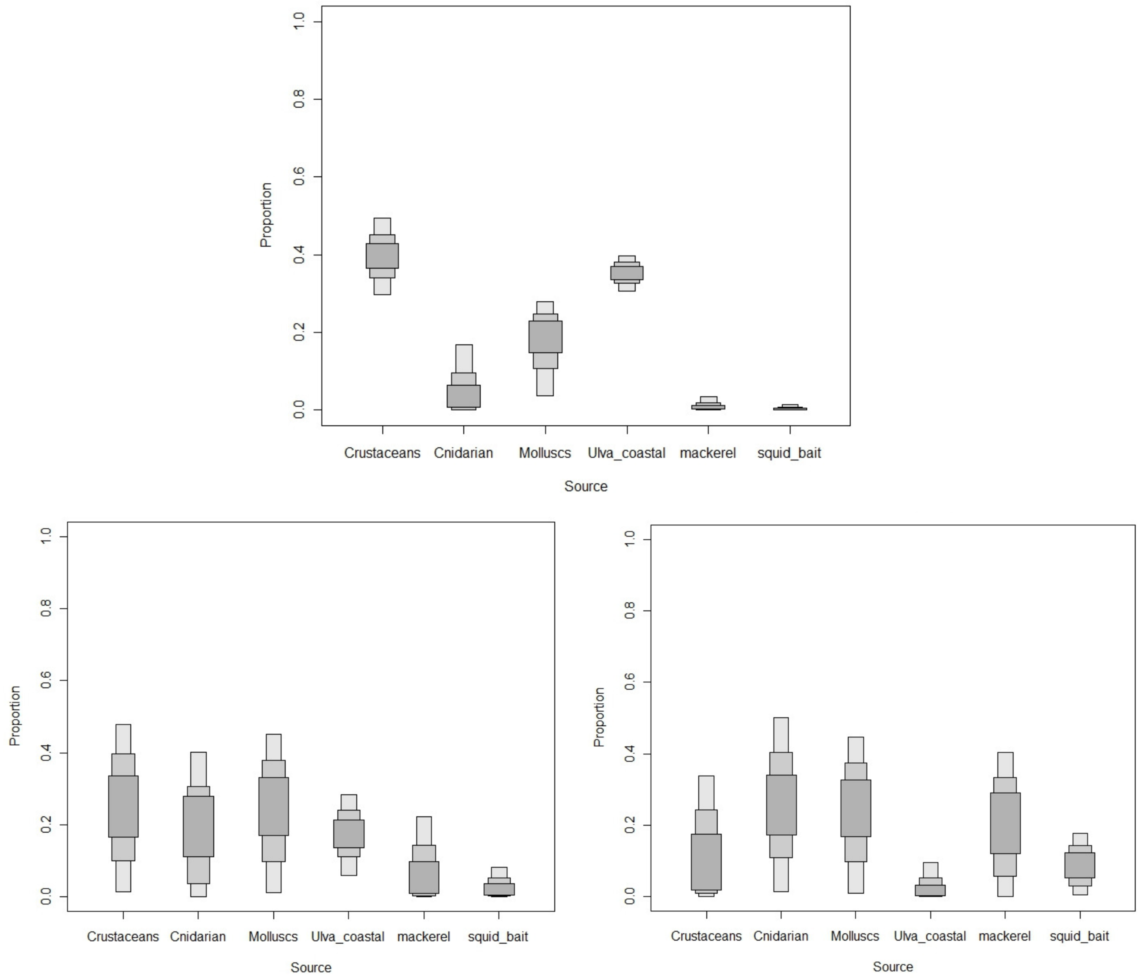

Figure 31: Distribution of the proportional contributions of each source to the diet of green (top panel), olive ridley (bottom right panel) and loggerhead (bottom left panel).

Table 28: Mixing models results showing data per species and source.

source	*Green*	*Olive ridley*	*Loggerhead*
Crustaceans			
mode %	**40**	**23.7**	3
range %	**29.7 – 49.4**	**1.3 – 47.8**	0 – 33.7
Cnidarians			
mode %	1.8	21.5	**24.8**
range %	0 – 16.8	0 – 40.1	**1.3 – 50.2**
Mollusks			
mode %	**20**	**25.3**	**25.7**
range %	**3.7 – 27.9**	**1.2 – 45.1**	**0.8 – 44.6**
Ulva (coastal)			
mode %	**35.2**	**17**	0.9
range %	**30.5 – 39.6**	**6 – 28.3**	0 – 9.5
Mackerel (bait)			
mode %	0.6	2.1	**21.2**
range %	0 - 3.2	0 - 22.2	**0.08 - 40.2**
Squid (bait)			
mode %	0.1	1	**8.7**
range %	0 - 1.3	0 - 8.2	**0.3 - 17.6**
SD carbon			
mode %	4.9	68.4	77.3
range %	0 - 43.4	17.9 - 110.2	52.7 - 113.4
SD nitrogen			
mode %	39.4	96.3	187.7
range %	0 - 92.4	27.4 - 171.7	121.7 - 280.4

Regarding the variability of the stable isotope values of the consumers in each species model, it can be observed in Table 28 that the most variable consumer was loggerhead for both carbon and nitrogen while green was the less variable consumer. Also, nitrogen was a greater source of variability than carbon for each consumer group.

3.4. Discussion

Mixing models are a great technique to study diet preferences because of the integration of prey signatures in consumer tissues. Our study shows proportional contributions of three or four sources for each species with different degrees of certainty. The most precise contribution estimates were for green turtles, while for olive ridleys the distributions were wider so less precise, which might be the result of the small sample size for that particular species.

In our study, results show how sea turtle species seem to be feeding on different preys. To our knowledge this is the first multispecies study of sea turtle trophic ecology in oceanic environments and our data suggest some interesting findings. First, in the case of green and olive ridley, they seem to be preying on the same source groups: crustaceans, mollusks and coastal *Ulva*. Second, coastal *Ulva* as an indicator of coastal prey in the diet of green and olive ridley seem to be important. And third, the different source results for loggerhead and the selection of mackerel and squid bait as important sources.

In this particular study, coastal *Ulva* was added as a source due to its high contents of carbon and the fact that none of the samples collected in oceanic environments showed high carbon contents (Table 26). Stable carbon is considered as a spatial indicator because of several spatial trends being the strongest the variation from coastal to offshore areas having higher values in coastal areas and lower values in oceanic ones. In this study, we are interpreting our results not as that turtles are feeding on coastal

Ulva directly but we are using *Ulva* as an indicator of prey sources from coastal areas due to spatial patterns that exist. Therefore, there are two possibilities that could explain these results. The first one is that coastal prey has influence in oceanic areas by means of horizontal transport. This possibility seems unlikely because our potential prey sampling efforts did not result in species with high stable carbon values and even the green algae *Ulva* sp. and *Enteromorpha* sp. that we collected had average carbon values of -17.23‰. However, there is a small amount of coastal sources including green algae that get transported to oceanic areas by fishing vessels in the form of fouling and actually one green turtle we captured had a large piece of green algae *Ulva* sp. in its mouth. But, in order for this signature to be picked up by sea turtles, they will have to consume considerable amounts of fouling from fishing vessels which does not seem likely. Also, high carbon values were not observed in loggerheads that were also found in the central zone.

The other possibility is that green and olive ridley sea turtles are using both oceanic and neritic habitat during their juvenile and subadult developmental stage. And as the standard life cycle and life history of sea turtles suggest, subadults should have higher probabilities of using neritic areas. In our sample, 19% of the green turtles and 23% of olive ridleys were in the subadult range size (*C. mydas*: CCL 60.7 – 86.7 cm, *L. olivacea*: CCL 59.2 -64.9, Figure 32) and to further investigate this possibility we conducted correlation tests to investigate δ^{13} C relative to sea turtle size (CCLnt) but the analysis resulted in no significant correlations for either species (Figure 33).

Nevertheless, the possibility that the reason for high δ^{13} carbon in juvenile and subadult green and olive ridley is that they are using both neritic and oceanic habitats is a strong one. And it is further supported by new insights in the life cycle of juveniles / subadults sea turtle of several species. For example, McClellan and Read (2007) observed using satellite telemetry how juvenile loggerheads, that had supposedly recruited into neritic areas, moved back into oceanic areas. Moreover, other satellite telemetry studies and stable isotopes analysis further evidenced this deviation from the stereotyped life cycle of sea turtles (Mansfield et al. 2009, McClellan et al. 2010). In Japan, this facultative use of oceanic and neritic habitat had been observed in adult female sea turtles and not only in loggerheads but also in green turtles (Hatase et al. 2006, Hatase et al. 2010). Furthermore, recent satellite telemetry studies with small green turtles off Argentina showed how these juveniles used both neritic and oceanic habitats (Gonzalez-Carman et al. 2011). If as we suspect, "oceanic" greens and olive ridleys are using both oceanic and neritic habitats, it will be necessary to consider the additive threats at which this developmental stage is exposed to when conducting population assessments and elaborating management plans . Therefore, coastal gillnets and trawls, among other anthropogenic threats in coastal areas will have to be added to pelagic longline fisheries when considering threats for "oceanic" green and olive ridley.

Another possibility that we should not discard is the spatial trend that had been observed from the equator to the poles. Our results from section 2 show spatial correlations with latitude for olive ridley with higher values in the north zone when considering all turtles captured in the entire study zone. However these trends were not observed for green turtles. Moreover, this correlation is not significant when considering turtles only in the central zone. Nevertheless, we cannot rule out the possibility that individuals of these two species were foraging in the north zone and were captured in the central zone. Our lack of understanding on movements of oceanic greens and olive ridleys in the Southeast Pacific prevent us from deriving any conclusion about this possibility. We believed that the study of movements and diving behavior of oceanic greens and olive ridleys in the southeast Pacific is a research priority.

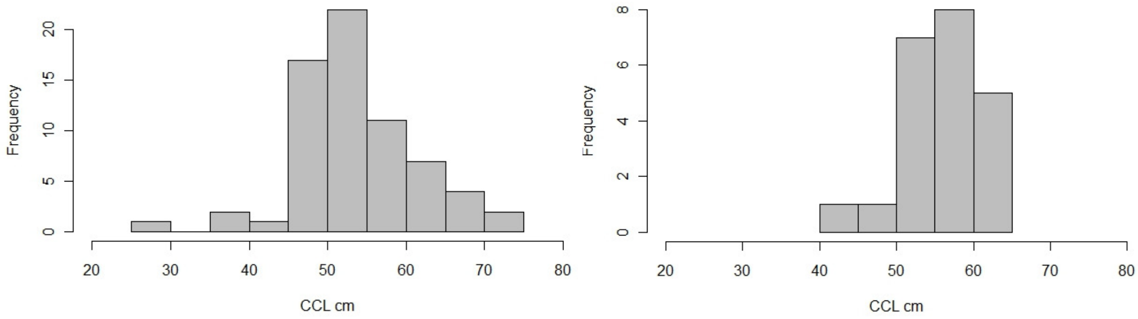

Figure 32: Size distribution (CCL n-t cm) of green turtles (right panel) and olive ridleys (left panel) from the central zone.

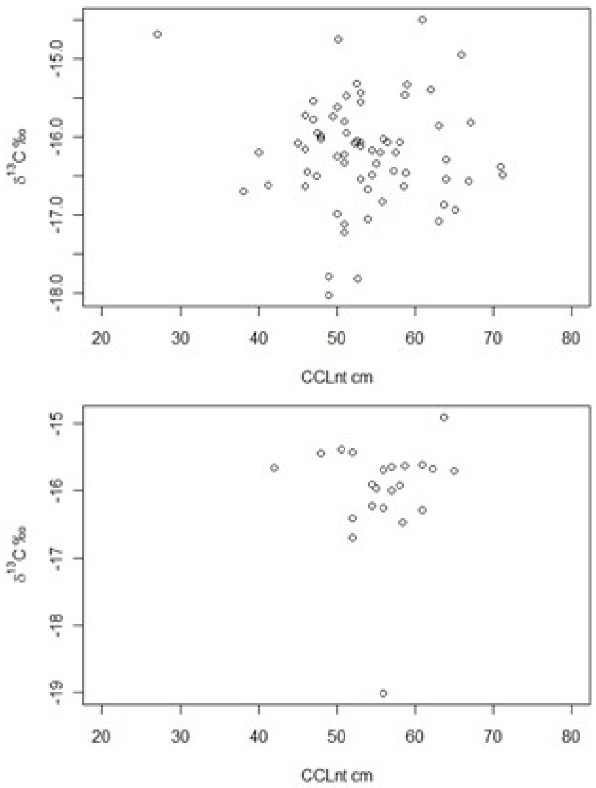

Figure 33: Scatter plot of δ13 carbon relative to size for green turtle (top panel) and olive ridley (bottom panel).

