‘OCEANS AND LAKES’

INTERUNIVERSITY MASTER IN MARINE AND LACUSTRINE SCIENCE AND MANAGEMENT

Ecology of the East Pacific green turtle (*Chelonia mydas*) at Virrila Estuary, northern coast of Peru: conservation and management implications

Evelyn Paredes Coral

August 2017

Thesis submitted in partial fulfillment for master degree in Marine and Lacustrine Science and Management

Supervisor: Prof. Dr. Marc Kochzius

Co-supervisor: MSc. Javier A. Quiñones Dávila

To Libni, my beloved mom, for her invaluable support day by day and for motivating me to fulfill my dreams.

“For most of the wild things on earth, the future must depend on the conscience of mankind”

Archie Carr

ACKNOWLEDGEMENTS

I deeply thank VLIR-UOS for the opportunity to be part of this interuniversity master.

I would like to offer my special thanks to my supervisor Marc Kochzius for his valuable suggestions and remarks.

I would like to express my very great appreciation to my co-supervisor Javier Quiñones for his guidance during the planning and development of this thesis. His willingness to give his time so generously has been very much appreciated.

My special thanks are extended to the staff of Oceans & Lakes for their guidance during the entire master.

I would like to thank the Instituto del Mar del Peru for supporting my project and make possible the collection of the data. Special thanks to the DGIRP, the OIDS and the Coastal Laboratories of Paita and Santa Rosa for providing qualified staff and logistic support during the surveys.

I am particularly grateful with Romulo Juarez, Sixto Quispe, Joe Macalupú, David Torres, Elisa Goya, Vanessa Bachmann, Cynthia Romero, Santos Puemape, Javier Castañeda, Diego Salazar, Edward Barriga, Moises Segura, David Sarmiento, Jennifer Chauca and Orgelis Contreras for their amazing work during the development of the surveys.

I wish to acknowledge the help provided by the Gremio de Pescadores Artesanales de Parachique during the surveys.

My special thanks are extended to Dr. Ken Takahashi for providing the data concerning the Piura River discharge.

Advice given by Nele De Meester, Sarah di Giglio, Sara Purca and Charlene Guillamod has been a great help during the data analysis.

Finally, I would like to thank my lovely family and Philippe Pernet for their support during the elaboration of the manuscript.

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

ACA	Area de Conservación Ambiental
ACOREMA	Áreas Costeras y Recursos Marinos
ANOVA	Analysis of variance
AP	Action plan
APECO	Asociación Peruana para la Conservación de la Naturaleza
BCI	Body condition index
CCL	Curved carapace length
CCW	Curved carapace width
CENPAR	Censo Nacional de Pescadores Artesanales
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CPPS	Comisión Permanente del Pacífico Sur
CPUE	Catch per unit effort
CTL	Post-cloacal tail length
DICAPI	Dirección General de Capitanías y Guardacostas
ECOCEANICA	Centro para la Conservación Integral de Los Ecosistemas Marinos del Pacifico Este
EN	El Niño
ENSO	El Niño–Southern Oscillation
GPS	Global Positioning System
HP	Horse power
HW	Head width
IAC	Inter-American Sea Turtle Convention
IMARPE	Instituto del Mar del Peru
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature

kts	knots
MINAGRI	Ministry of Agriculture and Irrigation
NGO	Non-governmental organization
NHUS	Northern Humboldt Upwelling System
NOAA	National Oceanic and Atmospheric Administration
PL	Plastron length
POI	Peruvian Oscillation Index
PRODUCE	Ministry of Production
PSU	Practical Salinity Unit
PW	Plastron width
SCL	Straight carapace length
SD	Standard deviation
SERFOR	Servicio Forestal y de Fauna Silvestre
SERMANAT	Secretaría de Medio Ambiente y Recursos Naturales
SERNANP	Servicio Nacional de Áreas Naturales Protegidas
SLR	Sea Level Rise
SST	Sea surface temperature
TTL	Total tail length
WWF	World Wildlife Fund

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The ecology of sea turtles has been assessed mostly at nesting sites, although sea turtles spend most of their lives at sea. The ecology of green turtles in the East Pacific has been taking more attention in the last decade. This is especially the case of Peru, where punctual information exists on feeding grounds. However, the link with environmental drivers as well as the quantification of anthropogenic impacts remain unclear. This study focuses on Virrila Estuary, a natural aggregation area for green turtles in the northern coast of Peru, located in a transitional zone influenced from upwelling and warm equatorial conditions. At Virrila Estuary, 13 surveys were carried out from 2012 - 2017 and one pilot study in 2011. Overall, 615 green turtles were captured during the in-water surveys and 838 individuals were registered as stranding records. Population structure was largely dominated by juvenile individuals (68.7 %; n = 765) and recapture rate was very low (4.9 %), indicative of a large population. Information obtained from recaptured individuals, indicates that green turtles probably spend a median of 219.5 days (0.6 yr) in the estuary with a maximum of 1054 days (2.9 yr). Somatic growth rate was one the highest in the East Pacific and together with the body condition index reflected values of healthy individuals and a population with a non-monotonic growth pattern with a peak in 81-90 cm curved carapace length. Based on information from stranding surveys, the main anthropogenic-derived threats were boat strikes (57.7 %; n = 45) followed by illegal capture (42.3 %; n = 33). We also discuss alternative ways to prevent and reduce anthropogenic-derived threats and the necessity of an active management intervention in Peru. Additionally, green turtle occurrence at Virrila Estuary showed to be linked with the environmental variability caused by El Niño events. This study indicates that Virrila Estuary is an important developmental habitat for juvenile East Pacific green turtles and we strongly exhort that management efforts should focus on reducing anthropogenic-derived threats and law enforcement.

Keywords: Green turtles, Virrila Estuary, population ecology, anthropogenic impacts, conservation, El Niño

RESUMEN

La ecología de las tortugas marinas ha sido investigada principalmente en sitios de anidación, a pesar de que las tortugas marinas pasan la mayor parte de sus vidas en el mar. La ecología de las tortugas verdes en el Pacífico Oriental ha tomado mayor atención en la ultima década. Especialmente en el caso de Perú, donde existe información puntual en áreas de alimentación. Sin embargo, la relación entre las variables ambientales así como la cuantificación de impactos antropogénicos permanece poco claro. Este estudio se enfoca en el Estuario de Virrilá, un área de agregación natural de tortugas verdes en la costa norte de Perú, ubicada en la zona de transición con influencia de condiciones de afloramiento y aguas cálidas ecuatoriales. En el Estuario de Virrilá, 13 prospecciones fueron realizadas del 2012 al 2017 y un estudio piloto en 2011. En general, 615 tortugas verdes fueron capturadas durante monitoreos acuáticos y 838 individuos fueron registrados como varamientos. La estructura poblacional estuvo dominada en gran parte por ejemplares juveniles (68.7 %; n = 765) y la tasa de recaptura resultó muy baja (4.9 %), lo cual es un indicativo de una población numerosa. La información obtenida de individuos recapturados indica que las tortugas verdes probablemente pasan un promedio de 219.5 días (0.6 años) en el estuario con un máximo de 1054 días (2.9 años). La tasa de crecimiento somático fue una de las más altas en el Pacífico Oriental y junto con los índices de condición corporal reflejaron valores de individuos saludables y una población con un patrón de crecimiento no monotónico con un pico máximo entre 81 y 90 cm de longitud curva del caparazón. Basados en la información de varamientos, la mayor amenaza de causa antropogénica fueron las colisiones con embarcaciones (57.7 %; n = 45) seguido por la captura ilegal (42.3 %; n = 33). También se incluye una discusión sobre alternativas para prevenir y reducir las amenaza de causa antropogénica y la necesidad de una intervención activa en la gestión en el Perú. Adicionalmente, la ocurrencia de tortugas verdes en el Estuario de Virrilá mostró estar relacionada con la variabilidad ambiental causada por eventos El Niño. Este estudio indica que el Estuario de Virrilá es un área importante de desarrollo para ejemplares juveniles de la tortuga verde del Pacífico Oriental y se recomienda enfáticamente que los esfuerzos de manejo deben enfocarse en reducir las amenazas de causa antropogénica y en la aplicación de la ley.

Palabras clave: tortuga verde, Estuario de Virrilá, ecología poblacional, impactos antropogénicos, conservación, El Niño

I. INTRODUCTION

Sea turtles play a fundamental role in marine ecosystems. The green turtle (*Chelonia mydas*) experiences ontogenetic habitat changes during its life cycle, shifting from an epipelagic-oceanic juvenile phase, in which it drifts away during a few years (Carr & Meylan, 1980; Carr, 1987; Luschi et al., 2003) to a neritic juvenile, sub-adult and adult phase where it feeds and grows in order to reach sexual maturity (Bjorndal, 1980; Musick & Limpus, 1997). During the neritic phase, green turtles inhabit diverse ecosystems, such as seagrass beds (Mortimer, 1981), habitats with mangroves, algae (Seminoff *et al*., 2002a; López-Mendilaharsu *et al*., 2005; Arthur *et al*., 2009; Carrión-Cortez *et al*., 2010) and coral reefs (Limpus, 1993; Chaloupka & Limpus, 2001). All of these ecosystems are considered as important developmental habitats for juveniles until they reach sexual maturity (Luschi *et al*., 2003). Considering the time turtles spend in those neritic areas, studies in those areas represent a unique opportunity to understand basic aspects of their life history, population dynamics (Bjorndal & Jackson, 2003; Meylan *et al*., 2011; Patricio *et al*., 2011), feeding ecology (Seminoff *et al*., 2002a) and their ecosystem function (Wabnitz et al., 2010).

From the seven species of sea turtles in the world, five of them are present in Peruvian waters, among them the East Pacific green turtle (*Chelonia mydas*) (IMARPE, 2011). Neritic habitats constitute important feeding grounds for this species in Peru (Velez-Zuazo et al., 2014). They arrive there after the dispersal period from their main nesting beaches at Galapagos (Green, 1984; Seminoff, 2004), Colola and Maruata in Michoacan (Alvarado-Díaz et al., 2001), Revillagigedo Islands, Mexico (Holroyd & Trefry, 2010), and from secondary nesting beaches throughout Central America (Blanco et al., 2012; Santidrián-Tomillo et al., 2014); as well as after their epipelagic-oceanic phase (Luschi *et al*., 2003). Several sea turtle feeding areas have been reported in Peru, such as the coast of Tumbes (Punta Sal, Punta Mero, Bocapan, Puerto Pizarro y Casitas, ~4ºS), Punta Restin (~4.5ºS; Aranda & Chandler, 1989; de Paz & Alfaro-Shigueto, 2008); Sechura Bay and Virrila Estuary (~5.7ºS; Santillán, 2008; Paredes-Coral *et al*., 2016; Jimenez et al., 2017), Lobos de Tierra Island (~6.5ºS; Quiñones *et al*., 2015), Paracas (~14ºS; Quiñones *et al*., in press) and Tambo de Mora (~13.3ºS; Aranda & Chandler, 1989).