Results for loggerhead turtles show a different foraging behavior compared with green and olive ridleys and it is remarkable that given the scarcity and patchiness of food, they are able to forage differently from the other species. The lack of importance of coastal *Ulva*, as a proxy for coastal sources, in the diet of loggerhead highlights once more the oceanic nature of this juvenile aggregation in the south east Pacific. It is this characteristic that made cryptic this species in Peru until sea turtle research started onboard of longline vessels (Hays-Brown and Brown 1982, Kelez et al. 2003, Alfaro-Shigueto et al. 2004).

Mollusks and cnidarians had the highest and very similar proportional contributions with 25.7% and 24.8% respectively. Mollusks specifically, had been categorized as important food items for loggerheads in studies of stomach contents of oceanic loggerheads. Species like harp carinaria *Carinaria cithara*, and the pelagic plantonic sea slugs *Janthina globosa*, *Janthina janthina*, *Pterotrachea* sp., *Creseis* sp. were important food items in the stomach content analysis (Brongersma 1972, Witherington 2000, Parker et al. 2005). During our potential prey sampling the most common mollusk was the blue sea slug *Glaucus atlanticus*, a species reported in stomach content studies (Frick et al. 2009) and the one we believed could be an important prey of loggerheads in the Southeast Pacific.

Cnidarians were not an important source for green and olive ridley and its importance in the diet of loggerhead is highlighted as it is the second source with highest mode and distribution. Cnidarians have been reported as principal prey items of oceanic loggerheads in the North Atlantic (Azores and Madeira, off Florida), Gulf of Mexico (off Texas) and North Pacific (Brongersma 1972, Plotkin 1996, Bjorndal 1997, Witherington 2000, Parker et al. 2005, Frick et al. 2009). Contrastingly, the few studies on the diet of oceanic green only report one record of cnidarians in a post-hatchling off Australia and show a greater importance of mollusks, crustaceans, and fish eggs as food items (Fritts 1981, Revelles et al. 2007b, Boyle and Limpus 2008) which also agrees with our findings of crustaceans and mollusks as 2 of the 3 important food items for greens. In the case of olive ridley, only two studies had been published and one of them identifies cnidarians as an important food item which does not agree with our findings. However, crustacean and mollusks were also included in the prey items list (Fritts 1981, Kopitsky 2002). We recognize that our sample size for olive ridley was small and that it could have increase the uncertainty associated with the results than in the case of the other two turtle species. Consequently, we believe there is a need for further research regarding olive ridley diet in oceanic environments and not only because it is the most common species in the Eastern Pacific but also because of its pelagic nature, a combination that could highly improved our understanding about oceanic environments and sea turtles.

The presence of both mackerel and squid bait as important sources is a particular finding for loggerheads. Squid bait had the highest δ^{15} nitrogen values in our sample, 19 ± 0.79 ‰ (Figure 28 and Table 26) while mackerel had also high values, 12.6 ± 0.73‰. No other potential prey items we collected had such high values of δ^{15} nitrogen as the squid but some items collected had similar δ^{15} nitrogen values as mackerel but were not included in the model because they were not recognized as food items for oceanic sea turtles in the literature. Therefore, as the mixing model results suggest; loggerheads should be eating chub mackerel and Humboldt squid in the form of bait. We do not believe it is possible for loggerheads to target live chub mackerel or Humboldt squids; therefore, loggerheads are either taking the baits from the longline hooks or are eating the baits that were thrown to the water by fishermen during the retrieval of the line.

Loggerheads are known to be the sea turtle species that interacts with longlines the most (Table 10). In Peru, loggerheads are the second most common species captured by pelagic longlines after green turtles (Table 9) but considering the smaller population size of loggerhead compared to the green turtle population (Table 16), the interaction of loggerheads with longlines becomes the highest. In the north Atlantic, squid bait from the swordfish longline fishery were found in oceanic loggerhead stomachs and obtained a high index of relative importance (Frick et al. 2009). Moreover, in the Mediterranean, squid bait from longlines and also cnidarians were found to be the staple food of immature loggerheads (Revelles et al. 2007b), results that agree with our mixing model findings.

In order for the high δ^{15} nitrogen values of the mackerel and squid baits to be integrated in loggerhead tissues, the consumption of baits should be somehow frequent. Hooking rates of loggerheads are higher with squid bait than with fish bait in longline fisheries. And this is mainly because turtles can tear in pieces the flesh of the fish and avoid getting hook but the texture of the squid makes it difficult for loggerheads to eat the squid and avoid the hook (Stokes et al. 2011). Humboldt squid is the preferred bait in longline fisheries because it is a free supply that is fished during the fishing trip as compared with fish bait that needs to be bought before the fishing trip. Therefore, it is unlikely that the use of squid baits will be reduced as a bycatch mitigation method and as a consequence if, as we propose, loggerheads are interacting multiple times with longline hooks, then, there should be not only an increased risk of getting hook but also an increase effect of the cumulative interactions among loggerheads and longline gear which in the long term could be detrimental for the survival of the individual.

In general, our mixing models results show that loggerheads are eating higher in the trophic chain (i.e. baits and cnidarians) compared to greens whose δ^{15} nitrogen values were the lowest and therefore mollusks resulted in the most important food item and that olive ridleys are in between. But due to the potential spatial variability of δ^{15} nitrogen at the base of the food web, and even though we restricted our analysis to only one zone to minimize this variability (i.e. central zone), spatial variability could be having an effect in our results. Thankfully, a new technique, compound-specific nitrogen analysis, to estimate trophic level of a consumer base on analysis of its own essential and non-essential aminoacids had been developed and is a great tool that would solve the issue of spatial variability of δ^{15} nitrogen at the base of the food web (McClelland and Montoya 2002).

To date, four of our samples (green n=1, olive ridley n=2, and loggerhead n=1) have been analyzed using this new technique (i.e. compound specific stable isotope analysis) in a collaboration with Dr. Brian Popp and Dr. Karen Arthur at the University of Hawaii. Results from those analyses agree with our findings: green seems to be eating at a lower trophic level than loggerheads. Eleven more will be analyzed this summer and they will be critical in determining sea turtle trophic levels and δ^{15} nitrogen at the base of the food web.

References

Abrego, M. E. 2010. Panama, Informe Anual 2010. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

Abreu-Grobois, A., and P. Plotkin. 2007. MSTG global assessment of olive ridley turtles for the IUCN Red List. Submitted to IUCN Species Survival Commission, April 2007.

Alava, J. J., P. Jimenez, M. Peñafiel, W. Aguirre, and P. Amador. 2005. Sea turtle strandings and mortality in Ecuador: 1994-1999. Marine Turtle Newsletter **108**:4-7.

Alfaro-Shigueto, J., P. H. Dutton, J. Mangel, and D. Vega. 2004. First confirmed occurrence of loggerhead turtles in Peru. Marine Turtle Newsletter **103**:7-11.

Alfaro-Shigueto, J., P. H. Dutton, M.-F. Van Bressem, and J. Mangel. 2007. Interaction between leatherback turtles and peruvian artisanal fisheries. Chelonian Conservation and Biology **6**:129-134.

Alfaro-Shigueto, J., J. Mangel, P. Pajuelo, C. Caceres, J. A. Seminoff, and P. H. Dutton. 2008. Bycatch in Peruvian artisanal fisheries: gillnets versus longlines. Page 192 *in* A. F. Rees, M. Frick, A. Panagopoulou, and K. Williams, editors. Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-569.

Alfaro, J., J. C. Mangel, J. A. Seminoff, and P. H. Dutton. 2008. Demography of loggerhead turtles Caretta caretta in the southeastern Pacific Ocean: fisheries-based observations and implications for management. Endangered Species Research **5**:129-135.

Alio, J. J., L. A. Marcano, and D. E. Altuve. 2010. Incidental capture and mortality of sea turtles in the industrial shrimp trawling fishery of northeastern Venezuela. Ciencias Marinas **36**:161-178.

Allain, V., R. Olson, F. Galvan-Magana, B. Popp, and J. Sibert. 2008. JIMAR Annual report for FY2008. Trophic structure and tuna movement in the cold tongue-warm pool pelagic ecosystem of the equatorial Pacific (PROJECT # 659559).

Aranda, C., and M. W. Chandler. 1989. Las tortugas marinas del Peru y su situacion actual. Boletin de Lima **62**:77-86.

Arauz, R. 1990. The importance of testing TED efficiency in Costa Rica. Pages 51-53 *in* T. H. Richardson, J. I. Richardson, and M. Donnelly, editors. Proceedings of the Tenth Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFC-278.

Arauz, R. 1996. A description of the Central America shrimp fisheries with estimates of incidental capture and mortality of sea turtles. Pages 5-9 *in* J. A. Keinath, D. E. Barnard, J. A. Musick, and B. A. Bell, editors. Proceedings of the Fifteenth Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-387.

Arauz, R. 1999. Description of the Eastern Pacific High-Seas Longline and Coastal Gillnet Swordfish Fisheries of South America, including sea turtle interaction, and management recommendations. Sea Turtle Restoration Project.

Arauz, R. 2000. Equitable fisheries and conservation of marine resources: An evaluation of Public Law 101-162, Section 609. Central America report. Submitted to the Smithsonian Institution, Research and Conservation Center. Washington DC.

Arauz, R. 2004. Incidental capture of sea turtles by High seas longline pelagic fisheries in Costa Rica's Exclusive Economic Zone (EEZ) - A second look. Pages 40-42 *in* M. S. Coyne and R. D. Clark, editors. Proceedings of the Twenty-First Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-528.

Arauz, R. 2006. Dead without a TED: Turtles drowning in U.S.-cetified shrimp nets. Page 208 *in* N. J. Pilcher, editor. Proceedings of the Twenty-Third Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-536.

Arauz, R., I. Naranjo, R. Rojas, and R. Vargas. 1998a. Evaluation of the super shooter and seymour turtle excluder devices with different deflector bar spacing in the shrimp fishery of Pacific Costa Rica. Pages 121-125 *in* S. P. Epperly and J. Braun, editors. Proceedings of the Seventheenth Annual Sea Turtle Symposium. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-SEFSC-415.

Arauz, R., O. Rodriguez, R. Vargas, and A. Segura. 2000. Incidental capture of sea turtles by Costa Rica's Longline fleet. Pages 62-64 *in* H. J. Kalb and T. Wibbels, editors. Proceedings of the Nineteenth Annual Symposium on Sea Turtle Biology and Conservation. U.S. Dept. Commerce. NOAA Tech. Memo. NMFS-SEFSC-443.

Arauz, R., R. Vargas, I. Naranjo, and C. Gamboa. 1998b. Analysis of the incidental capture and mortality of sea turtles in the shrimp fleet of Pacific Costa Rica. Pages 1-5 *in* S. P. Epperly and J. Braun, editors. Proceedings of the Seventeenth Annual Sea Turtle Symposium. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-SEFSC-415.

Araya, M. V. 2006. Costa Rica, Informe Anual 2006. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

Arthur, K. E., M. C. Boyle, and C. J. Limpus. 2008. Ontogenetic changes in diet and habitat use in green sea turtle (Chelonia mydas) life history. Mar Ecol Prog Ser **362**:303-311.

Arthur, K. E., K. M. McMahon, C. J. Limpus, and W. C. Dennison. 2009. Feeding ecology of green turtles (Chelonia mydas) from Shoalwater Bay, Australia. Marine Turtle Newsletter **123**:6-12.

Azócar, J., J. C. Saavedra, L. Miranda, P. Barría, and G. Rosson. 2009. Sea turtle bycatch in the longline fishery off Chile (Southeastern Pacific Ocean) from 2001 to 2008. III Simposio Regional de Tortugas Marinas del Pacifico Sur Oriental, Santa Elena, Ecuador.

Bakun, A., and S. J. Weeks. 2008. The marine ecosystem off Peru: What are the secrets of its fishery productivity and what might its future hold? Progress in Oceanography **79**:290-299.

Ballance, L. T., R. L. Pitman, and P. C. Fiedler. 2006. Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. Progress in Oceanography **69**:360-390.

Barber, R. T. 2001. Ocean ecosystems. Pages 427-437 Encyclopedia of Biodiversity. Academic Press, San Diego.

Barreto, L. J., A. Reina, and R. Correa. 2008a. Bycatch of sea turtles in Tumaco's fisheries. Pages 188-189 *in* Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-569.

Barreto, L. J., L. A. Zapata, and D. Amorocho. 2008b. Experiments with circle hooks for mitigating bycatch of sea turtles in longline fisheries from the Colombian Pacific. Pages 189-190 *in* A. F. Rees, M. Frick, A. Panagopoulou, and K. Williams, editors. Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-569.

Barrientos, K., and C. Ramirez. 2008. Estado actual de Lepidochelys olivacea en el Valle, Pacifico Chocoano, Colombia. Pages 17-21 *in* S. Kelez, F. van Oordt, N. de Paz, and K. Forsberg, editors. Libro de resumenes. II Simposio de tortugas marinas en el Pacifico Sur Oriental.

Bearhop, S., S. Waldron, S. C. Votier, and R. W. Furness. 2002. Factors that influence assimilation rates and fractionation of nitrogen and carbon stable isotopes in avian blood and feathers. Physiological and Biochemical Zoology **75**:451-458.

Bernardo, J., and P. T. Plotkin. 2007. An evolutionary perspective on the arribada phenomenon and reproductive behavioral polymorphism of Olive Ridley sea turtles (*Lepidochelys olivacea*). Pages 59-87 *in* P. T. Plotkin, editor. Biology and Conservation of Ridley Sea Turtles. Johns Hopkins University Press, Baltimore, MD.

Beteta, V. 2009. Peru, Informe Anual 2009. Convencion Interamericana para la Proteccion y Conservacion de las Tortugas Marinas.

Biasatti, D. M. 2004. Stable carbon isotopic profiles of sea turtle humeri: implications for ecology and physiology. Palaeogeography, Palaeoclimatology, Palaeocology **206**:203-216.

Bjorndal, K., and A. Bolten. 2010. Hawksbill sea turtles in seagrass pastures: success in a peripheral habitat. Marine biology **157**:135-145.

Bjorndal, K. A. 1997. Foraging ecology and nutrition of sea turtles. Pages 199-231 *in* P. L. Lutz and J. A. Musick, editors. The biology of sea turtles. CRC Press.

Bjorndal, K. A., and A. B. Bolten. 2003. Estimates of survival probabilities for oceanic-stage loggerhead sea turtles (*Caretta caretta*) in the North Atlantic. Fishery Bulletin **101**:732-736.

Bjorndal, K. A., A. B. Bolten, T. Dellinger, C. Delgado, and H. R. Martins. 2003. Compensatory growth in oceanic loggerhead sea turtles: response to a stochastic environment Ecology **84**:1237-1249.

Bolaños, M. 2005. Costa Rica, Characterization of the Costa Rican semi-industrial coastal shrimp trawling fishery and the small scale artisanal shrimp trawling fishery. FAO.

Bolten, A., H. Martins, E. Isidro, R. Ferreira, M. Santos, E. Bettencourt, A. Giga, A. Cruz, B. Riewald, and K. Bjormdal. 2002. Preliminary results of experiments to evaluate effects of hook type on sea turtle bycatch in the swordfish longline fishery in the Azores.*in* D. Margaritoulis, editor. First Mediterranean Conference on Marine Turtles, 24-25 October 2001.

Bolten, A. B. 1999. Techniques for measuring sea turtles.*in* K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois, and M. Donnelly, editors. Research and Management Techniques for the Conservation of Sea Turtles. IUCN/SSC Marine Turtle Specialist Group Publication No. 4.

Bolten, A. B., L. B. Crowder, M. G. Dodd, S. L. MacPherson, J. A. Musick, B. A. Schroeder, B. E. Witherington, K. J. Long, and M. L. Snover. 2010. Quantifying multiple threats to endangered species: an example from loggerhead sea turtles. Frontiers in Ecology and the Environment.

Bowen, B. W., F. A. Abreu-Grobois, G. H. Balazs, N. Kamezaki, C. J. Limpus, and R. J. Ferl. 1995. Trans-Pacific migrations of the loggerhead turtle (*Caretta caretta*) demostrated with mitochondrial DNA markers. Proceedings of the National Academy of Sciences USA **92**:3731-3734.

Bowen, B. W., A. M. Clark, F. A. Abreu-Grobois, A. Chaves, H. A. Reichart, and R. J. Ferl. 1998. Global phylogeography of the ridley sea turtles (Lepidochelys spp.) as inferred from mitochondrial DNA sequences. Genetica **101**:179-189.

Boyle, M. C., N. N. FitzSimmons, C. J. Limpus, S. Kelez, X. Velez-Zuazo, and M. Waycott. 2009. Evidence for transoceanic migrations by loggerhead sea turtles in the southern Pacific Ocean. Proceedings of the Royal Society B **276**:1993-1999.

Boyle, M. C., and C. J. Limpus. 2008. The stomach contents of post-hatchling green and loggerhead sea turtles in the southwest Pacific: an insight into habitat association. Marine biology **155**:233-241.

Brazner, J. C., and J. McMillan. 2008. Loggerhead turtle (Caretta caretta) bycatch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. Fisheries Research **91**:310-324.

Brewer, D., D. Heales, D. Milton, Q. Dell, G. Fry, B. Venables, and P. Jones. 2006. The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. Fisheries Research **81**:176-188.

Briseño-Dueñas, R. 1998. Variación genética en la región control del ADN mitocondrial de poblaciones de la tortuga golfina Lepidochelys olivacea en el Pacífico oriental y las implicaciones para su conservación. Universidad Autónoma de Sinaloa.

Brito, J. L. 1998. The marine turtle situation in Chile. Pages 12-15 *in* Proceedings of the Seventeenth annual sea turtle symposium. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-SEFSC-415.

Brito, J. L. 2001. Informe preliminar. Tortugas marinas en Chile: Su situacion actual. Taller Nacional de trabajo para definir las lineas de accion prioritarias de un programa para la conservacion de las tortugas marinas. Comision Permanente del Pacifico Sur-CPPS, Fondo Mundial para la Naturaleza-WWF, National Marine Fisheries Service-NMFS, Programa de las Nacionaes Unidas para el Medio Ambiente-PNUMA.

Brongersma, L. D. 1972. European atlantic turtles. Zoologische Verhandelingen (Leiden) **121**:1-318.

Caceres-Bueno, C., J. Alfaro-Shigueto, and J. Mangel. 2010. Green turtle captures in net fisheries in the port of Constante, Peru. 30th Annual Symposium on Sea Turtle Biology and Conservtion, Goa, India.

Camacho-Mosquera, L., D. Amorocho, L. M. Mejia-Ladino, J. D. Palacio-Mejia, and F. Rondon-Gonzales. 2008. Caracterizacion genetica de la colonia reproductiva de la tortuga marina golfina - Lepidochelys olivacea- en el Parque Nacional Natural Gorgona (Pacifico Colombiano) a partir de secuencias de ADN mitocondrial. Boletín de investigaciones marinas y costeras **37**:77-92.

Cardona, L., A. Aguilar, and L. Pazos. 2009. Delayed ontogenic dietary shift and high levels of omnivory in green turtles (Chelonia mydas) from the NW coast of Africa. Marine biology **156**:1487-1495.

Cardona, L., M. Revelles, C. Carreras, M. San Felix, M. Gazo, and A. Aguilar. 2005. Western Mediterranean immature loggerhead turtles: habitat use in spring and summer assessed through satellite tracking and aerial surveys. Marine biology **147**:583-591.

Carranza, A., A. Domingo, and A. Estrades. 2006. Pelagic longlines: A threat to sea turtles in the Equatorial Eastern Atlantic. Biological Conservation **131**:52-57.

Casale, P., D. Freggi, R. Basso, C. Vallini, and R. Argano. 2007. A model of area fidelity, nomadism, and distribution patterns of loggerhead sea turtles (Caretta caretta) in the Mediterranean Sea. Marine biology **152**:1039-1049.

Castro, J., J. De la Cruz, and P. Ramirez. 2010. Captura incidental de tortugas marinas con redes de enmalle frente al litoral de la Region Lambayeque, Enero de 1996 a Dicimebre de 1998. II Congreso de Ciencias del Mar del Perú – CONCIMAR, Piura, Peru.

Catenazzi, A., and M. A. Donnelly. 2007. The Ulva connection: marine algae subsidize terrestrial predators in coastal Peru. OIKOS **116**:75-86.

Caut, S., E. Angulo, and F. Courchamp. 2009. Variation in discrimination factors (Δ15N and Δ13C): the effect of diet isotopic values and applications for diet reconstruction. Journal of Applied Ecology **46**:443-453.

Chaigneau, A., A. Gizolme, and C. Grados. 2008. Mesoscale eddies off Peru in altimeter records: Identification algorithms and eddy spatio-temporal patterns. Progress in Oceanography **79**:106-119.

Chaloupka, M., D. Parker, and G. Balazs. 2004. Modelling post-release mortality of loggerhead sea turtles exposed to the Hawaii-based pelagic longline fishery. MARINE ECOLOGY PROGRESS SERIES **280**:285-293.

Chandler, M. 1991. New records of marine turtles in Chile. Marine Turtle Newsletter **52**:8-11.

Chassin-Noria, O., A. Abreu-Grobois, P. H. Dutton, and K. Oyama. 2004. Conservation genetics of the east Pacific green turtle (Chelonia mydas) in Michoacan, Mexico. Genetica **121**:195-206.

Chavez, F. P., A. Bertrand, R. Guevara-Carrasco, P. Soler, and J. Csirke. 2008. The northern Humboldt Current System: Brief history, present status and a view towards the future. Progress in Oceanography **79**:95-105.

Cliffton, K., D. O. Cornejo, and R. S. Felger. 1982. Sea turtles of the Pacific coast of Mexico. Pages 199-209 *in* K. A. Bjorndal, editor. Biology and Conservation of Sea Turtles. Smithsonian Inst. Press, Washington, DC.

Cline, J. D., and F. A. Richards. 1972. Oxygen deficient conditions and nitrate reduction in the Eastern Tropical North Pacific Ocean. Limnology and Oceanography **17**:885-900.

Conant, T., P. Dutton, T. Eguchi, S. Epperly, C. Fahy, M. Godfrey, S. MacPherson, E. Possardt, B. Schroeder, and J. Seminoff. 2009. Loggerhead sea turtle (Caretta caretta) 2009 status review under the US Endangered Species Act. Report of the Biological Review Team to the National Marine Fisheries Service.

Cornelius, S. E. 1982. Status of sea turtles along the Pacific coast of Middle America. Pages 211-219 *in* K. A. Bjorndal, editor. Biology and Conservation of Sea Turtles. Smithsonian Inst. Press, Washington, DC.

Cornelius, S. E., and D. C. Robinson-Clark. 1986. Post-nesting movements of female olive ridley turtles tagged in Costa Rica. Vida Silvestre Neotropical **1**:12-23.

Crouse, D. T., L. B. Crowder, and H. Caswell. 1987. A Stage-Based Population Model for Loggerhead Sea Turtles and Implications for Conservation. Ecology **68**:1412-1423.

Crowder, L. B., D. T. Crouse, S. Heppell, and T. H. Martin. 1994. Predicting the impact of turtle excluder devices on Loggerhead sea turtle populations. Ecological Applications **4**:437-445.

Crowder, L. B., and S. S. Heppell. 2011. The Decline and Rise of a Sea Turtle: How Kemp's Ridleys Are Recovering in the Gulf of Mexico. Solutions **2**:67-73.

Crowder, L. B., S. R. Hopkins-Murphy, and J. A. Royle. 1995. Effects of turtle excluder devices (TEDs) on Loggerhead sea turtle strandings with implication for conservation. Copeia **1995**:773-779.

Crowder, L. B., and S. A. Murawski. 1998. Fisheries bycatch: implications for management. Fisheries **23**:8-17.

Dalerum, F., and A. Angerbjörn. 2005. Resolving temporal variation in vertebrate diets using naturally occurring stable isotopes. Oecologia **144**:647-658.