Due to several factors, mainly capture of females and egg's collection at nesting beaches (Nichols, 2003), as well as bycatch and illegal captures in feeding areas (Alfaro-Shigueto *et al*., 2011; Quiñones et al., 2017), the East Pacific green turtle population has been diminished and now is listed as *endangered* by the International Union for the Conservation of Nature (IUCN; Seminof et al., 2004) and its international trade is prohibit by the Convention on International Trade in Endangered Species of Wild Fauna and Flora - Appendix I (CITES, 2017). Additionally, green turtles are considered *endangered* by the Peruvian legislation (D.S 034-2014-MINAGRI).

Given that the cumulative impacts from different threatening sources can significantly affect green turtle individuals and populations, conservation strategies are being planned at national and regional level (IMARPE, 2011; Wallace *et al*., 2013). In this sense, the knowledge about their ecology and the identification of main threats is fundamental for the development and the implementation of conservation and management plans (Bjorndal, 1980; López-Mendilaharsu *et al*., 2005).

In Peru, an analysis of the conservation status of sea turtles was performed in 2011 sponsored by the Permanent Commission of the Southeast Pacific (CPPS) and the Peruvian Institute for Marine Research (IMARPE). This document was the basic input to start the elaboration of a national document such as the Action Plan. In 2014, as an initiative of the government, a multisectorial workgroup of government agencies was created in order to elaborate the National Action Plan for the conservation of sea turtles. After a period of revision, data input and consultation by the main actors, it is expected to be published by 2018. With the creation of this management tool, Peru takes a step forward in the implementation of conservation measures for these endangered species.

For this study, I have analysed data obtained in the framework of the project ‘Monitoring of sea turtles at the Virrila Estuary’ carried out by the Peruvian Institute for Marine Research (IMARPE) from 2012 to 2017 and I also include one pilot study performed on 2011.

II. OBJECTIVES

1. General objective

Assessing the ecology of the East Pacific green turtle at Virrila Estuary and linking it to the potential implications for conservation and management.

2. Specific objectives

a) Estimating the population parameters in terms of size composition, residence time, somatic growth rate and body condition.

b) Quantifying the stranding occurrence in the estuary and examining the causes.

c) Determining the climate-driven occurrence of green turtles at the Virrila Estuary

c) Identifying the main threats for East Pacific green turtles at Virrila Estuary and their implications for conservation and management.

III. BACKGROUND

III.1 Biology of the East Pacific green turtle

III.1.1 *Morphology*

East Pacific green turtles have a hearth-shaped carapace with usually five central scutes, four lateral pairs and 11 marginal pairs. The head is relatively small with one pair of prefrontal scales and the beak is sharp (Appendix 1). Adults have the dorsal side almost black with some grey/green spots. However, several colourations are present in juveniles and sub-adults such as brownish, black, reddish and yellow (Appendix 2). East Pacific green turtles are smaller than individuals from Atlantic populations. Adult individuals can measure between 70.5 - 90 cm and weight up to 126 kg (Marquez, 1996).

III.1.2 *Life stages*

East Pacific green turtles are conventionally classified in three life stages: juveniles, sub-adults and adults. Given that the majority of green turtles that occur in Peruvian waters are coming from the Galapagos Islands (Lester-Coll *et al*., 2016), my study will use the minimum and average carapace curve length (CCL) from nesting females at Galapagos according to Zárate *et al*. (2013). All the individuals with a CCL smaller than the CCL of nesting females at Galapagos (<69 cm) will be classified as juveniles, individuals with size between the minimum and the average CCL (≥69 x ≤85 cm) as sub-adults and the ones with CCL bigger than the average (>85 cm) will be classified as adults.

III.1.3 *Distribution*

The distribution of the East Pacific green turtle ranges from San Diego Bay, USA to central Chile (Appendix 3). Aggregation areas are in the Gulf of California (Seminoff et al., 2002a) and Bahía Magdalena (Mexico) (Garcia-Martínez & Nichols, 2001), Gulf of Fonseca (El Salvador-Honduras-Nicaragua) (Blanco, 2012), Coco Island, Golfo Dulce, Punta Coyote and Cabo Blanco (Costa Rica) (Arauz et al., 2013; Heidemeyer et al., 2014; Chacón-Chaverri et al., 2015), Gorgona National Park, (Colombia) (Sampson et al., 2014), Galapagos Islands (Seminoff, 2004) and Isla de la Plata (Ecuador) (Chaves et al., 2017), Sechura Bay and Virrila Estuary (northern Peru) (Santillán, 2008; Paredes-Coral et al., 2015; Pingo et al., 2017), Paracas (central Peru) (Quiñones et al., in press), Playa Chinchorro and Bahía Chipana (northern Chile) (Veliz et al., 2014) and Bahia Salado (central Chile) (Álvarez-Varas et al., 2017).

III.1.4 *Reproduction and nesting beaches*

This species have several reproductive areas (Appendix 4) and the most important are located at Michoacan, the beaches of Colola and Maruata (Alvarado-Díaz et al., 2001), Revillagigedo Islands (Mexico) (Holroyd & Trefry, 2010) and Galapagos Islands (Seminoff, 2004). Moreover, secondary nesting areas have been reported in Nombre de Jesús and Playa Cabuyal in Costa Rica (Blanco et al., 2012; Santidrián Tomillo et al., 2014) and Isla de Cañas (Panama) (MiAmbiente, 2017). The age of sexual maturity has been estimated between 26 and 40 years (Seminoff, 2004). In general, females do not reproduce every year, the period between each reproduction depends of the interval of remigration, which is two and six years (Zárate et al. 2013). Nesting season is from August to January in Mexico (SERMANAT, 2011) and between December and June in Galapagos, although sporadic nesting take place all year round (Zárate & Dutton, 2002). The mean number of eggs per nest is 125, which are incubated in sand for a period of 45 - 70 days, depending on the temperature. High temperature accelerates the growth but also generates a larger proportion of females (Mrosovsky & Yntema, 1980).

Projections of future scenarios of climate warming in the next 100 years predict accelerated increase of temperature between 0.3 and 7.5 ºC for North America (IPCC 2001). This will potentially affect sea turtles at nesting beaches generating skewed sex ratios, earlier nesting and longer nesting seasons (Hawkes et al., 2007). Additionally, warming land and sea temperatures may be allowing the turtles to expand farther south into habitats now suitable for nesting such as northern Peru (Kelez & Velez-Zuazo, 2014). Other consequences of climate change that would potentially affect sea turtles is sea level rise (SLR). SLR will affect sea turtles in terms of habitat loss due to inundation of nesting beaches, mainly in scenarios with SLR more than 0.2 m and decrease in hatchling success. Even if turtles are able to shift nesting beaches for new sites, this is not possible in areas with high anthropogenic development (Fish et al., 2005; Fuentes et al., 2011).

III.2 Green turtles and El Niño

The Northern Humboldt Upwelling System (NHUS) is one of the most productive ecosystems worldwide, supporting the largest single-species fishery in the world (by weight) based on the Peruvian anchovy (*Engraulis ringens*) (Chavez et al., 1999; 2008; Pennington et al., 2006). However, ecosystem function in the NHUS is dramatically impacted at interannual time scales by the El Niño Southern Oscillation (ENSO) (Espinoza-Morriberón et al., 2017).

During an ENSO, physical, chemical, and nutritional conditions of the ocean are affected with a consequently alteration of the entire food web (Fiedler et al., 1991; Chavez et al., 1999; Ayón et al., 2004). Due to the weakening of equatorial zonal winds, an upwelling of warmer waters occurs caused by the deepening of the thermocline (Ji & Leetmaa, 1997). Thus, the primary production is seriously reduced (Barber & Chavez, 1983) affecting benthic and grazing fauna (Fernandez et al., 1999). Moreover, pelagic species like anchovy reduces its habitat aggregating mostly on shallower waters and large die off occurs (Csirke, 1989; Bertrand et al., 2004). Consequently, mortality of seabirds and marine mammals increases due to limitation of food availability (Jahncke et al., 2004; Trillmich & Ono, 2012). Additionally, the role of sea temperature as an environmental factor, in association with ENSO, was hypothesised to affect the migration of green turtles to its foraging areas. Warmer waters that approach the Peruvian coast during ENSO facilitate the access of turtles to this area (Quiñones et al., 2010).

Studies at eastern Australian green turtle rookeries show that ENSO also affects the sea turtle breeding. Massed nesting occurs two years after major ENSO and extremely low nesting numbers occur two years after major La Niña events (Limpus & Nicholls, 2000). On the other hand, green turtle nesting females at Galapagos Islands showed an alteration in the nesting period (early start) and unusual behavior during major ENSO 1982/83 and

1987/88. Likewise, the number of nesting females severely decreased during major ENSO 1982/83 (Hurtado, 1989).

III.3 Conservation and management of sea turtles in Peru

III.3.1. National legislation and stakeholders

The following section contains the legal framework in force (Table 1) as well as a list of stakeholders involved in sea turtle conservation (Table 2).

III.3.2. The action plan for the conservation of sea turtles in Peru

The action plan (AP) is a management tool that leads concrete actions in order to achieve the conservation and protection of sea turtles in Peru. The authority leading the elaboration of the action plan is the Ministry of Environment through the National Forest and Wildlife Service (SERFOR). Moreover, many stakeholders listed in Table 2 participate during the process. At the moment of the redaction of this thesis, the AP was in revision and constantly received input from the main actors through regional workshops.

The main goal of the AP is to ensure the conservation and sustainable management of the five species of sea turtles and their habitats. Specific objectives include (1) articulating in an appropriate way the efforts made by the state and civil society for the conservation of sea turtles in the country, (2) reducing the illegal capture of the five species of sea turtles present in Peruvian waters, (3) improving the control and monitoring systems to ensure an adequate monitoring of capture and trade of products and by-products and (4) reducing the impacts that are generated by coastal activities.

The AP considers four lines of action as follows:

1. Interinstitutional strengthening by articulating the efforts made by the state and civil society for the conservation of sea turtles in the country.

2. Mitigation of major conservation issues by reducing the illegal capture of the five species of sea turtles.

3. Sensitize civil society on the importance of sea turtles by reducing the impacts that are generated by coastal activities.