Dandonneau, Y., A. Vega, H. Loisel, Y. d. Penhoat, and C. Menkes. 2003. Oceanic Rossby Waves Acting as a "Hay Rake" for Ecosystem Floating By-Products. SCIENCE **302**:1548-1551.

de Paz, N., and J. Alfaro. 2008. Foraging grounds for sea turtles in inshore peruvian waters. Page 88 *in* H. Kalb, A. Rohde, K. Gayheart, and K. Shanker, editors. Proceedings of the Twenty-Fifth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-582.

de Paz, N., P. Diaz, A. Cruz, F. Gomez, and M. Valqui. 2008. Preliminary data of sea turtles bycatch in Peruvian artisanal longline fisheries: distribution & poulation structure. Page 107 *in* K. Dean and M. Lopez, editors. 28th Annual Symposium on Sea Turtle Biology and Conservation. Book of Abstracts.

de Paz, N., J. C. Reyes, and M. Echegaray. 2002. Datos sobre captura, comercio y biologia de tortugas marinas en el area de Pisco - Paracas. Pages 125-129 *in* I Jornada Cientifica "Bases ecologicas y socioeconomicas para el manejo de los recursos vivos de la Reserva Nacional de Paracas", Universidad Nacional Agraria La Molina.

DeNiro, M. J., and S. Epstein. 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochimica et Cosmochimica Acta **42**:495-506.

DeNiro, M. J., and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochimica et Cosmochimica Acta **45**:341-351.

DOF. 2007. Norma Oficial Mexicana MEXICANA NOM-029-PESC-2006, Pesca responsable de tiburones y rayas. Especificaciones para su aprovechamiento.

DOF. 2010. Carta nacional pesquera. México, D. F. 2 de Diciembre de 2010.

Domingo, A., Y. Swimmer, C. Barcelo, M. Pons, P. Miller, and M. Cornes. 2008. Tests of circle vs. "J" hooks in the Uruguayan longline fishery.*in* K. Dean and M. Lopez, editors. 28th Annual Symposium on Sea Turtle Biology and Conservation. Book of Abstracts.

Donoso, M., and P. Dutton. 2010. Sea turtle bycatch in the Chilean pelagic longline fishery in the southeastern Pacific: Opportunities for conservation. Biological Conservation **143**:2672–2684.

Duque-Goodman, F. 1988. Observaciones sobre la captura de tortugas marians por un buque arrastrero camaronero, en aguas someras del Pacifico Colombiano. Trianea **2**:351-372.

Dutton, P. H., G. H. Balazs, R. A. LeRoux, S. K. K. Murakawa, P. Zarate, and L. Sarti M. 2008. Composition of Hawaiian green turtle foraging aggregations: mtDNA evidence for a distinct regional population. Endangered Species Research **5**:37-44.

Dutton, P. H., B. W. Bowen, D. W. Owens, A. R. Barragan, and S. K. Davis. 1999. Global phylogeography of the leatherbak turtle (Dermochelys coriacea). Journal of Zoology, London **284**:397-409.

Dutton, P. H., A. Frey, R. LeRoux, and G. Balazs. 2000. Molecular ecology of leatherbacks in the Pacific. Pages 248-253 *in* N. Pilcher and G. Ismael, editors. Sea Turtles of the Indo-Pacific: Research, Management and Conservation. London ASEAN Academic Press Ltd.

Echevin, V., O. Aumont, J. Ledesma, and G. Flores. 2008. The seasonal cycle of surface chlorophyll in the Peruvian upwelling system: A modelling study. Progress in Oceanography **79**:167-176.

Echwikhi, K., I. Jribi, M. Bradai, and A. Bouain. 2010. Effect of type of bait on pelagic longline fishery-loggerhead turtle interactions in the Gulf of Gabes (Tunisia). Aquatic Conservation: Marine and Freshwater Ecosystems **20**:525–530.

Eckert, S. A. 2008. Promoting the survival of leatherback turtles in the Greater Atlantic Ocean by eliminating capture and mortality associated with coastal gillnets in Trinidad. Final Report, February 2008.

Eckert, S. A., and J. Gearhart. 2008. Promoting the survival of leatherback turtles in the Greater Atlantic Ocean by eliminating capture and mortality associated with coastal gillnets in Trinidad. Final Report 2008.

Eckert, S. A., and J. Gearhart. 2009. Final report 2009: Reducing leatherback sea turtle bycatch by Trinidad's artisanal fishing industry.

Eckert, S. A., J. Gearhart, and K. L. Eckert. 2008. Reducing leatherback sea turtle bycatch in the surface drift-gillnet fishery in Trinidad. Bycatch Communication Network Newsletter **8**:2-6.

Eckert, S. A., and L. Sarti. 1997. Distant fisheries implicated in the loss of the world's largest leatherback nesting population. Marine Turtle Newsletter **78**:2-7.

Eguchi, T., T. Gerrodette, R. L. Pitman, J. A. Seminoff, and P. H. Dutton. 2007. At-sea density and abundance estimates of the olive ridley turtle Lepidochelys olivacea in the eastern tropical Pacific. Endangered Species Research **3**:191-203.

Elias, E., and R. Castro. 2010. Crucero de investigacion pesca experimental del recurso dorado (Coryphaena hippurus) en la costa Ecuatoriana durante Marzo de 2010. Informe Ejecutivo. Instituto Nacional de Pesca del Ecuador.

Epperly, S. 2003. Fisheries-Related Mortality and Turtle Excluder Devices (TEDs). The Biology of Sea Turtles, Volume II. CRC Press.

Estrada, J. A., M. Lutcavage, and S. R. Thorrold. 2005. Diet and trophic position of Atlantic bluefin tuna (Thunnus thynnus) inferred from stable carbon and nitrogen isotope analysis. Marine Biology **147**:37-45.

Farrell, J. W., T. F. Pedersen, S. E. Calvert, and B. Nielsen. 1995. Glacial-interglacial changes in nutrient utilization in the equatorial Pacific Ocean. NATURE **377**.

Ferreira, R. L., H. R. Martins, A. A. Silva, and A. B. Bolten. 2001. Impact of swordfish fisheries on sea turtles in the Azores. Arquipelago. Life and Marine Sciences **18A**:75-79.

Frazier, J., R. Arauz, J. Chevalier, A. Formia, J. Fretey, M. H. Godfrey, R. Márquez-M., B. Pandav, and K. Shanker. 2007. Human-turtle interactions at sea. Pages 253-295 *in* P. T. Plotkin, editor. Biology and Conservation of Ridley Sea Turtles. Johns Hopkins University Press, Baltimore, MD.

Frazier, J. G., and J. L. Brito. 1990. Incidental capture of marine turtles by the swordfish fishery at San Antonio, Chile. Marine Turtle Newsletter **49**.

Frick, M., K. Williams, A. Bolten, K. Bjorndal, and H. Martins. 2009. Foraging ecology of oceanic-stage loggerhead turtles Caretta caretta. Endangered Species Research **9**:91-97.

Fritts, T. H. 1981. Pelagic feeding habits of turtles in the Eastern Pacific. Marine Turtle Newsletter **17**.

Fry, B. 2006. Stable isotope ecology. Springer.

Fuenzalida, R., W. Schneider, J. Garcés-Vargas, L. Bravo, and C. Lange. 2009. Vertical and horizontal extension of the oxygen minimum zone in the eastern South Pacific Ocean. Deep Sea Research Part II: Topical Studies in Oceanography **56**:992-1003.

Gaos, A. R., F. A. Abreu-Grobois, J. Alfaro-Shigueto, D. Amorocho, R. Arauz, A. Baquero, R. Briseño, D. Chacón, C. Dueñas, C. Hasbún, M. Liles, G. Mariona, C. Muccio, J. P. Muñoz, W. J. Nichols, M. Peña, J. A. Seminoff, M. Vásquez, J. Urteaga, B. Wallace, I. L. Yañez, and P. Zárate. 2010. Signs of hope in the eastern Pacific: international collaboration reveals encouraging status for the severely depleted population of hawksbill turtles Eretmochelys imbricata. Oryx **44**:595-601.

Garrison, L. P. 2005. Estimated bycatch of marine mamals and turtles in the U.S. Atlantic pelagic longline fleet during 2004. NOAA Technical Memorandum NMFS-SEFSC-531.

Gearhart, J., S. A. Eckert, and C. E. Bergmann. 2009. Reducing leatherback (Dermochelys coriacea) sea turtle bycatch in the surface gillnet fisheries of Trinidad, West Indies. Pages 47-48 *in* E. Gilman, editor. Proceedings of the Technical Workshop on Mitigating Sea Turtle Bycatch in Coastal Net Fisheries. IUCN, Western Pacific Regional Fishery Management Council, Southeast Asian Fisheries Development Center, Indian Ocean - South-East Asian Marine Turtle MoU, U.S. National Marine Fisheries Service, Southeast Fisheries Science Center, Gland, Switzerland; Honolulu, Bangkok, and Pascagoula, USA.

Gilman, E., J. Gearhart, B. Price, S. Eckert, H. Milliken, J. Wang, Y. Swimmer, D. Shiode, O. Abe, S. H. Peckham, M. Chaloupka, M. Hall, J. Mangel, J. Alfaro-Shigueto, P. Dalzell, and A. Ishizaki. 2009. Mitigating sea turtle by-catch in coastal passive net fisheries. Fish and Fisheries.

Gilman, E., D. Kobayashi, T. Swenarton, N. Brothers, P. Dalzell, and I. Kinan-Kelly. 2007. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biological Conservation **139**:19-28.

Gilman, E. L., J. W. Watson, C. Boggs, S. P. Epperly, E. Zollett, S. Beverly, H. Nakano, Y. Swimmer, K. Davis, D. Shiode, P. Dalzell, and I. Kinan. 2005. Review of the state of the knowledge for reducing sea turtle bycatch in pelagic longline gear. Western Pacific Regional Fishery Management Council.

Giron, L. E. 2006. Legislation that protects sea turtles in Guatemala. Pages 121-122 *in* M. Frick, A. Panagopoulou, A. F. Rees, and K. Williams, editors. Book of abstracts. Twenty Sixth Annual Symposium on sea turtle biology and conservation., Creta, Greece.

Godley, B., S. Richardson, A. Broderick, M. Coyne, F. Glen, and G. Hays. 2002. Long-term satellite telemetry of the movements and habitat utilisation by green turtles in the Mediterranean. Ecography **25**:352-362.

Godley, B. J., D. R. Thompson, S. Waldron, and R. W. Furness. 1998. The trophic status of marine turtles as determined by stable isotope analysis. MARINE ECOLOGY PROGRESS SERIES **166**:277-284.

Gomez-Cubillos, M. C., and D. Amorocho. 2008. Impacto de la actividad pesquera artesanal en las poblaciones de tortugas marinas presentes en la zona de influencia marino-costera del Parque Nacional Natural Gorgona, Pacifico Colombiano. Pages 50-57 *in* S. Kelez, F. van Oordt, N. de Paz, and K. Forsberg, editors. Libro de resumenes. II Simposio de tortugas marinas en el Pacifico Sur Oriental.

Gomez-Cubillos, M. C., D. F. Amorocho, and L. A. Merizalde. 2008. Reduccion de la captura incidental de tortugas marinas en redes de pesca y espinel en la costa del Pacifico Colombiano. Reporte Tecnico Final presentado a Conservacion Internacional Colombia. Centro de Investigacion para el manejo ambiental y el desarrollo.

Gonzales, E. 2010. Peru, Informe Anual 2010. Convencion Interamericana para la Proteccion y Conservacion de las Tortugas Marinas.

Gonzalez-Carman, V., V. Falabella, I. Bruno, L. Diaz, G. Svendsen, K. Alvarez, D. Albareda, H. Mianzan, and C. Campagna. 2011. Satellite tracking of small juvenile green turtles (Chelonia mydas) in Argentina. Thirty-first Annual Symposium on Sea Turtle Biology and Conservation.

Graham, B., B. Popp, B. Fry, R. Olson, V. Allain, and F. Galvan-Magana. 2008. Marine isoscapes: determining residency and net movements of top predators in the equatorial Pacific Ocean using bulk and compound-specific stable isotope analysis. Isoscapes 2008, Santa Barbara.

Green, D., and F. Ortiz-Crespo. 1982. Status of sea turtle populations in the Central Eastern Pacific. Pages 221-233 *in* K. A. Bjorndal, editor. Biology and conservation of sea turtles. Smithsonian Inst. Press, Washington, DC.

Gutiérrez, R. 2004. Crucero de pesca comercial de camarón de profundidad Heterocarpus affinis, en el Pacífico nicaragüense. Enero - febrero 2004. CIPA.

Gutiérrez, R. 2009. Resultados del primer monitoreo realizado al camarón costero del Pacífico de Nicaragua. Noviembre - Diciembre 2008. Proyecto apoyo de Noruega al sector pesqueri de Nicaragua. CIPA/INPESCA.

Hall, M. A., N. Vogel, and M. Orozco. 2006. Eastern Pacific Regional Sea Turtle Program. Final project report, June 2006, to the Western Pacific Regional Fishery Management Council.

Hatase, H., K. Omuta, and K. Tsukamoto. 2010. Oceanic residents, neritic migrants: a possible mechanism underlying foraging dichotomy in adult female loggerhead turtles (Caretta caretta). Marine biology **157**:1337-1342.

Hatase, H., K. Sato, M. Yamaguchi, K. Takahashi, and K. Tsukamoto. 2006. Individual variation in feeding habitat use by adult female green sea turtles (Chelonia mydas): are they obligately neritic herbivores? Oecologia **149**:52-64.

Hatase, H., N. Takai, Y. Matsuzawa, W. Sakamoto, K. Omuta, K. Goto, N. Arai, and T. Fujiwara. 2002. Size-related differences in feeding habitat use of adult female loggerhead turtles *Caretta caretta* around Japan determined by stable isotope analyses and satellite telemetry. MARINE ECOLOGY PROGRESS SERIES **233**:273-281.

Hays-Brown, C., and W. M. Brown. 1982. Status of sea turtles in the Southeastern Pacific: Emphasis on Peru. Pages 235-240 *in* K. A. Bjorndal, editor. Biology and conservation of Sea Turtles. Smithsonian Institution Press.

Hays, G., S. Akesson, A. Broderick, F. Glen, B. Godley, P. Luschi, C. Martin, J. Metcalfe, and F. Papi. 2001. The diving behaviour of green turtles undertaking oceanic migration to and from Ascension Island: dive durations, dive profiles and depth distribution. Journal of Experimental Biology **204**:4093-4098.

Helly, J. J., and L. A. Levin. 2004. Global distribution of naturally occurring marine hypoxia on continental margins. Deep Sea Research Part I: Oceanographic Research Papers **51**:1159-1168.

Henwood, T. A., and W. E. Stuntz. 1987. Analysis of sea turtle captures and mortalities during commercial shrimp trawling. Fishery Bulletin of the Fish and Wildlife Service **85**:813-817.

Heppell, S. S., S. A. Heppell, A. J. Read, and L. B. Crowder. 2005. Effects of fishing on long-lived marine organisms. Pages 211-231 *in* E. A. Norse and L. B. Crowder, editors. Marine Conservation Biology: The science of maintaining the sea's biodiversity. IslandPress, Washington. Covelo. London.

Herrera, A. F. 2001. La pesca de arrastre del camaron en Costa Rica y el impacto sobre el ambiente marino: Evaluacion de la percepcion de los cambios tecnologicos y la actitud para modificar las practicas pesqueras. . Pages 286-294 *in* FAO, editor. Tropical shrimp fisheries and their impact on living resources. FAO Fisheries Circular No. 974, Rome, Italy.

Hirth, H. F. 1997. Synopsis of the biological data on the green turtle Chelonia mydas (Linnaeus 1758). Fish and Wildlife Service, US Dept. of the Interior.

Hobson, K. A., and R. G. Clark. 1992. Assesing avian diet using stable isotopes. 2. Factor influencing diet-tissue fractionation. Condor **94**:189-197.

Hobson, K. A., J. F. Piatt, and J. Pitocchelli. 1994. Using Stable Isotopes to Determine Seabird Trophic Relationships. Journal of Animal Ecology **63**:786-798.

IATTC. 2011. Authorized large longline. Vessel database.

IFOP. 2004. Caracteristicas de la Pesqueria Pez Espada.

INAPESCA/WWF. 2009. Dinámica de la pesca ribereña palangrera de Teacapán (Sinaloa, México) al operar anzuelos circulares 13/0. 25 p. Disponible en: http://www.wwf.org.mx.

INP. 2000a. La pesqueria de pez espada Oceano Pacifico. Instituto Nacional de la Pesca, Mexico.

INP. 2000b. Pesquerias del Pacifico, Camaron del Oceano Pacifico. Instituto Nacional de la Pesca, Mexico.

INPESCA. 2009. Anuario pesquero y de acuicultura en Nicaragua 2008.

IUCN. 2010. IUCN Red List of Threatened Species. Version 2010.2. http://www.iucnredlist.org Downloaded on 29 June 2010.

Jaeger, A., M. Connan, P. Richard, and Y. Cherel. 2010. Use of stable isotopes to quantify seasonal changes of trophic niche and levels of population and individual specialisation in seabirds. MARINE ECOLOGY PROGRESS SERIES **401**:269-277.

Juarez, R., and C. Muccio. 1997. Sea turtle conservation in Guatemala. Marine Turtle Newsletter **77**:15-17.

Kamezaki, N., Y. Matsuzawa, O. Abe, H. Asakawa, T. Fujii, K. Goto, S. Hagino, M. Hayami, M. Ishii, T. Iwamoto, T. Kamata, H. Kato, J.-I. Kodama, Y. Kondo, I. Miyawaki, K. Mizobuchi, Y. Nakamura, Y. Nakashima, H. Naruse, K. Omuta, M. Samejima, H. Suganuma, H. Takeshita, T. Tanaka, T.-i. Toji, M. Uematsu, A. Yamamoto, T. Yamato, and I. Wakabayashi. 2003. Loggerhead turtles nesting in Japan. Pages 210-217 *in* A. B. Bolten and B. E. Witherington, editors. Loggerhead sea turtles. Smithsonian Books, Washington.

Kelez, S., X. Velez-Zuazo, and C. Manrique. 2003. New evidence on the loggerhead sea turtle Caretta caretta (Linnaeus 1758) in Peru. Ecologia Aplicada **2**:141-142.

Kelez, S., X. Velez-Zuazo, and C. Manrique. 2010. Captura incidental de tortugas marinas en palangre en el Perú: 8 años de monitoreo. II Congreso de Ciencias del Mar del Perú – CONCIMAR, Piura, Peru.

Kopitsky, K. L. 2002. Pelagic ecology of olive ridley sea turtles, Lepidochelys olivacea, in the eastern tropical Pacific. University of Delaware.

Largacha, E., M. Parrales, L. Rendón, V. Velásquez, M. Orosco, and M. Hall. 2005. Working with the Ecuatorian fishing community to reduce the mortality of sea turtles in long lines: The first year March 2004-March 2005. Western Pacific Regional Fishery Management Council.

Laurent, L., J. A. Camiñas, P. Casale, M. Deflorio, G. De Metrio, A. Kapantagakis, D. Margaritoulis, C. Y. Politou, and J. Valeiras. 2001. Assessing marine turtle bycatch in European drifting longline and trawl fisheries for identifying fishing regulations. Project-EC-DG Fisheries 98-008. Joint project of BIOINSIGHT, IEO, IMBC, STPS and University of Bari, Villeurbanne.

Lewison, R. L., S. A. Freeman, and L. B. Crowder. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecology Letters **7**:221-231.

Liles, M. J., M. V. Jandres, W. A. López, G. I. Mariona, C. R. Hasbún, and J. A. Seminoff. 2011. Hawksbill turtles *Eretmochelys imbricata* in El Salvador: nesting distribution and mortality at the largest remaining nesting aggregation in the eastern Pacific Ocean. Endangered Species Research **14**:23-30.

Limpus, C. J. 1985. A study of the loggerhead sea turtle, Caretta caretta, in Eastern Australia. University of Queensland.

Limpus, C. J. 2008. A biological review of Australian marine turtles. 1. Loggerhead turtle *Caretta caretta* (Linnaeus). Environmental Protection Agency.

Limpus, C. J., and D. J. Limpus. 2003. Loggerhead turtles in the Equatorial and Southern Pacific Ocean: A species in decline. Pages 199-209 *in* A. B. Bolten and B. E. Witherington, editors. Loggerhead Sea Turtles. Smithsonian Institution Press, Washington, DC.

Liu, K. K., and I. R. Kaplan. 1989. The eastern tropical Pacific as a source of ^{15}N-enriched nitrate in seawater off southern California. Limnology and Oceanography **34**:820-830.

Lopez-Castro, M. C., and A. Rocha-Olivares. 2005. The panmixia paradigm of eastern Pacific olive ridley turtles revised: consequences for their conservation and evolutionary biology. Molecular ecology **14**:3325-3334.

Lopez, J. A. 2009. Revisión de la magnitud, importancia socioeconómica y actividades nacionales relacionadas con la pesca de arrastre del camarón. Proyecto “Reduccion del impacto ambiental por la pesca de arrastre de camaron tropical a traves de la introduccion de las tecnologias para reduccion de la captura incidental y cambio de gestion" (REBYC II).

Lutcavage, M., and P. L. Lutz. 1997. Diving physiology. Pages 277-296 *in* P. L. Lutz and J. A. Musick, editors. The biology of sea turtles. CRC Press.

Lutcavage, M. E., and P. L. Lutz. 1991. Voluntary diving metabolism and ventilation in the loggerhead sea turtle. Journal of Experimental Marine Biology and Ecology **147**:287-296.

Macko, S. A., M. L. F. Estep, M. H. Engel, and P. E. Hare. 1986. Kinetic fractionation of stable nitrogen isotopes during amino acid transamination. Geochimica et Cosmochimica Acta **50**:2143-2146.

Majluf, P., E. A. Babcock, J. C. Riveros, M. A. Schreiber, and W. Alderete. 2002. Catch and bycatch of sea birds and marine mammals in the small-scale fishery of Punta San Juan, Peru. Conservation Biology **16**:1333-1343.

Maldonado, D., H. Peckham, and W. J. Nichols. 2006. Reducing the bycatch of loggerhead turtle (Caretta caretta) in Baja California Sur: Experimental modification of gillnets for fishing halibut. Pages 59- *in* I. Kinan, editor. Proceedings of the Second Western Pacific Sea Turtle Cooperative Research and Management Workshop. Volume II: North Pacific Loggerhead Sea Turtles. March 2-3, 2005, Honolulu, HI. Western Pacific Regional Fishery Management Council: Honolulu, HI, USA.

Mansfield, K. L., V. S. Saba, J. A. Keinath, and J. A. Musick. 2009. Satellite tracking reveals a dichotomy in migration strategies among juvenile loggerhead turtles in the Northwest Atlantic. Marine biology **156**:2555-2570.

MARENA. 2007. Estrategia para la conservación de tortugas marinas en el Pacífico de Nicaragua. MARENA.

Marquez, R. 1990. FAO Species Catalogue. Vol. 11 Sea turtle of the World. An annotated and ilustrated catalogue of sea turtle species known to date.

Martinez, J. 2010. Guatemala, Informe Anual 2010. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

McClellan, C., J. Braun-McNeill, L. Avens, B. Wallace, and A. Read. 2010. Stable isotopes confirm a foraging dichotomy in juvenile loggerhead sea turtles. Journal of Experimental Marine Biology and Ecology **387**:44-51.

McClellan, C. M., and A. J. Read. 2007. Complexity and variation in loggerhead sea turtle life history. Biology Letters **3**:592-594.

McClelland, J., and J. Montoya. 2002. Trophic relationships and the nitrogen isotopic composition of amino acids in plankton. Ecology **83**:2173-2180.

McDonald, D., and P. Dutton. 1990. Fibropapillomas on sea turtles in San Diego Bay, California. Marine Turtle Newsletter **51**:9-10.

Mejuto, J., B. Garcia-Cortes, A. Ramos-Cartelle, and J. Ariz. 2007. Preliminary overall estimations of bycatch landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Pacific Ocean and interactions with marine turtles and sea birds: years 1990-2005. Working group on bycatch. 6th Meeting. La Jolla, California (USA) 9-10 Februaryo 2007. Document BYC-6-INF A. Inter-American Tropical Tuna Commission.

Michener, R. H., and L. Kaufman. 2007. Stable isotope ratios as tracers in marine food webs: An update. Pages 238-282 *in* R. Michener and K. Lajtha, editors. Stable isotopes in ecology and environmnetal sciences. Blackwell Publishing.

Miller, J. D. 1997. Reproduction in sea turtles. Pages 51-81 *in* P. L. Lutz and J. A. Musick, editors. The biology of sea turtles. CRC Press.