4. Increase the biological and ecological knowledge needed to improve sea turtle management.

III.3.3. International Agreements

3.1 *Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)*: Green turtles are enlisted in Appendix I, which includes endangered species and whose international trade is under regulation.

3.2 *Convention on Migratory Species (CMS)*: Green turtles are enlisted in Appendix I, which includes threatened species that require immediate protection.

3.3 *Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC)*: Promotes the protection, conservation and recovery of the populations of sea turtles and those habitats on which they depend, on the basis of the best available data and taking into consideration the environmental, socioeconomic and cultural characteristics of the Parties. These actions should cover both nesting beaches and the Parties' territorial waters.

3.4 *Permanent Commission of the Southeast Pacific (CPPS)*: Through the Regional Program for the Conservation of Sea Turtles in the Southeast Pacific, the CPPS intends to recover sea turtle populations and their habitats in the Southeast Pacific by mitigating major threats with participatory strategies designed with the best available socio-economic, biological and ecological information at a regional level.

3.5 *Convention on Biological Diversity (CBD)*: There is a commitment to preserve biological diversity and promote the protection of ecosystems and natural habitats and the maintenance of viable populations of species in natural environments.

Table 1. Compilation of the National legislation regarding sea turtle conservation in Peru.

Resolution/Decree	**Date of creation**	**Penalties**	**Responsible authority**
Legislative Decree N° 635 – Criminal code Title XIII: Environmental Crimes, Chapter II, Article 308.- Illegal trafficking in protected flora and fauna species: “Any person who acquires, sells, transports, stores, imports, exports or re-exports products or specimens of non-timber wild flora and / or wildlife species protected by national legislation without a permit or valid certificate, whose unauthorized origin knows or can presume, shall be punished according to the law".	April 8, 1981	Imprisonment of not less than three years nor more than five years and with 180 to 400 days-fine.	Public Ministry
Ministerial Resolution N° 01065-76-PE The Ministry of Fisheries closes the leatherback turtle (*Dermochelys coriacea*) fisheries and establishes a Minimum Allowable Catch Size for green turtles (*Chelonia mydas agassizii*).	December 31, 1976	not mentioned	Ministry of Production (ex Ministry of Fisheries)
Ministerial Resolution N° 103-95-PE It prohibits the directed capture of all species of sea turtles existing in Peruvian jurisdictional waters. Whoever intentionally captures, processes, commercialises or transports specimens of "sea turtles" shall be sanctioned in accordance with the legal provisions in force.	March 2, 1995	Sanction in accordance with the legal regulations.	Ministry of Production (ex Ministry of Fisheries)
Supreme Decree N° 026-2001-PE It maintains the prohibition regarding directed capture of all species of sea turtles existing in Peruvian jurisdictional waters.	June 28, 2001	Sanction in accordance with the legal regulations.	Ministry of Production (ex Ministry of Fisheries), Ministry of Interior and Ministry of Defense
Supreme Decree N° 034-2004-AG This Decree aproves the categorization of three hundred and one (301) threatened species of wildlife. It prohibites its hunting, capture, possession, transport or export for commercial purposes.	September 22, 2004	not mentioned	Ministry of Agriculture and Irrigation
Supreme Decree N° 016-2007-PRODUCE Extraction, processing, commercialisation, transport or storage of legally protected species is considered as a serious violation.	August 1, 2007	Confiscation and a fine. The fine in case of legally protected species is 2 tax units for each specimen (~2 210 EUR).	Ministry of Production
Supreme Decree N° 004-2014-MINAGRI It is an update of the red list of protected endangered species of wildlife. Green turtles are enlisted as endangered species and their commercial hunting, capture, holding, trade, transportation or export, products and / or by-products is prohibited.	April 7, 2014	not mentioned	Ministry of Agriculture and Irrigation

Table 2. List of stakeholders and their function regarding sea turtle conservation in Peru.

Governmental entities		
Institution	**Authority/Department in charge**	**Function**
Ministry of Production (PRODUCE) Vice minister of Fisheries	> Department of Supervision, Audit and Sanctions	Ensures good practices of the extraction and consumption of marine species along the Peruvian coast.
		Formulate plans, programs or projects for supervision, control and sanctions.
	> Department of Policy and Fishery development	Formulate, propose, disseminate and supervise the accomplishment of national and sectoral policies and plans in the field of fisheries and aquaculture, in coordination with governmental agencies belonging to the Ministry of Production and other governmental levels.
	> Department of Sustainable Fisheries	Promote the policies and strategies in fisheries and aquaculture, in harmony with the protection of the environment, conservation of hydrobiological resources, including biodiversity, under the principle of sustainability.
		Analyze and promote topics related to protocols, national and international agreements related to environmental issues and the protection of natural resources linked to fishing and aquaculture.
	> Peruvian Institute of Marine Research (IMARPE)	Performs scientific research as well as the study of the Peruvian sea and its resources, to advise the government on the decision-making.
		Investigates the relationship between the marine resources, the environment and fisheries, providing advice on the management of resources and the marine environment, respecting and promoting the concepts of sustainable development, conservation of marine biodiversity, environmental protection and responsible fishing.
Ministry of Agriculture and Irrigation (MINAGRI)	National Forest and Wildlife Service (SERFOR)	Promotes the sustainable and participatory management of forest resources and wildlife, and the use of its ecosystem services, providing quality services that contribute to the well-being of citizens.
		Defines the policies for the forestry and wildlife sector.
		Is the administrative authority of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).
Peruvian Navy	Coast guard (DICAPI)	Exercises the maritime authority, is responsible for regulating and ensuring the safety of human life, the protection of the environment and its natural resources and to repress any illegal act at sea.
		Controls and monitors all activities carried out in the aquatic environment, in compliance with the law and international agreements.
Ministry of Environment (MINAM)	National Service of Natural Protected Areas (SERNANP) >The Guano Islands and Capes National Reserve System >Paracas Marine Reserve	Manages the protected areas including Marine Protected Areas (MPAs). Establish the control mechanisms, as well as the corresponding administrative infractions and penalties.
		Exercises the sanctioning power in cases of non-compliance, applying the sanctions of reprimand, fine, confiscation, immobilization, closure or suspension.
Public Ministry	Specialised Attorney in Environmental Matters	Designs and establishes a fiscal organization specialized in environmental matters that allows the prevention and investigation of environmental crime.
National Police of Peru	Division of Environmental Protection	Deals with crimes that threaten natural resources.
Non-Governmental Organisations (NGOs)		
	Organisation	**Function**
	Prodelphinus Acorema EcOceanica Apeco WWF Planeta Oceano Asociación Biósfera del Noroeste	Performs scientific research on endangered marine species. Promotes the social awareness. Develops environmental education programs.
	Fishermen guild	Groups more than 55 thousand of fisherman from differente ports and regions along the coast.

IV. MATERIALS AND METHODS

IV.1 Study area

The Virrila Estuary is located 40 km south of Sechura town, Piura (~5.7 ºS) and has approximately 30 km length (Figure 1). The estuary is connected with the Piura River through the Ramon, Ñapique and La Niña lagoons only during the rainy season (November-May) and El Niño (EN) events. The estuary mouth is located at the southern part of Sechura Bay, where the Parachique artisanal dock is placed. The Virrila Estuary has 2 m average depth and 2 km maximum width. Surface water temperature ranges from 18 to 33.9 °C (the last value was registered during the coastal EN 2017) and salinity varies among 38 to 81 practical salinity units (PSU). However, it drops dramatically during EN events due to tremendous amount of freshwater input. The estuary is also affected by strong tidal changes, which influence turtle movements in and out of the estuary.

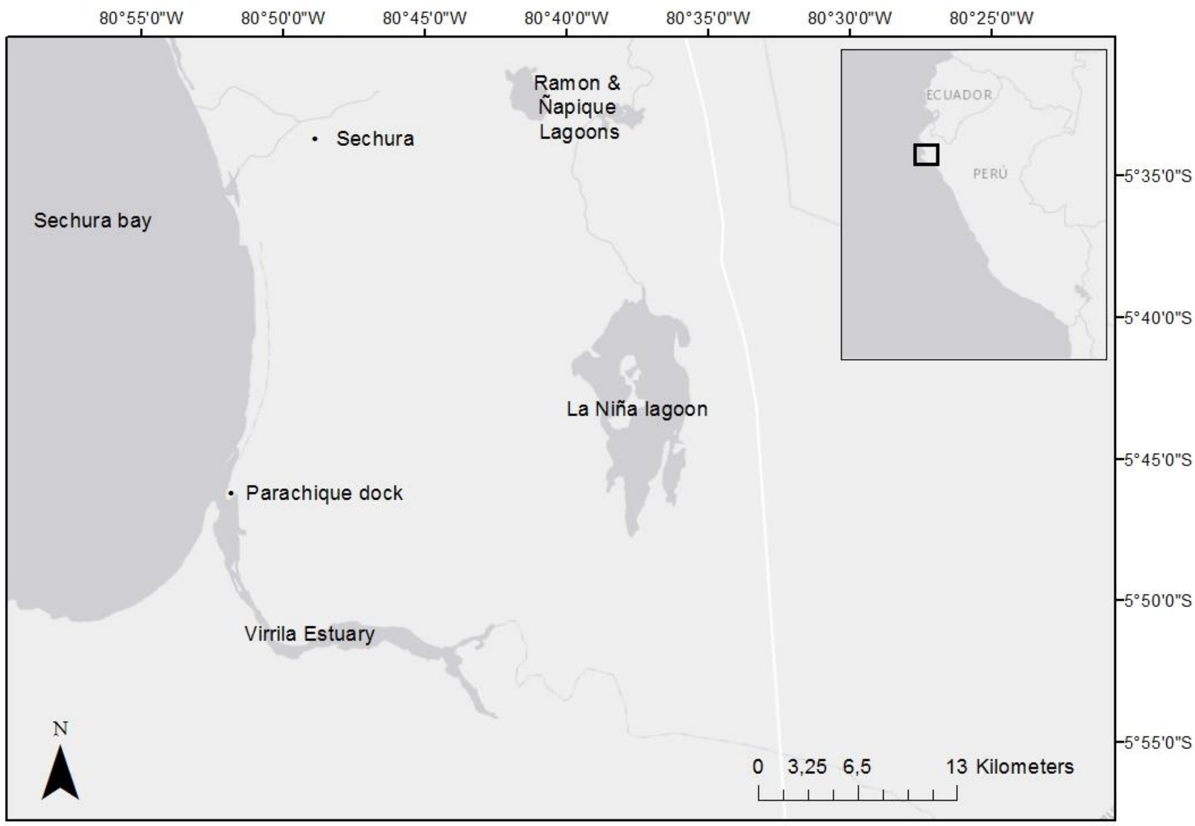


Figure 1. Location of the Virrila Estuary (Peru). The mouth of the estuary is located at the southern part of Sechura Bay and during El Niño events is connected to La Niña, Ramon and Ñapique lagoons.