Minagawa, M., and E. Wada. 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between d^{15}N and animal age. Geochimica et Cosmochimica Acta **48**:1135-1140.

Mituhasi, T., C. E. Bergmann, M. Parrales, J. Calderon, A. Cruz, C. Boggs, M. McCracken, and M. Hall. 2008. Experiments in the Eastern Pacific to assess the effect of a new hook design on reduction of incidental catches of sea turtles. Page 205 *in* Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-569.

Montecino, V., and C. B. Lange. 2009. The Humboldt Current System: Ecosystem components and processes, fisheries, and sediment studies. Progress in Oceanography **83**:65-79.

Montoya, J. P. 2007. Natural abundances of 15N in marine planktonic ecosystems. Pages 176-201 *in* R. Michener and K. Lajtha, editors. Stable isotopes in ecology and environmental science. Blackwell Publishing.

Mortimer, J. A., and M. Donnelly. 2008. Marine Turtle Specialist Group, 2007 IUCN Red List Status Assessment, Hawksbill Turtle (Eretmochelys imbricata).

Mug, M., M. Hall, C. Lennert-Cody, S. Andraka, T. Mituhasi, A. Segura, J. Calderon, N. de Paz, S. Kelez, S. Salaverria, S. Perez, R. Sanchez, L. Pacheco, M. Jolon, M. Parrales, L. Rendon, S. Siu, D. Barahona, Y. Hara, and A. Cruz. 2007a. Understanding and mitigating the incidental mortality of sea turtles in the long-line fisheries of the Eastern Pacific. Page 37 *in* CREA, editor. VII Simposio sobre medio ambiente: Estado Actual y Perspectivas de la Investigacion y Conservacion de las Tortugas Marinas en las Costas del Pacifico Sur Oriental, Antofagasta, Chile.

Mug, M., M. Hall, T. Mituhasi, A. Segura, N. Vogel, and S. Andraka. 2007b. An Observer Program for marine turtle by-catch mitigation across the Eastern Pacific Ocean. Pages 344-346 *in* Proceedings of the 5th International Fisheries Observer Conference - 15 - 18 May 2007, Victoria, British Columbia, Canada. NSW Department of Primary Industries, Cronulla Fisheries Research Centre of Excellence, Cronulla, Australia, 412 pp. ISBN 978 0 7347 1861 7.

Mug, M., M. Hall, and N. Vogel. 2008. Bycatch initiative: Eastern Pacific Programme. A vehicle towards sustainable fisheries. Progress report of fishing experiments with modified gear (2004-2007).

Newsome, S. D., M. T. Tinker, D. H. Monson, O. T. Oftedal, K. Ralls, M. M. Staedler, M. L. Fogel, and J. A. Estes. 2009. Using stable isotopes to investigate individual diet specialization in California sea otters (Enhydra lutris nereis). Ecology **90**:961-974.

Nichols, W. J. 2004. Varamientos, captura incidental, y aprovechamiento: patrones de mortalidad en tortugas marinas a lo largo de la Peninsula de Baja California, Mexico (1994-1999). Pages 29-51 *in* UABCS/WWF, editor. Taller de Conservacion de tortugas marinas en el Noroeste Mexicano.

NMFS, and U.S. Fish and Wildlife Service. 1998. Recovery Plan for U.S. Pacific Populations of the East Pacific Green Turtle (Chelonia mydas). National Marine Fisheries Service, Silver Spring, MD.

Olson, P. A., R. L. Pitman, L. T. Ballance, K. R. Hough, P. Dutton, and S. B. Reilly. 2001a. Summary of seabird, marine turtle, and surface fauna data collected during a survey in the Eastern Tropical Pacific Ocean, July 28 - December 9, 1999. NOAA-TM-NMFS-SWFSC-301.

Olson, P. A., R. L. Pitman, L. T. Ballance, K. R. Hough, P. H. Dutton, and S. B. Reilly. 2001b. Summary of seabird, marine turtle, and surface fauna data collected during a survey in the Eastern Tropical Pacific Ocean, July 28 - December 9, 2000. NOAA-TM-NMFS-SWFSC-304.

Olson, P. A., R. L. Pitman, L. T. Ballance, and S. B. Reilly. 2000. Summary of seabird, marine turtle, and surface fauna data collected during a survey in the Eastern Tropical Pacific Ocean, July 30 - December 9, 1998. NOAA-TM-NMFS-SWFSC-298.

Ordonez, H., and K. Duchez. 2007. Guatemala, Informe Anual 2007. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

Pacheco, L., A. Segura, M. Mug, S. Andraka, T. Mituhasi, and M. Hall. 2007. Addressing the sea turtle by catches in the longline fisheries: The Panamanian observer program in the eastern pacific. Page 367 *in* T. A. McVea and S. J. Kennelly, editors. Proceedings of the 5th International Fisheries Observer Conference - 15 - 18 May 2007, Victoria, British Columbia, Canada. NSW Department of Primary Industries, Cronulla Fisheries Research Centre of Excellence, Cronulla, Australia, 412 pp. ISBN 978 0 7347 1861 7.

Pajuelo, M., K. A. Bjorndal, J. Alfaro-Shigueto, J. A. Seminoff, J. C. Mangel, and A. B. Bolten. 2010. Stable isotope variation in loggerhead turtles reveals Pacific–Atlantic oceanographic differences. Mar Ecol Prog Ser **417**:277-285.

Palma, S. 1994. Distribución y abundancia de larvas de langostino colorado Pleuroncodes monodon frente a la costa de Concepción, Chile. Investigacion Marina, Valparaiso **22**:13-29.

Parker, D., G. Balazs, S. Murakawa, and J. J. Polovina. 2004. Post-hooking survival of sea turtles taken by pelagic longline fishing in the North Pacific.*in* M. S. Coyne and R. D. Clark, editors. Proceedings of the Twenty-first Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-528.

Parker, D. M., W. J. Cooke, and G. H. Balazs. 2005. Diet of oceanic loggerhead sea turtles (Caretta caretta) in the central North Pacific. Fishery Bulletin **103**:142-152.

Parnell, A. C., R. Inger, S. Bearhop, and A. L. Jackson. 2010. Source Partitioning Using Stable Isotopes: Coping with Too Much Variation. PLoS One **5**:e9672.

Peckham, H., and W. J. Nichols. 2006. An integrated approach to reducing mortality of north pacific loggerhead turtles in Baja California Sur, Mexico. Pages 49-57 *in* I. Kinan, editor. Proceedings of the Second Western Pacific Sea Turtle Cooperative Research and Management Workshop. Volume II: North Pacific Loggerhead Sea Turtles. March 2-3, 2005, Honolulu, HI. Western Pacific Regional Fishery Management Council: Honolulu, HI, USA.

Peckham, H. S., D. Maldonado-Diaz, V. Koch, A. Mancini, A. Gaos, M. T. Tinker, and W. J. Nichols. 2008. High mortality of loggerhead turtles due to bycatch, human consumption and strandings at Baja California Sur, Mexico, 2003 to 2007. Endangered Species Research **5**:171-183.

Peckham, H. S., D. Maldonado, A. Walli, G. Ruiz, and L. B. Crowder. 2007. Small-scale fisheries bycatch jeopardizes endangered Pacific loggerhead turtles. PLoS One **10**:e1041.

Peckham, S. H., D. Maldonado-Diaz, J. Lucero, A. Fuentes-Montalvo, and A. R. Gaos. 2009. Loggerhead bycatch and reduction off the Pacific Coast of Baja California Sur, Mexico. Pages 51-53 *in* E. Gilman, editor. Proceedings of the Technical Workshop on Mitigating Sea Turtle Bycatch in Coastal Net Fisheries. IUCN, Western Pacific Regional Fishery Management Council, Southeast Asian Fisheries Development Center, Indian Ocean - South-East Asian Marine Turtle MoU, U.S. National Marine Fisheries Service, Southeast Fisheries Science Center, Gland, Switzerland; Honolulu, Bangkok, and Pascagoula, USA.

Pelletier, D., D. Roos, and S. Ciccione. 2003. Oceanic survival and movements of wild and captive-reared immature green turtles (Chelonia mydas) in the Indian Ocean. Aquating Living Resources **16**:35-41.

Peñaflores, M. C. 2007. Informe de la temporada de anidaciones de tortugas marinas en las playas de Escobilla, Morro Ayuta y Barra de la Cruz, temporada 2006-2007. Informe Tecnico Final. Centro Mexicano de la Tortuga, Playa La Escobilla, Morro Ayuta y Barra de la Cruz, Oficina Regional Pacifico Sur.

Petersen, S. L., M. B. Honig, P. G. Ryan, R. Nel, and L. G. Underhill. 2009. Turtle bycatch in the pelagic longline fishery off southern Africa. African Journal of Marine Science **31**:87-96.

Peterson, B., and B. Fry. 1987. Stable isotopes in ecosystem studies. Annual review of ecology and systematics **18**:293-320.

Phillips, D. L., and J. W. Gregg. 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia **136**:261-269.

Phillips, R. A., S. Bearhop, R. A. R. Mcgill, and D. A. Dawson. 2009. Stable isotopes reveal individual variation in migration strategies and habitat preferences in a suite of seabirds during the nonbreeding period. Oecologia **160**:795-806.

Pinedo, M. C., & T. Polacheck. 2004. Sea turtle by-catch in pelagic longline sets off southern Brazil. Biological Conservation **119**:335-339.

Plotkin, P. T. 1996. Occurrence and diet of juvenile loggerhead sea turtles, Caretta caretta, in the northwestern Gulf of Mexico. Chelonian Conservation and Biology **2**:78-79.

Polovina, J. J., G. H. Balazs, E. A. Howell, D. M. Parker, M. P. Seki, and P. H. Dutton. 2004. Forage and migration habitat of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the Central North Pacific Ocean. Fisheries Oceanography **13**:36-51.

Polovina, J. J., E. A. Howell, D. M. Parker, and G. H. Balazs. 2003. Dive-depth distribution of loggerhead (Caretta caretta) and olive ridley (Lepidochelys olivacea) sea turtles in the central North Pacific: Might deep longline sets catch fewer turtles? Fishery Bulletin **101**:189-193.

Polovina, J. J., D. R. Kobayashi, D. M. Parker, M. P. Seki, and G. H. Balazs. 2000. Turtles on the edge: movement of loggerhead turtles (Caretta caretta) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997-1998. Fisheries Oceanography **9**:71-82.

Popp, B. N., B. S. Graham, R. J. Olson, C. C. S. Hannides, M. J. Lott, G. A. Lopez-Ibarra, F. Galván-Magaña, and B. Fry. 2007. Insight into the trophic ecology of yellowfin tuna, Thunnus albacares, from compound-specific nitrogen isotope analysis of proteinaceous amino acids. Pages 173-190 *in* T. E. Dawson and R. T. W. Siegwolf, editors. Stable isotopes as indicators of ecological change.

PRETOMA. 2009. U.S. Halts Costa Rican Shrimp Shipments For Failure To Protect Sea Turtles. Press Releases 2009.

Price, B., and C. van Salisbury. 2007. Low-Profile Gillnet Testing in the Deep Water Region of Pamlico Sound, NC. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC, USA.

Pritchard, P. C. H. 1980. Dermochelys coriacea. Catalogue of American Amphibians and Reptiles **238**:1-4.

Pritchard , P. C. H. 1997. Evolution, phylogeny, and current status. Pages 1-28 *in* P. L. Lutz and J. A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton, FL.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL: http://www.R-project.org.

Ram, P. S., S. A. Rao, and Y. Sadhuram. 2009. Drifting and Meandering of Olive Ridley Sea Turtles in the Bay of Bengal: Role of Oceanic Rossby Waves. Marine Geodesy **32**:372-378.

Read, A. J. 2007. Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. Biological Conservation **135**:155-169.

Reich, K., K. Bjorndal, and A. Bolten. 2007. The ‘lost years’ of green turtles: using stable isotopes to study cryptic lifestages. Biology Letters **3**:712.

Reich, K., K. Bjorndal, and C. Martínez del Rio. 2008. Effects of growth and tissue type on the kinetics of 13 C and 15 N incorporation in a rapidly growing ectotherm. Oecologia **155**:651-663.

Reich, K. J., K. A. Bjorndal, M. G. Frick, B. E. Witherington, C. Johnson, and A. B. Bolten. 2010. Polymodal foraging in adult female loggerheads (Caretta caretta). Marine biology **157**:113-121.

Reina, R., P. Mayor, J. Spotila, R. Piedra, and F. Paladino. 2002. Nesting ecology of the leatherback turtle, Dermochelys coriacea, at Parque Nacional Marino Las Baulas, Costa Rica: 1988–89 to 1999–2000. Copeia **2002**:653-664.

Revelles, M., L. Cardona, A. Aguilar, A. Borrell, G. Fernández, and M. San Félix. 2007a. Stable C and N isotope concentration in several tissues of the loggerhead sea turtle Caretta caretta from the western Mediterranean and dietary implications. Scientia Marina **71**:87-93.

Revelles, M., L. Cardona, A. Aguilar, and G. Fernández. 2007b. The diet of pelagic loggerhead sea turtles (Caretta caretta) off the Balearic archipelago (western Mediterranean): relevance of long-line baits. Journal of the Marine Biological Association of the UK **87**:805-813.

Revelles, M., L. Cardona, A. Aguilar, M. San Félix, and G. Fernández. 2007c. Habitat use by immature loggerhead sea turtles in the Algerian Basin (western Mediterranean): swimming behaviour, seasonality and dispersal pattern. Marine biology **151**:1501-1515.

Revelles, M., J. Isern-Fontanet, L. Cardona, M. San Félix, C. Carreras, and A. Aguilar. 2007d. Mesoscale eddies, surface circulation and the scale of habitat selection by immature loggerhead sea turtles. Journal of Experimental Marine Biology and Ecology **347**:41-57.

Rice, M. R., and G. H. Balazs. 2008. Diving behavior of the Hawaiian green turtle (Chelonia mydas) during oceanic migrations. Journal of Experimental Marine Biology and Ecology **356**:121-127.

Rico-Mejia, F., and M. Rueda. 2007. Evaluación experimental bioeconómica de cambios en la tecnología de captura de camarón con redes de arrastre en aguas someras del Pacífico colombiano. Boletín de investigaciones marinas y costeras **36**:79-109.

Rodríguez-Valencia, J. A., M. Á. Cisneros-Mata, H. Ortega-Casillas, I. Castro-Leal, G. Rodríguez-Domínguez, A. Chávez-Castro, and L. G. Rodríguez-Delgado. 2008. Anzuelos circulares como opción para reducir la captura incidental en las operaciones pesqueras de los palangreros ribereños de Sinaloa (México). Ciencia Pesquera **16**:67-78.

Rojas, P., and L. A. Zapata. 2006. Peces demersales del Parque Nacional Natural Gorgona y su área de influencia, Pacífico colombiano. Biota colombiana **7**:211-244.

Rosales, C. A., M. Vera, and J. Llanos. 2010. Varamientos y captura incidental de tortugas marinas en el litoral de Tumbes, Perú. Revista Peruana de Biologia **17**:293-301.

Rubenstein, D. R., and K. A. Hobson. 2004. From birds to butterflies: animal movement patterns and stable isotopes. Trends in Ecology & Evolution **19**:256-263.

Ruiz-Slater, M., and J. Acevedo. 2006. Reporte final del proyecto "Estimación de la Tasa de Captura Incidental de Tortugas Marinas en las Actividades de Pesca Ribereña en la Costa de Michoacán". Gobierno de Michoacán, Fondo Ecológico Banamex.

Ryder, C. E., T. A. Conant, and B. A. Schroeder. 2006. Report of the workshop on marine turtle longline post-interaction mortality. NOAA Technical Memorandum NMFS-OPR.

Saino, T., and A. Hattori. 1987. Geographical variation of the water column distrubution of suspended particulate organic nitrogen and its ^{15}N natural abundance in the Pacific and its marginal seas. Deep Sea Research Part A. Oceanographic Research Papers **34**:807-827.

Salaverría Reyes, A. 1998. Base de Datos. Cruceros de Investigación para los recursos de pargo y camarones de la Costa Pacifica de Guatemala (1996-1998). Guatemala: USAC-CEMA.

Sales, G., B. Giffoni, F. N. Fiedler, V. G. Azevedo, J. E. Kotas, J. Y. Swimmer, and L. Bugoni. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems **20**:428-436.

Santana, H. 2008. Captura incidental obtenida durante la experimentacion de redes de arrastre para camaron con y sin excluidor de tortugas marinas. Datos generados por Programa Nacional de Evaluación de la Captura Incidental y del Impacto Técnico y Económico del Uso de los Excluidores de Tortugas Marinas del Instituto Nacional de la Pesca de México.

Santana, H., and J. J. Valdez. 2006. Selectividad y eficiencia del palangre de deriva con tres tipos de anzuelo y dos tipos de carnada en la pesca de tiburon Page 14 *in* I. N. d. l. P. SAGARPA, editor.

Santana Hernandez, H., and J. J. Valdez. 2003. La captura incidental en pesquerias de palangre del Pacifico Oriental Mexicano, con enfasis en tortugas marinas.

Santidrian Tomillo, P., V. Saba, R. Piedra, F. Paladino, and J. Spotila. 2008. Effects of illegal harvest of eggs on the population decline of leatherback turtles in Las Baulas Marine National Park, Costa Rica. Conservation Biology **22**:1216-1224.

Santidrian Tomillo, P., E. Velez, R. D. Reina, R. Piedra, F. V. Paladino, and J. R. Spotila. 2007. Reassessment of the leatherback turtle (Dermochelys coriacea) nesting population at Parque Nacional Marino Las Baulas, Costa Rica: Effects of conservation efforts. Chelonian Conservation and Biology **6**:54-62.

Santos, M. R., A. B. Bolten, H. R. Martins, B. Riewald, K. A. Bjorndal, R. Ferreira, and J. Goncalves. 2006. Distribution of oceanic stage north Atlantic loggerheads: are seamounts important hotspots? Pages 110-111 *in* M. Frick, A. Panagopoulou, A. F. Rees, and K. Williams, editors. Book of abstracts. Twenty Sixth Annual Symposium on sea turtle biology and conservation., Creta, Greece.

Sarti, L., A. R. Barragan, D. Garcia Muñoz, N. Garcia, P. Huerta, and F. Vargas. 2007. Conservation and biology of the leatherback turtle in the Mexican Pacific. Chelonian Conservation and Biology **6**:70-78.

Sarti, L., S. A. Eckert, P. H. Dutton, A. R. Barragan, and N. Garcia. 2000. The current situation of the Leatherback population on the Pacific coast of Mexico and Central America, abundance and distribution of the nestings: an update. Pages 85-

87 *in* Proceedings of the nineteenth annual symposium on sea turtle conservation and biology. NOAA Technical Memorandum NMFS-SEFSC-443.

Segura, A., and R. Arauz. 1995. By-catch capture of sea turtles by two kinds of experimental longline gears in Pacific Costa Rica waters. Pages 125-126 *in* J. I. Richardson and T. H. Richardson, editors. Proceedings of the Twelfh Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFC-361.

Seminoff, J., T. Jones, T. Eguchi, M. Hastings, and D. Jones. 2009. Stable carbon and nitrogen isotope discrimination in soft tissues of the leatherback turtle (Dermochelys coriacea): Insights for trophic studies of marine turtles. Journal of Experimental Marine Biology and Ecology **381**:33-41.

Seminoff, J. A. 2004. Marine turtle specialist group review, 2004 Global status assessment, Green turtle (Chelonia mydas). Marine Turtle Specialist Group, The World Conservation Union (IUCN), Species Survival Commission, Red List Programme.

Seminoff, J. A., T. T. Jones, T. Eguchi, D. R. Jones, and P. H. Dutton. 2006. Stable isotope discrimination (δ13C and δ15N) between soft tissues of the green sea turtle Chelonia mydas and its diet. MARINE ECOLOGY PROGRESS SERIES **308**:271-278.

Seminoff, J. A., W. J. Nichols, A. Resendiz, and L. Brooks. 2003. Ocurrence of Hawksbill turtles, Eretmochelys imbricata (Reptilia: Cheloniidae), near the Baja California Peninsula, Mexico. Pacific Science **57**:9-16.

Seminoff, J. A., A. Resendiz, B. Resendiz, and W. J. Nichols. 2004. Occurrence of Loggerhead sea turtles (*Caretta caretta*) in the Gulf of California, Mexico: Evidence of Life-History Variation in the Pacific Ocean. Herpetological Review **35**:24-27.

Seminoff, J. A., P. Zarate, M. Coyne, D. G. Foley, D. Parker, B. N. Lyon, and P. H. Dutton. 2008. Post-nesting migrations of Galapagos green turtles Chelonia mydas in relation to oceanographic conditions: integrating satellite telemetry with remotely sensed ocean data. Endangered Species Research **4**:57-72.

SERMANAT. 2005. Capítulo 5. Aprovechamiento de los recursos forestales, pesqueros y de la vida silvestre.

Shillinger, G. L., D. M. Palacios, H. Bailey, S. J. Bograd, A. M. Swithenbank, P. Gaspar, B. P. Wallace, J. R. Spotila, F. V. Paladino, and R. Piedra. 2008. Persistent Leatherback Turtle Migrations Present Opportunities for Conservation. PLoS Biology **6**:e171.

Solano, M. 2010. Costa Rica, Informe Anual 2010. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

Sotelo, F. 2010. Honduras, Informe Anual 2010. Convencion Interamericana para la proteccion y conservacion de las tortugas marinas.

Spotila, J., A. Dunham, A. Leslie, A. Steyermark, P. Plotkin, and F. Paladino. 1996. Worldwide population decline of Dermochelys coriacea: are leatherback turtles going extinct? Chelonian Conservation and Biology **2**:209-222.

Spotila, J. R., R. D. Reina, A. C. Steyermark, P. T. Plotkin, and F. V. Paladino. 2000. Pacific leatherback turtles face extinction. Nature **405**:529-530.

Starbird, C., A. Baldridge, and J. Harvey. 1993. Seasonal occurrence of leatherback sea turtles(Dermochelys coriacea) in the Monterey Bay region, with notes on other sea turtles, 1986-1991. California Fish and Game **79**:54-62.

Steele, K. W., and R. M. Daniel. 1978. Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of 15N for tracer studies. The Journal of Agricultural Science **90**:7-9.

Stokes, L. W., D. Hataway, S. P. Epperly, A. K. Shah, C. E. Bergmann, J. W. Watson, and B. M. Higgins. 2011. Hook ingestion rates in loggerhead sea turtles Caretta

caretta as a function of animal size, hook size, and bait. Endangered Species Research **14**:1-11.

Stramma, L., R. G. Peterson, and M. Tomczak. 1995. The South Pacific Current. Journal of Physical Oceanography **25**:77-91.

Stromme, T. 1988. Final report. Surveys of the fish resources on the Pacific shelf from Colombia to southern Mexico, 1987: Bergen, Norway, Institute of Marine Research, Reports on surveys with R/V DR. FRIDTJOF NANSEN.

Swimmer, Y., R. Arauz, B. Higgins, L. McNaughton, M. McCracken, J. Ballestero, and R. Brill. 2005. Food color and marine turtle feeding behavior: Can blue bait reduce turtle bycatch in commercial fisheries? MARINE ECOLOGY PROGRESS SERIES **295**:273-278.

Swimmer, Y., R. Arauz, M. McCracken, L. McNaughton, J. Ballestero, M. Musyl, K. Bigelow, and R. Brill. 2006. Diving beahvior and delayed mortality of olive ridley sea turtles (Lepidochelys olivacea) after their release from longline fishing gear. MARINE ECOLOGY PROGRESS SERIES **323**:253-261.

Swimmer, Y., R. Arauz, J. Wang, J. Suter, M. Musyl, A. Bolanos, and A. Lopez. 2010a. Comparing the effects of offset and non-offset circle hooks on catch rates of fish and sea turtles in a shallow longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems **20**:445-451.

Swimmer, Y., J. Suter, R. Arauz, K. Bigelow, A. López, I. Zanela, A. Bolaños, J. Ballestero, R. Suárez, and J. Wang. 2010b. Sustainable fishing gear: the case of modified circle hooks in a Costa Rican longline fishery. Marine biology **158**:757–767.

Swimmer, Y., J. Wang, R. Arauz, M. Musyl, M. L. McCracken, J. Ballestero, and C. Boggs. 2008. Turtle bycatch in longline fisheries: offset vs non offset circular hooks. Page 193 *in* A. F. Rees, M. Frick, A. Panagopoulou, and K. Williams, editors. Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-569.