Parachique is an artisanal dock located at the estuary's mouth and counts with 1,200 artisanal fishermen and a fleet of approximately 250 artisanal boats, which operate mainly at Sechura Bay and offshore. The total population depending on artisanal fisheries is about

3,000 people. The most common fishing gears used are gillnets and trawling nets. The main target species are the Peruvian rock seabass (*Paralabrax humeralis*), Horse mackerel (*Scomber japonicus peruanus*), Peruvian weakfish (*Cynoscion analis*), Peruvian scallop (*Argopecten purpuratus*), Jack mackerel (*Trachurus picturatus murphyi*), starry grouper (*Epinephelus labriformis*) and the striped mullet (*Mugil cephalus*) (CENPAR, 2012). Is important to mention that Parachique artisanal dock depends primarily on the Peruvian scallop aquaculture at natural banks in Sechura Bay, which has been the most important cultured species in Peru in terms of export value until the last coastal EN 2017. The export volume of Peruvian scallop fluctuated between 5,000 tons in 2015 and almost 15,000 tons in 2013, with France as the most important market (Seafood Trade Intelligence Portal, 2016).

Along the estuary, several families temporary fish with wooden rafts targeting mainly the striped mullet *Mugil cephalus* and occasionally white anchovy (*Anchoa nasus*) (Paredes-Coral et al., 2016), with captures ranging from 100 to 270 kg per wooden raft during April 2016 (IMARPE, Unpublished data).

The estuary constitutes an important staging area for migratory birds and sea turtles. Regarding its conservation status, the Virrila Estuary is recognised as an Environmental Conservation Area (ACA) by the Regional Government of Piura (Municipal Ordinance No. 37-2015-MPS) and is listed as an Important Bird and Biodiversity Area (BirdLife, 2017). Moreover, in two occasions the Andean condor (*Vultur gryphus*) was observed opportunistically scavenging on turtle carcasses (Evelyn Paredes, *personal observation*). Additionally, small mammals have been reported, such as the Pampas cat (*Leopardus colocolo*), skunks (*Conepatus chinga*) and the Sechuran fox (*Lycalopex sechurae*) (Garcia-Olaechea & Hurtado, 2016).

IV.2 In-water surveys

In order to assess the population structure, mark-recapture and flipper tag techniques were performed (Seminoff, 2003; Velez-Zuazo et al., 2014; Quiñones et al., in press). Gillnets were designed following the traditional dimensions used by fishermen. Three nets were assembled together with a total length of 380 m, the central net with 180 m length, 4.3 m width and 36 cm mesh size and two lateral nets each one with 100 m length, 3 m width and 42 cm mesh size. Cylindrical floats were attached to the headline and lead weights were distributed along the ground line (Figure 2). Captures were performed at the main island of the estuary (Figure 3) between high and low tide. Gillnets were set across the secondary branch of the estuary using a wooden raft. The first headline was tied to a bush on the main island shore above the high-water mark and the second headline was secure to a wood stick on the other shore. When a turtle was entangled, it was quickly released and transported to the shore for data collection using the wooden raft.

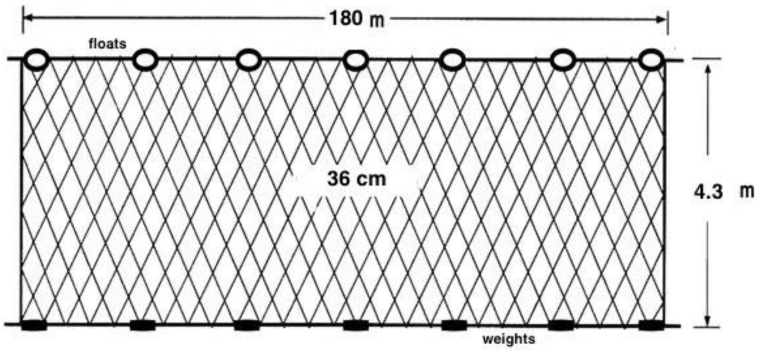


Figure 2. Design details of the central gillnet operated during the in-water surveys at Virrila Estuary (Peru). The lateral nets present the same design with different dimensions.

In total, 13 surveys were carried out at the Virrila Estuary from 2012 to 2017 and one pilot survey carried out in 2011 (Table 1). For the pilot study, a beach-seine net with a mesh size of 2.75 inch (~7 cm) was used. The net was set from an artisanal vessel with the first end of the rope being set perpendicular to the shore, the net set parallel to the shore, and the second end of the rope set back to the shore. Both end of the ropes were hauled onto the shore evenly, by hand, herding the turtles into the net. Hauling continued until the net and turtles were dragged onto the shore. Data from the pilot survey was considered for size composition analysis but excluded from other analysis given the differences in methodology.

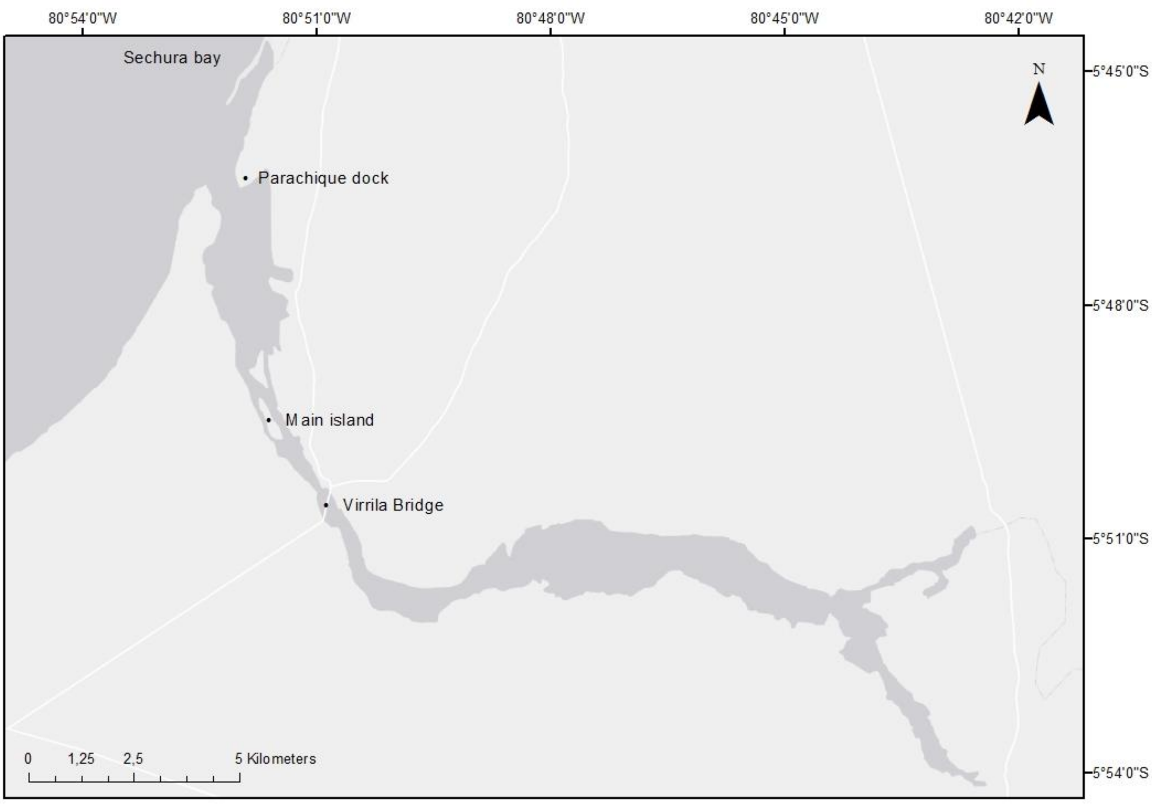


Figure 3. Study area along the Virrila Estuary (Peru). Parachique artisanal dock is located at the estuary mouth. Captures were performed at the main island and stranding surveys along the Northeast, Northwest and Southwest shorelines.

The following biological data of captured turtles were recorded: curved carapace length (CCL), curved carapace width (CCW), head width (HW), total tail length (TTL), post-cloacal tail length (CTL), plastron length (PL) and plastron width (PW). Number of central, lateral and marginal scutes and coloration of the carapace were also reported. Additionally, turtles were weighed using a digital scale. When possible, sex was assigned based on the TTL (Seminoff, 2003).

IV.3 Population parameters

IV.3.1. Size composition, residence time and somatic growth rate

The variability in the size of the East Pacific green turtles at Virrila estuary was determined in function of the CCL. Life stages were assigned according to the size of nesting females in Galapagos (Zárate et al., 2003). All measurements from live and stranded turtles were used. The estimated time of residency within the estuary was calculated as the time interval in days between a turtle's first and last capture. Somatic growth rates (in centimeters per year; cm $year^{-1}$) were estimated from the capture-recapture records as: growth rate = $(\Delta CCL/\Delta t) \times 365$, where ΔCCL was the CCL variation between captures (in cm) and Δt was the number of days elapsed since initial capture. Only turtles with recapture intervals greater than 180 days (6 months) were considered (Sampson et al., 2015), given that Virrila Estuary is located at the transitional zone (ecotone) between the Tropical Eastern Pacific Ecoregion and the Warm Temperate Southeastern Pacific Ecoregion and no marked seasonal effects are expected.

IV.3.2. Body Condition

A rapid visual-assessment technique for categorising body condition based on the shape of a turtle's plastron was used. Three body condition categories were assigned in the field through visual-assessment technique (1) "good" when the plastron was convex; (2) "fair" when it was flat and (3) "poor" when it was concave (Thomson et al., 2009) (Figure 4).

In addition, in order to compare the body condition of turtles at Virrila Estuary with the rest of populations in the Pacific, the body condition index (BCI) was calculated using the following formula: $BCI = body\ mass/SCL^3 * 10^4$ (Luschi et al., 2003). This index is an estimator of the turtle's health condition (Velez-Zuazo et al., 2014).