Takai, N., S. Onaka, Y. Ikeda, A. Yatsu, H. Kidokoro, and W. Sakamoto. 2000. Geographical variations in carbon and nitrogen stable isotope ratios in squid. Journal of the Marine Biological Association of the United Kingdom **80**:675-684.

Taylor, M. H., J. Tam, V. Blaskovic, P. Espinoza, R. Michael Ballón, C. Wosnitza-Mendo, J. Argüelles, E. Díaz, S. Purca, N. Ochoa, P. Ayón, E. Goya, D. Gutiérrez, L. Quipuzcoa, and M. Wolff. 2008. Trophic modeling of the Northern Humboldt Current Ecosystem, Part II: Elucidating ecosystem dynamics from 1995 to 2004 with a focus on the impact of ENSO. Progress in Oceanography **79**:366-378.

Tieszen, L., T. Boutton, K. Tesdahl, and N. Slade. 1983. Fractionation and turnover of stable carbon isotopes in animal tissues: implications for 13 C analysis of diet. Oecologia **57**:32-37.

Tomas, J., F. J. Aznar, and J. A. Raga. 2001. Feeding ecology of the loggerhead turtle Caretta caretta in the western Mediterranean. Journal of Zoology, London **255**:525-532.

Troncoso, F., and M. Urbina. 2007. Actualizacion del registro de tortugas marinas para el Sur de Chile. Page 41 *in* CREA, editor. VII Simposio sobre medio ambiente: Estado Actual y Perspectivas de la Investigacion y Conservacion de las Tortugas Marinas en las Costas del Pacifico Sur Oriental, Antofagasta, Chile.

Ulloa, J. B. 2003. Monitoreo y evaluacion del recurso camaron de mar en El Salvador (Periodo de Julio de 1998 a Octubre de 1999). Ministerio de Agricultura y Ganaderia, Centro de Desarrollo de la Pesca y la Acuicultura, Unidad de Pesquerias.

UNIVISION. 2010. Denuncian muerte de tortugas marinas en costas guatemaltecas. Radio La Primerisima, Ciudad de Guatemala.

Valqui, M., A. Cruz, J. Alfaro-Shigueto, S. Kelez, M. Pajuelo, J. Mangel, and P. Melly. 2006. First year results of the hook substitution experiment to reduce sea turtle bycatch. Pages 270-271 *in* M. Frick, A. Panagopoulou, A. F. Rees, and K.

Williams, editors. Book of abstracts. Twenty Sixth Annual Symposium on sea turtle biology and conservation, Creta, Greece.

Vander Zanden, H., K. Bjorndal, K. Reich, and A. Bolten. 2010. Individual specialists in a generalist population: results from a long-term stable isotope series. Biology Letters **6**:711–714.

Vargas, P., P. Tello, and C. Aranda. 1994. Sea turtle conservation in Peru: the present situation and a strategy for immediate action. Pages 159-162 *in* Proceedings of the Fourteenth Annual Symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-351.

Velez-Zuazo, X., and S. Kelez. 2010. Multiyear analysis of sea turtle bycatch by Peruvian longline fisheries: a genetic perspective. 30th Annual Symposium on Sea Turtle Biology and Conservtion, Goa, India.

Voss, M., J. W. Dippner, and J. P. Montoya. 2001. Nitrogen isotope patterns in the oxygen-deficient waters of the Eastern Tropical North Pacific Ocean. Deep-Sea Research I **48**:1905-1921.

Wada, E., and A. Hattori. 1976. Natural abundance of ^{15}N in particulate organic matter in the North Pacific Ocean. Geochemica et Cosmochemica Acta **40**:249-251.

Wada, E., M. Terazaki, Y. Kabaya, and T. Nemoto. 1987. ^{15}N and ^{13}C abundances in the Antartic Ocean with emphasis on the biogeochemical structure of the food web. Deep Sea Research Part A. Oceanographic Research Papers **34**:829-841.

Wallace, B., L. Avens, J. Braun-McNeill, and C. McClellan. 2009. The diet composition of immature loggerheads: Insights on trophic niche, growth rates, and fisheries interactions. Journal of Experimental Marine Biology and Ecology **373**:50-57.

Wallace, B., A. DiMatteo, B. Hurley, E. Finkbeiner, A. Bolten, M. Chaloupka, B. Hutchinson, F. Abreu-Grobois, D. Amorocho, and K. Bjorndal. 2010. Regional Management Units for Marine Turtles: A Novel Framework for Prioritizing Conservation and Research across Multiple Scales. PLoS One **5**:955-966.

Wallace, B. P., J. A. Seminoff, S. S. Kilham, J. R. Spotila, and P. H. Dutton. 2006. Leatherback turtles as oceanographic indicators: stable isotope analyses reveal a trophic dichotomy between ocean basins. Marine biology **149**:953-960.

Wang, J., S. Fisler, and Y. Swimmer. 2009. Developing visual deterrrents to reduce se turtle bycatch: testing shark shapes and net illumination. Pages 49-50 *in* E. Gilman, editor. Proceedings of the Technical Workshop on Mitigating Sea Turtle Bycatch in Coastal Net Fisheries. IUCN, Western Pacific Regional Fishery Management Council, Southeast Asian Fisheries Development Center, Indian Ocean - South-East Asian Marine Turtle MoU, U.S. National Marine Fisheries Service, Southeast Fisheries Science Center, Gland, Switzerland; Honolulu, Bangkok, and Pascagoula, USA.

Watson, J., and A. Smith. 1998. The southeastern United States experience with the introduction and acceptance of new sustainable technologies. FAO Fisheries Report. 588.

Watson, J. W., S. P. Epperly, A. K. Shah, and D. G. Foster. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Canadian Journal of Fisheries and Aquatic Sciences **62**:965-981.

Whiting, S., J. Long, and M. Coyne. 2007. Migration routes and foraging behaviour of olive ridley turtles Lepidochelys olivacea in northern Australia. Endangered Species Research **3**:1-9.

Witherington, B. E. 2000. Habitats and bad habits of young loggerhead turtles in the open ocean. Pages 34-35 *in* F. A. Abreu-Grobois, R. Briseño-Dueñas, R. Marquez, and L. Sarti, editors. Proceedings of the Eighteenth International Sea Turtle Symposium. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-SEFSC-436.

Witzell, W. N. 1999. Distribution and relative abundance of sea turtles caught incidentally by the U.S. pelagic longline fleet in the western North Altantic Ocean, 1992-1995. Fishery Bulletin **97**:200-211.

Wosnitza-Mendo, C., and R. Guevara-Carrasco. 2000. Adaptive response of Peruvian hake to overfishing. NAGA **23**:24-28.

WWF. 2009. Interacciones de la tortuga laúd y las flotas artesanales de Michoacán, Guerrero y Oaxaca (México). Reporte técnico final de WWF para la Comisión para la Cooperación Ambiental de América del Norte (CCA). 59 p. Disponible en http://www.wwf.org.mx.

Yáñez, E., M. Barbieri, F. Ponce, M. Donoso, C. Canales, R. Toro, and J. Acevedo. 2003. Monitoreo y evaluación de la pesquería chilena de pez espada. Actividad Pesquera y de Acuicultura en Chile:143-156.

Yáñez, E., C. Silva, M. A. Barbieri, and K. Nieto. 1996. Pesquería artesanal de pez espada y temperatura superficial del mar registrada con satélites NOAA en Chile central. Invest. Mar., Valparaíso **24**:131-144.

Yáñez, E., C. Silva, M. A. Barbieri, A. Órdenes, and R. Vega. 2009. Environmental conditions associated with swordfish size compositions and catches off the Chilean coast. Latin American Journal of Aquatic Research **37**:71-81.

Zarate, P. 2006. Ecuador, Informe Anual 2006. Convencion Interamericana para la Proteccion de las Tortugas Marinas

Zarate, P. 2007. Ecuador, Informe Anual 2007. Convencion Interamericana para la Proteccion de las Tortugas Marinas

Zarate, P., A. Fernie, and P. Dutton. 2003. First results of the East Pacific green turtle, Chelonia mydas, nesting population assessment in the Galapagos Islands. Pages 70-73 *in* J. A. Seminoff, editor. Proceedings of the twenty-second annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-503.

Zuniga, T., A. Abreu-Grobois, and A. Espinosa. 2010. Phylogeography of the endangered hawksbill turtle (Eretmochelys imbricata) around the world. Page 157 *in* K. Dean and M. C. Lopez-Castro, editors. Proceedings of the twenty-eigth annual symposium on sea turtles biology and conservation. NOAA Technical Memorandum NOAA NMFS-SEFSC-602.

Zuta, S., and O. Guillen. 1970. Oceanografia de las aguas costeras del Peru. Boletin Instituto del Mar de Peru **2**:157-324.

Biography

Born: January 10, 1978, Lima, Perú

Education

2005-2011	Ph.D., Duke University, US
2002	Graduate courses, Summer term II, Duke University, US
1995-2000	B.S. Sciences, Ecology, Universidad Nacional Agraria La Molina, Peru

Refereed Publications

Kelez, S, & X Velez-Zuazo. (In Press). Reptiles Marinos. Tortugas de mar, populares pero desconocidas. In: Biodiversidad de Pisco.

Seminoff, JA, J Alfaro-Shigueto, D Amorocho, R Arauz, A Baquero, D Chacon, AR Gaos, S Kelez, J Mangel, J Urteaga, & BP Wallace. (In Press). Biology and conservation of sea turtles in the Eastern Pacific Ocean: A general overview. In: Seminoff JA, Wallace BP (editors). Sea Turtles of the Eastern Pacific Ocean: Research Advances, Conservation Challenges, and Signs of Success. University of Arizona Press, Tucson.

Stewart, K, R Lewison, D Dunn, R Bjorkland, S Kelez, P Halpin & L Crowder. 2010. Characterizing fishing effort and spatial extent of coastal fisheries. PlosOne 5(12): e14451.

Wallace, B, R Lewison, S McDonald, T McDonald, C Kot, S Kelez, R Bjorkland, E Finkbeiner, S Helmbrecht, & L Crowder. 2010. Global patterns of marine turtle bycatch. Conservation Letters 3:131-142.

Kelez, S, X Velez-Zuazo, F Angulo, & C Manrique. 2009. Olive Ridley *Lepidochelys olivacea* nesting in Peru: the southernmost records in the Eastern Pacific. Marine turtle newsletter 126: 5-9.

Boyle, MC, NN FitzSimmons, CJ Limpus, S Kelez, X Velez-Zuazo, & M Waycott. 2009. Evidence for transoceanic migrations by loggerhead sea turtles in the southern Pacific Ocean. Proceedings of the Royal Society B 276: 1993-1999.

Wallace, BP, SS Heppell, RL Lewison, S Kelez, & LB Crowder. 2008. Impacts of fisheries bycatch on loggerhead turtles worldwide inferred from reproductive value analyses. Journal of Applied Ecology 45: 1076-1085.

Smith, AC, S Kelez, & HM Buchanan-Smith. 2004. Factors affecting vigilance whiting wild mixed-species troops of saddleback (*Saguinus fuscicollis*) and moustached tamarins (*Saguinus mystax*). Behavioural Ecology & Sociobiology 56: 18-25.

Kelez, S, X Velez-Zuazo, & C Manrique. 2003. New evidence on the Loggerhead Sea Turtle *Caretta caretta* (Linnaeus, 1758) in Peru. Revista de Ecologia Aplicada 2(1): 141-142.

Grants received

2010	PADI Foundation: US$4000
2010	Oak Foundation Mini-Grants in Marine Conservation US$4000
2009	Oak Foundation Mini-Grants in Marine Conservation US$4000
2008	Graduate Field Research Grant, Center for Latin-American and Caribbean Studies US$1500
2008	Duke Marine Lab Oak Foundation grants $1137
2008	Rufford Small Grant for Nature Conservation UK£5912
2008	Oak Foundation Mini-Grants in Marine Conservation US$2980
2007	Travel Grant, Center for Latin American and Caribbean Studies $500
2006	Oak Foundation Mini-Grants in Marine Conservation US$3000
2006	Travel Grant, Center for Latin American and Caribbean Studies $500
2005-2007	Fulbright Scholarship for graduate studies, Fulbright Commission, US
2002	Global Fellowship in Marine Conservation, Duke University, NC, US