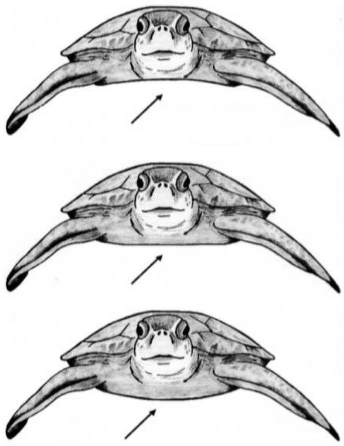


Figure 4. Line drawings illustrating plastron shapes (concave, flat, convex; from top to bottom) used to assign turtles to one of three body condition categories (Poor, Fair, Good). From Thomson et al., 2009.

IV.4 Stranding surveys

Stranding surveys were conducted through the shoreline of the estuary and the main island according to Senko et al (2014) (Figure 3). Every time a carcass was found, species name, carapace measurements and digital photographs were taken. All carcasses were marked with spray paint in order to avoid recounts. The CCL of intact carapaces was measured from the nuchal notch to the longest supracaudal tip using a flexible tape measure to the nearest mm. the location of each carcass was recorded using a handheld GPS device. In total, 12 surveys were carried out at the Virrila estuary from 2013 to 2017 and one pilot survey carried out on 2011 (Table 1). Carcasses were grouped into one of three possible cause-specific mortality categories depending on the external evidence: (1) poaching (when turtles were directly hunted to sell the meat on the black market, that was proved when the plastron was opened and moved aside); (2) boat strike (when the carcass presented injuries and carapaces were broken), and (3) unknown (when there was no obvious cause of death). A standard classification of carcasses was adapted from Flint et al (2009). A carcass condition classification and codification according to the level of decomposition is proposed (Table 3). Codification was assigned from live stranded turtles (D1) to dead ones with only bones remaining (D5). All the maps were done using the software ArcGIS 10.4 (ESRI, 2011).

Table 3. Turtle’s carcass condition and decomposition code adapted from Flint et al. (2009)

Code	Description
D1	Alive but will subsequently die
D2	Dead, carcass in good condition (fresh, suitable for necropsy and stomach content analysis)
D3	Dead, carcass decomposed but organs intact
D4	Dead, carcass in advanced decomposition with internal organs falling apart
D5	Dead, mummified carcass and disarticulated bones

IV.5 Statistical analysis

All statistical tests were performed using R Statistical Software 3.1.0 (R Core Team, 2014). The significance level of the statistical tests was $\alpha = 0.05$. All data were checked for normality using the Shapiro–Wilk test, and when normality was not met, nonparametric statistical analyses were undertaken. All descriptive statistics are presented as mean ± standard deviation (SD). In order to test significant differences in size among the years (2011-2017) an analysis of variance (ANOVA) was performed. When significant differences were detected, Tukey post-hoc test was performed in order to identify the significant different year(s). In order to test significant differences in body condition among life stages and among sampling years, the Kruskal-Wallis test was performed, when significant differences were found, post-hoc Dunn's-test was performed. Likewise, to test significant differences in growth rate among size classes and among sampling years, Kruskal-Wallis test was performed. In order to test the correlation between green turtle occurrence and river discharge, Spearman correlation test was performed.

V. RESULTS

V.1. Population parameters

V.1.1 Captures

During this study, a total of 92.9 net-set hours yielded a total of 603 captured green turtles with an average of 46.4 individuals per survey (range: 14 – 82). From all turtles caught, 581 were captured once and 22 were recaptures among surveys. Besides, two tagged turtles were found stranded during the same survey and two were found stranded between surveys. Additionally, the NGO EcOceanica reported eight tagged individuals. For all subsequent analyses, recaptures occurred during the same survey were excluded. The mean number of unique captures and recaptures was 44.8 ± 17 new turtles per survey (range: 14 – 79) and 1.8 ± 1.8 turtles (range: 0–6) respectively.

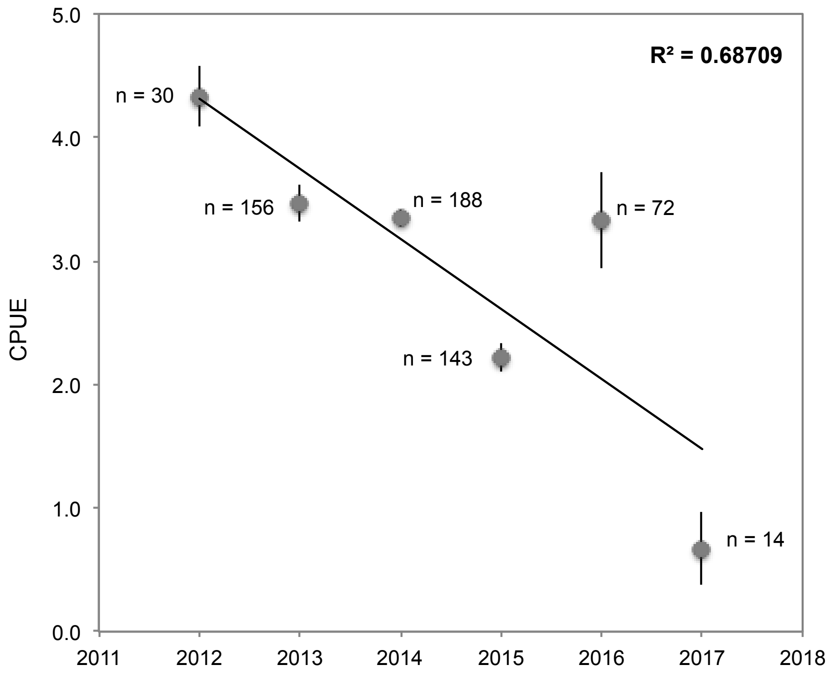


Figure 5. Evolution of the number of caught East Pacific green turtles (*Chelonia mydas*) per unit effort (CPUE) from 2012 – 2017 at Virrila Estuary (Peru). CPUE is expressed in number of turtles per kilometer of net per hour. Error bars indicate standard error. Notice the negative tendency and low values in 2015 and 2017, which match with El Niño events.

During a pilot study carried out in October 2011, a total of 12 individuals were caught. However, this survey was not considered for CPUE estimations given the differences in fishing gear. Caught turtles per unit effort (CPUE) was calculated as the #turtles*km_net/hour. Annual mean CPUE was calculated with a maximum in 2012 (4.3 turtles*km_net/h) and a minimum in 2017 (0.7 turtles*km_net/h) (Appendix 6). Figure 5 shows a negative trend for the CPUE.

In addition, the occurrence of turtles at Virrila Estuary, expressed as CPUE values, during the last EN 2015/2016 and the coastal EN 2017 events showed a high negative correlation with the Piura River discharge, as an indicator of freshwater input (Spearman correlation; rho = -0.64; $p < 0.05$) (Figure 18).

V.1.2 Size composition

For the calculation of size composition, the size (CCL) from alive and stranded turtles was considered together, with a total of 1113 individuals. In general, the size varied between 30.9 and 105.1 cm, with an average size of 64 ± 11.5 cm. Considering only caught turtles (n = 615), individuals weighed on average 34 ± 18.6 kg, ranging from 9.9 to 126.5 kg. Annual estimates per life stage are presented in Appendix 7. At Virrila Estuary, the majority of individuals (63 %; n = 706) were between 50 and 69 cm long (Figure 6) and regarding life stage, 68.7 % (n = 765) of the individuals were classified as juveniles, 26.5 % (n = 295) as sub-adults and 4.8% (n = 53) as adults. The average CCL of adult turtles was 90.2 ± 4.8 cm (range = 85.2 – 105.1 cm).

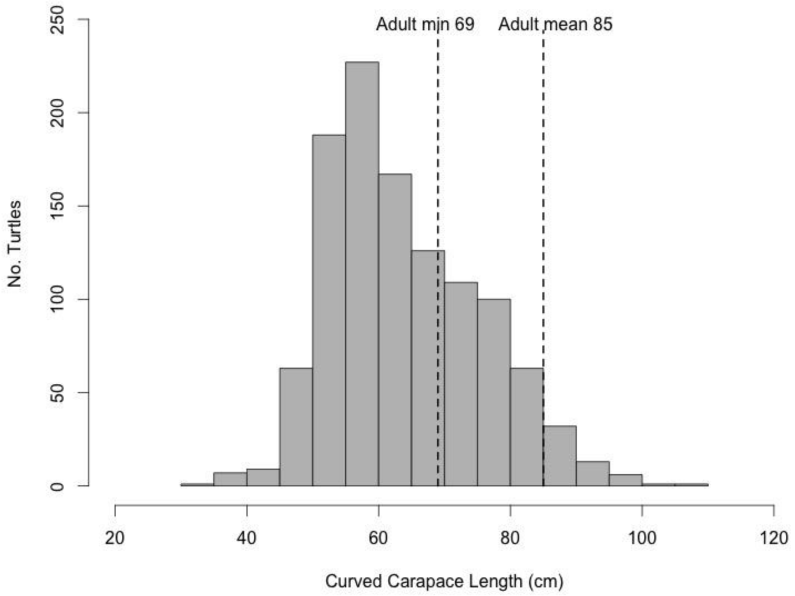


Figure 6. Size composition of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) with a mean CCL = 64 ± 11.5 cm (range 30.9 – 105.1 cm, n = 1113). Notice that turtles at Virrila Estuary are represented mainly by juveniles with the most frequent CCL size-range between 50 - 69 cm. Mean nesting size criteria represented by dotted lines was obtained from Zárate et al. (2013).

Significant differences in size (CCL) among sampling years were detected (ANOVA; F = 9.2196; p = $7.122e^{-10}$), with 2013 and 2014 being significantly lower than 2015 and 2016 (Figures 7 and 8). The larger individuals were presented in 2016 (66.8 ± 12 cm) and the smaller turtles were recorded in 2011 (60.5 ± 9.1 cm).

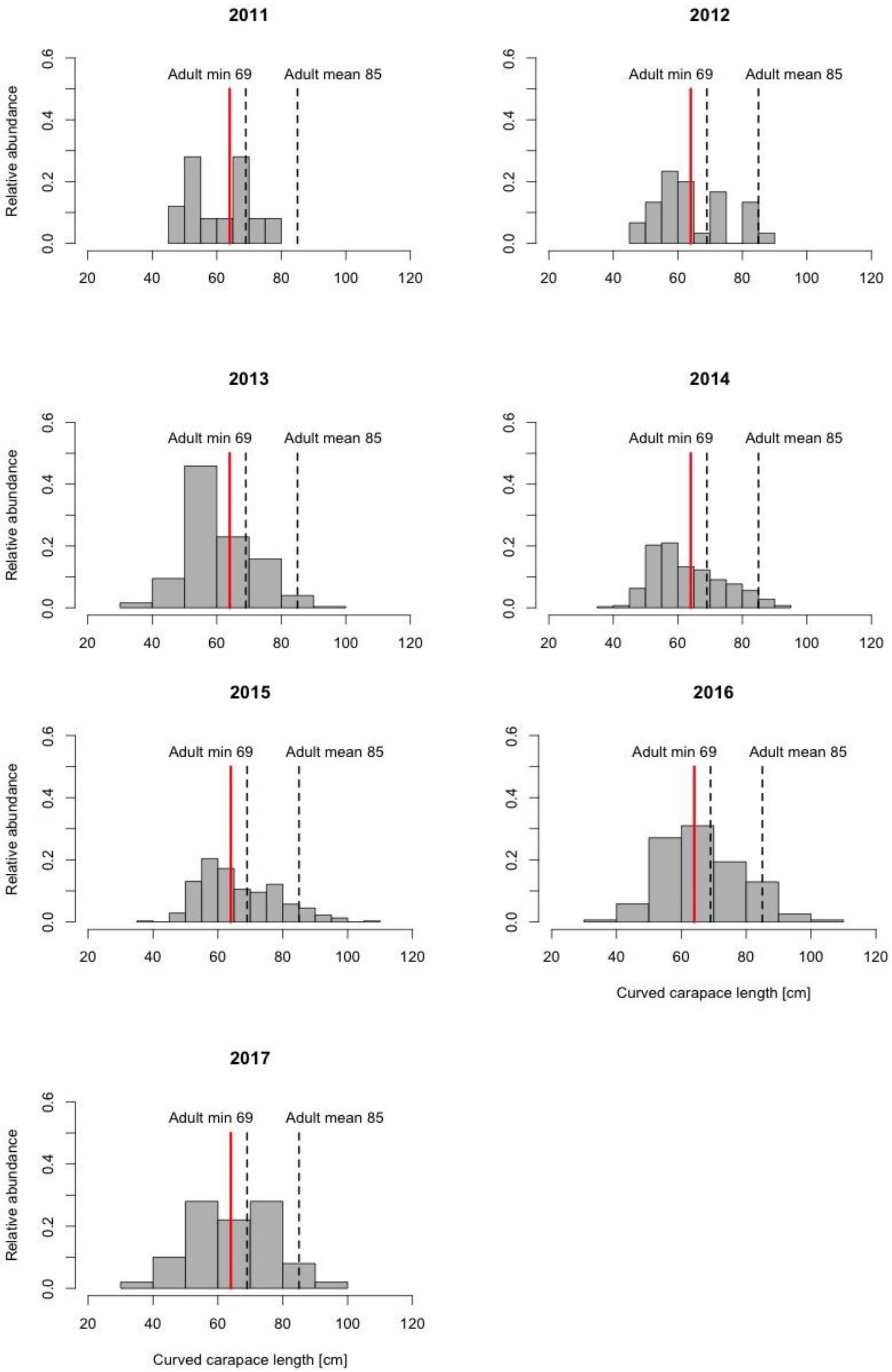


Figure 7. Size composition of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) by sampling year 2011 – 2017. Red lines indicate the mean curved carapace length (mCCL = 64 cm).

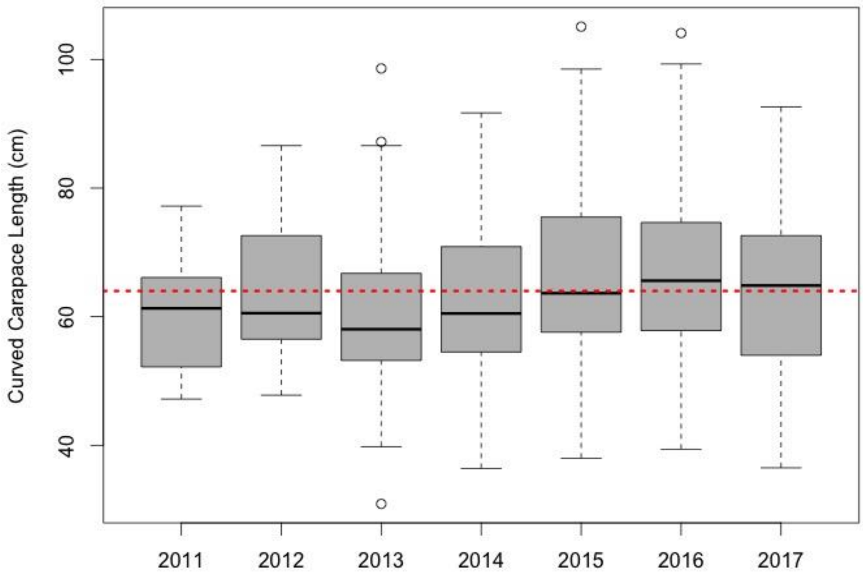


Figure 8. Boxplot showing the size variation among sampling years (2011 - 2017) of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru). Red dotted lines indicate the mean curved carapace length (mCCL = 64 cm).

V.1.3 Residence time

Overall, the mean recapture rate was 4.9 % and most of the individuals were captured only once (95.1 %; n = 567), 4.4 % (n = 26) were captured twice and 0.5 % (n = 3) were captured three times. Mostly juvenile turtles were the most recaptured (n = 24) followed by sub-adults (n = 4) and one adult individual (Figure 9). The recapture time interval had a median of 219.5 days (0.6 yr), with a minimum of 60 days and a maximum recapture interval of 1054 days (2.9 yr).

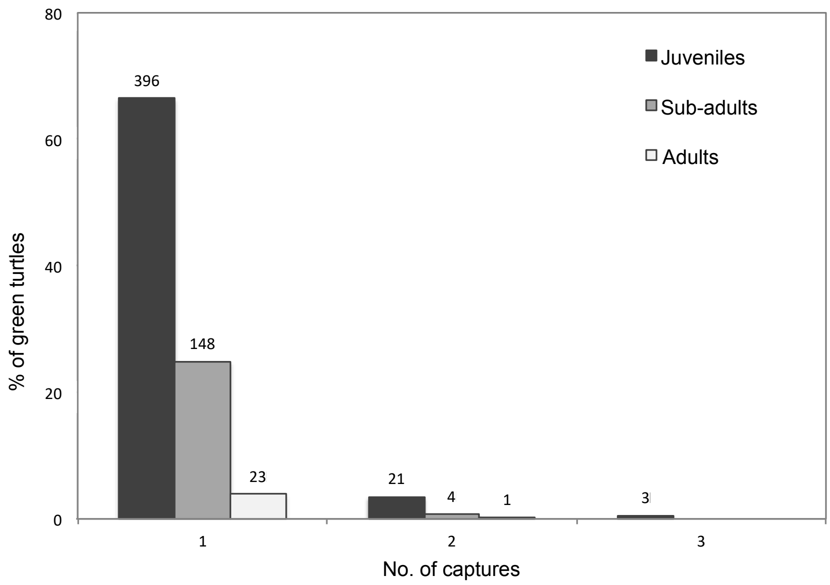


Figure 9. Number of captured East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru). Juvenile (black), sub-adult (grey) and adult (light grey) turtles that were captured once, twice and three times are shown. The labels at the top indicate the total number of turtles.

V.1.4 Somatic growth rate

From all 32 recapture records, only records with recapture intervals equal or higher than 6 months (180 days) were used. Overall, 21 growth increments from 19 individual turtles were recorded, from which 76.1% were juvenile individuals, 19 % sub-adult individuals and 4.8 % adult individual (n = 1). Additionally, growth rates were categorised by 10 cm size classes (Figure 10).

Recapture intervals varied between 196 days (0.5 yr) and 1054 days (2.9 yr), with a median of 324 days (0.9 yr). The overall growth rate (for all size classes and years combined) was estimated at 3.0 ± 2 cm year^{-1} (range: 0.5 – 8.4 cm year^{-1}). Considering only juvenile individuals (n = 16), mean growth rate was estimated at 2.7 ± 1.7 cm year-1 (range: 0.5 – 5.7 cm year^{-1}). Regarding only sub-adults (n = 4), mean growth rate was estimated at 3.9 ± 2.6 cm year^{-1} (range: 2.2 – 8.4 cm year^{-1}). For the only adult individual mean growth rate was 4.4 cm year^{-1}.

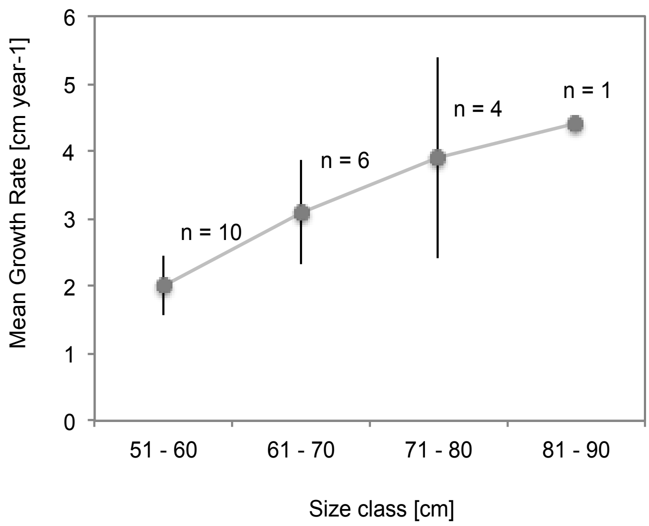


Figure 10. Somatic growth in cm year^{-1} of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) from 2011 to 2017. Error bars show the standard error, n denotes the number of recaptured turtles. Size classes as CCL.

There were no statistical differences in growth rates among size classes (Kruskal-Wallis, $\chi^2(3) = 3.7696$; $p > 0.05$) and sampling years (Kruskal-Wallis, $\chi^2(3) = 3.5706$; $p > 0.05$). Nevertheless, the somatic growth rate showed a non-monotonic pattern with a maximum peak for the 81-90 cm size class with 4.4 cm year-1. However, given that the estimate was obtained from a single individual, this result should be taken with caution.

V.1.5 Body condition

The overall body condition index (BCI) for all size classes and years combined, was 1.38. The lowest BCI exhibited per year and life stage was for juvenile individuals in 2015 (BCI = 1.32), while adult green turtles exhibited the highest BCI in 2012 (BCI = 1.77). However, the last value was obtained from a single individual (Appendix 8). Significant differences in body condition were detected among sampling years (Kruskal-Wallis, $\chi^2(6) = 53.8394$; $p < 0.05$), with BCI in 2011 and 2012 being significantly higher than in 2013, 2014, 2015 and 2016; while in 2017 BCI resulted being significantly higher than in 2014 and 2015 (Figure 12). Besides, significant differences in body condition were detected among life stages (Kruskal-Wallis, $\chi^2(2) = 14.7061$; $p < 0.05$), with juvenile individuals having significantly lower BCI than sub-adult individuals.

The visual-assessment technique to assign the body condition based on the shape of a the plastron indicated that 13.7 % of the turtles at Virrila exhibited good body condition, 53.8 % showed fair body condition and 32.5 % showed poor body condition.

V.2 Stranding occurrence

Overall, 836 green turtles were registered stranded from September 2011 to February 2017 at Virrilla Estuary. Additionally five hawksbill turtles *Eretmochelys imbricata* were registered with a mean CCL of 40.6 ± 6.4 cm (range 34.7 – 51.2 cm), however, they were not considered for further calculations. Dead carcasses were found along the shorelines up to 22.4 km upstream (Appendix 9).

Overall, 498 measurements of CCL were obtained. The mean CCL was 63.7 ± 12.7 cm (range 30.9 – 105.1 cm) and stranded turtles were mainly juveniles (66.7 %; n = 332), followed by sub-adults (27.5 %; n = 137) and adults (5.8 %; n = 29). From the total stranding records, 9.3 % was caused by some kind of anthropogenic interactions while 90.7 % was undetermined.

Undetermined cause was assigned when turtles did not have any exterior sign of injury or when due to the decomposition category, was not possible to infer the cause of death. When analyzing the anthropogenic interactions only, the primary threat for green turtles in the Virrila Estuary was identified as boat strikes (57.7 %; n = 45), followed by direct captures, which were evidenced by butchered carcases (42.3 %; n = 33).

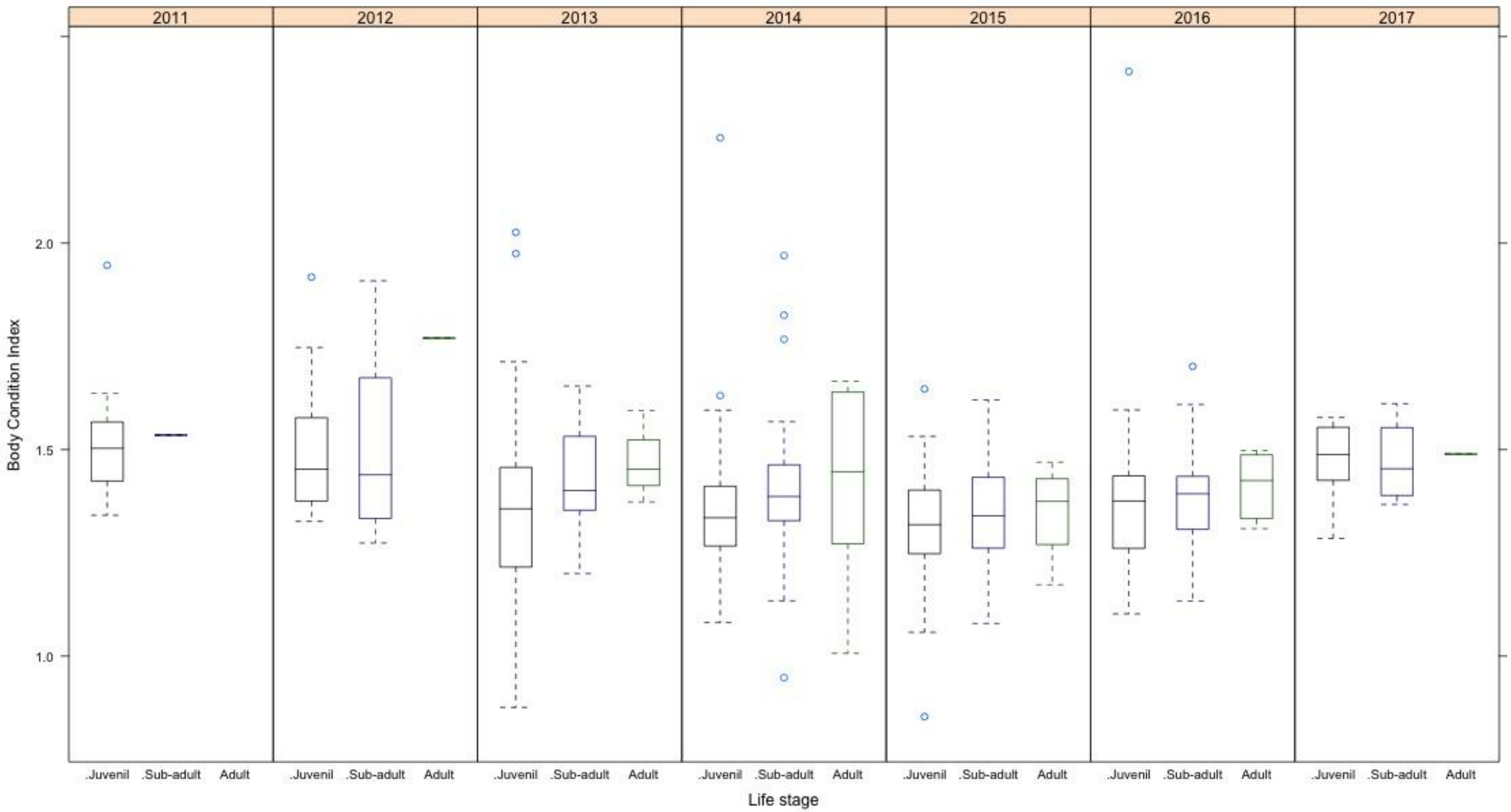


Figure 11. Boxplot for body condition index of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) from 2011 to 2017, classified per life stage: juveniles (black), sub-adults (blue) and adults (green).

VI. DISCUSSION

VI.1 Population parameters

VI.1.1 *Size composition*

The green turtle population at Virrila Estuary was composed mainly of juveniles (68.7%, n = 765), which is consistent with other coastal aggregation areas in the East Pacific, such as Sechura Bay, that was composed primarily by juveniles (89.5 %; n = 90) (Pingo et al., 2017). In line with this, at Paracas, 73 % (n = 117) of the individuals were classified as juveniles (Velez-Zuazo et al., 2014). Moreover, at Bahia Salado, 71 % (n = 5) of the captured turtles were juveniles (Alvarez-Varas et al., 2017). Likewise, 56 % (n = 112) individuals at Bahia de los Angeles were classified as juveniles (Seminoff et al., 2003) and at Machalilla National Park, individuals were dominated by immature/juvenile turtles (60 %; n = 26) (Chaves et al., 2017).

Conversely, at El Ñuro the population was dominated by subadult individuals (74.9 %; n = 152) (Velez-Zuazo et al., 2014). The fact that turtles at Virrila Estuary (~5.7 °S) are smaller than at El Ñuro (~4.2 °S) could be explained considering the differences in the marine biogeographic provinces based on latitudinal patterns. In line with the biogeographic classifications, Virrila Estuary is located between the Tropical Eastern Pacific Ecoregion and the Warm Temperate Southeastern Pacific Ecoregion (Spalding *et al.* 2007) matching the Peruvian (Humboldt) province (Ibañez, 2016). On the other hand, El Ñuro belongs to the ecotone (Hooker et al., 2013) with an affinity to the tropical waters of the Panamaic province (Ibañez, 2016). Thus, the differences in size composition in both areas could be explained as a result of the strong influence of warm and tropical conditions of the Tropical Eastern Pacific Ecoregion at El Ñuro and cold upwelling waters of the Warm Temperate Southeastern Pacific Ecoregion at Virrila Estuary.

VI.1.2 Residence time

At Virrila Estuary, recapture rates were considerably low (4.9 %) compared with other areas such as El Ñuro (26 %; Velez-Zuazo et al., 2014), Northeastern Australia (32 %; Chaloupka et al. 2004), Union Creek in southern Bahamas (41 %; Bjorndal et al. 2000), central coast of Florida (61 %; Kubis et al. 2009), and Bahia Magdalena (up to 32 %; Koch et al. 2007). Even so, some turtles showed to remain in the estuary for extended periods (> 2.5 years). However, a similar low recapture rate (4.2 %; Silva et al., 2017) was reported in southeastern Brazil, the author suggested that this may be caused by the recruitment of turtles migrating from southern areas, as well as recruits from the oceanic zone.

Low recapture rates at Virrila could indicate that turtles move to nearby areas with higher resource availability such as Sechura Bay (Matacaballo, Constante, Playa Blanca, Vichayo and Puerto Rico) in order to feed. Sechura Bay has been reported as an important feeding ground for green turtles (Santillán, 2008; Jiménez et al., 2017) due to its high productivity (Taylor et al., 2007). Thus, turtles seem to exploit available resources in the bay and also benefit from the undisturbed conditions and tranquility at Virrila. Low recapture rates could be also an indicative of high mortality of marked individuals, nevertheless, this was not verified during the stranding surveys. Tag loss could biased the recapture rate, however, few individuals with an indication of tag loss were recorded during the present study and for all of them tags were replaced.

Furthermore, is possible that the number of turtles at Virrila was so high that with the performed sampling effort, tagged turtles were not recaptured during the study period. High emigration rates of marked individuals could be another reason that explains the low recapture rate, specifically for adult turtles, of which a single recapture was recorded. Adult individuals would be using Virrila Estuary as a stepping-stone before migrating northwards in order to reach their reproductive areas and nesting beaches in Galapagos, Central America and Mexico. Additionally, the majority of recaptured turtles were juveniles (83 %), which is consistent with the juvenile-dominated population structure at Virrila Estuary. Still, this study suggest that the population at Virrila is composed by resident and transient individuals given that some turtles spent more than 2.5 years at the estuary.

VI.1.3 Somatic growth rate

Mean growth rate at Virrila Estuary (3.0 ± 2 cm year^{-1}) has one of the highest values in the East Pacific, overpassing values at several feeding and nesting areas such as San Diego Bay (1.03 cm year^{-1}; Eguchi et al., 2012), Bahia de los Angeles (1.4 cm year^{-1}; Seminoff et al., 2003), Punta abreojos (2.4 cm year^{-1}), Laguna San Ignacio (2.1 cm year^{-1}), Bahía Magdalena (1.4 cm year^{-1})(López-Castro et al., 2010), Gorgona Island (0.92 cm year^{-1}; Sampson et al., 2015) and Galapagos Islands (0.18 cm year^{-1}; Zárate et al., 2015). Mean growth rate at Virrila is surpassed only by Paracas (6.8 cm year^{-1}; Velez-Zuazo et al., 2014) and showed to be similar to the ones at El Ñuro (2.8 cm year^{-1}; Velez-Zuazo et al., 2014) and Laguna Ojo de Liebre (3,1 cm year^{-1}; López-Castro et al., 2010) (Figure 12).

When analyzing the somatic growth by size class, turtles at Virrila seem to exhibit a non-monotonic pattern with increasing growth rate as carapace length increases with a peak at 81 - 90 cm CCL (Figure 10). However, this peak was obtained from a unique value thus additional growth data for larger size classes are needed in order to evaluate the location of the growth peak over the entire size range. Then, the real growth peak will probably be located at smaller sizes such as 71- 80 cm CCL.

The non-monotonic pattern is consistent with other populations in the Pacific (Figure 13). For instance, the non-monotonic growth pattern at Bahia de Los Angeles showed an increase from ~55 reaching a peak at 80 - 90 cm SCL and then decreasing for larger individuals (Seminoff et al., 2002b). This is very similar to the pattern at the present study area, however, the growth rates at Virrila Estuary are about four times higher. Likewise, green turtles at the Great Barrier Reef presented a non-monotonic pattern with a peak at ~60 – 70 cm CCL (Chaloupka et al., 2004). Similarly, turtles at Gorgona Island showed the same pattern with a unique peak at 50.0 – 59.9 cm SCL (Sampson et al., 2015).

Contrary to the Pacific pattern, Galapagos Islands exhibited a monotonic pattern with a declining growth rate from 55 to 70 cm SCL (Zárate el al., 2015). Besides, turtles from

Atlantic populations at the Bahamas exhibited a monotonic declining growth pattern, with smaller individuals growing faster than the larger ones (Bjorndal et al., 2000).

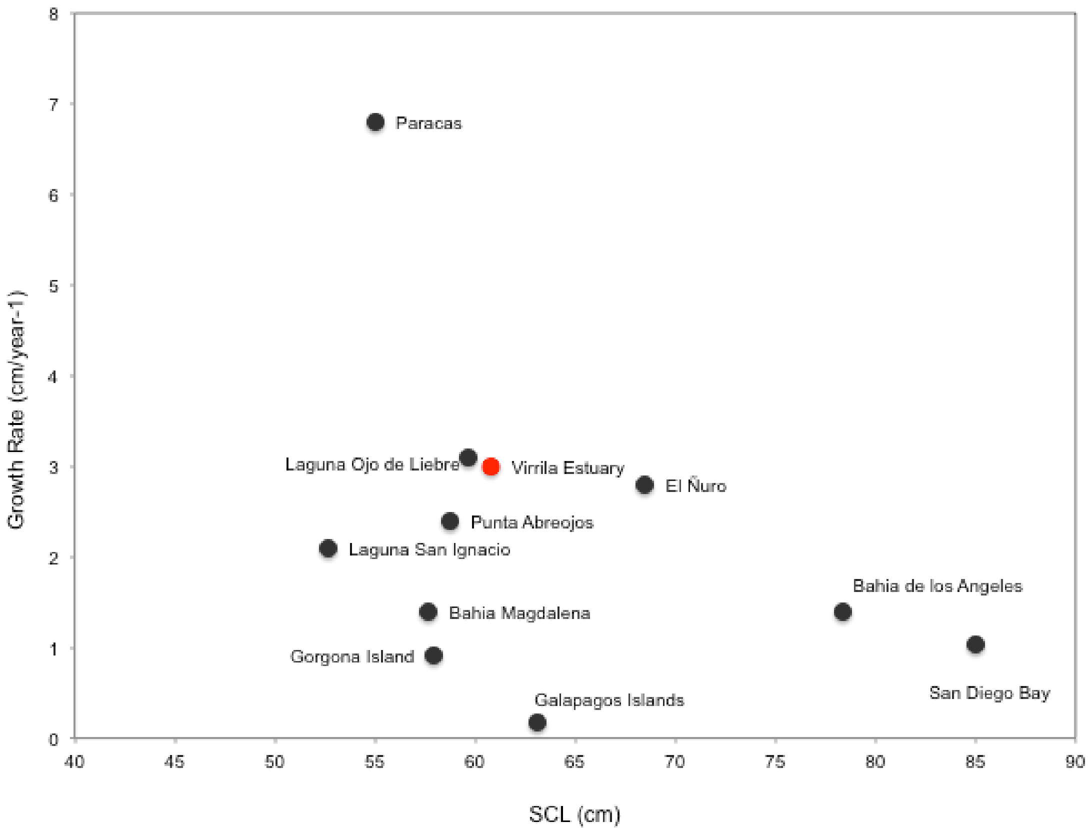


Figure 12. Average growth rate of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) from 2011-2017 compared with values of feeding and nesting areas in the East Pacific by straight carapace length (SCL). The red point indicates the high value of Virrila Estuary.

It is important to remark that at Virrila the single adult individual considered for the estimation of growth rate exhibited the highest value. According to Frazer & Ehrhart (1985), the growth of adult turtles is negligible; however, in this study we observed the highest value for an adult individual (4.4 cm yr^{-1}; CCL = 92.3 cm). Possibly, green turtles at Virrila Estuary may mature at sizes larger than the mean nesting size (CCL = 85 cm). Nevertheless, it has to be taken with caution given that additional growth data for smaller and larger size classes are needed to evaluate the growth function over the entire size range.

Numerous studies indicate that variability in growth rates may be caused by a number of factors such as genetics, environmental conditions, individual health and changes in population density (Limpus & Chaloupka, 1997; Bjorndal et al., 2000; Heppell et al., 2002; Kubis et al., 2009). In line with this, the high somatic growth at Virrila Estuary coincides with its location near an important productivity area, the Sechura Bay (Taylor et al., 2007).

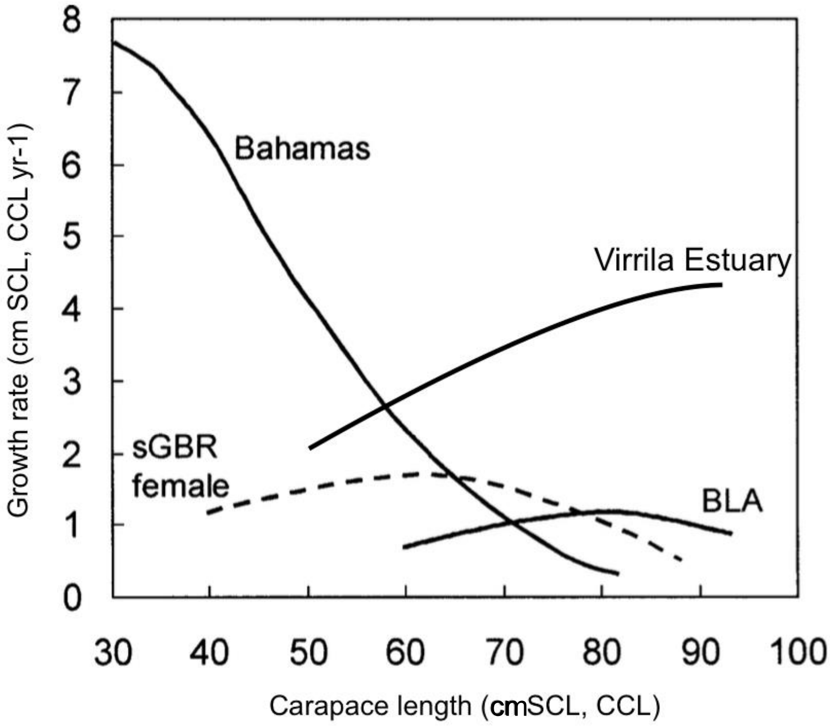


Figure 13. Comparison of size-specific growth rate for East Pacific green turtles (*Chelonia mydas*) from Virrila Estuary (Peru) with green turtle populations in the Bahamas (carapace length as SCL Bjorndal et al., 2000), southern Great Barrier Reef (sGBR, females; carapace length as CCL; Limpus and Chaloupka, 1997) and Bahia de los Angeles (BLA; carapace length as SCL; Seminoff et al., 2002). Qualitative comparisons given the differences in CCL, SCL and sexes are minor (Bjorndal and Bolten, 1989; Limpus and Chaloupka, 1997).

The current results suggest that green turtles at Virrila benefit from the high resource availability at Sechura Bay accelerating their growth. This is consistent with several studies which state that high growth rates have been related with the intake of high energy items, such as anemone, eggs of fish and gastropods and invertebrates in highly productive areas (Paredes-Coral, 2015; Quiñones et al., in press). In line with this, green turtles at Virrila are mostly omnivorous consuming striped mullet (*Mugil cephalus*), jumbo squid discards (*Dosidicus gigas*), shrimps (*Penaeus sp.*), green and red algae and seagrass (*Ruppia maritima*) as important items in their diet (IMARPE, unpublished data; Paredes-Coral, *personal observation*). On the other hand, low energy diet, consisting mainly of algae, jellyfish and floating vegetation has been linked with lower growth rates (Amorocho & Reina 2007; Sampson et al., 2015).

The high somatic growth rate estimated for juvenile individuals underscore the importance of developmental habitats, such as Virrila Estuary for the survival of juvenile turtles, which ultimately can affect the rate of growth and recovery potential of nesting stocks. This study reinforces the hypothesis that environmental productivity and growth rates are linked. Consequently, due to its proximity to Sechura Bay with its upwelling coastal system, Virrila Estuary supports one of the population with the highest growth rate of green turtles in the Pacific. It is possible that green turtles move in and out from the estuary seasonally in order to fulfill their nutritional requirements complementing their fish-based diet at Virrila with a diet rich in patagonian squid (*Doryteuthis gahi*) eggs as well as red and green algae at Sechura Bay (Jimenez et al., 2017).

VI.1.4 Body condition

The mean BCI reported on the present study (1.38) is similar to several other studies in the Eastern Pacific, with a range of 1.2 to 1.7. At Bahia Magdalena, mean BCI was 1.67 (Koch *et al.,* 2007), whereas at Baja California Peninsula the values ranged between 1.2 and 1.4 (López-Castro *et al.,* 2010). Bahia Vizcaino, showed a mean BCI of 1.48 (Rodríguez-Barón *et al.,* 2011) and Bahia de Los Angeles presented a value of 1.42 (Seminoff *et al.,* 2003). Green turtles at Gorgona Island had a mean BCI of 1.38 (Sampson et al., 2014). Moreover, green turtles at El Ñuro and Paracas showed a mean BCI of 1.5 (Velez-Zuazo et al., 2014)**.** This indicates that green turtles at Virrila Estuary exhibited good health and despite the differences in productivity and resource availability of the feeding areas, the body condition of turtles at Virrila Estuary is equivalent to other regions in the East Pacific.

Regarding life stage, adult turtles exhibited the best body condition (BCI = 1.42), followed by sub-adults (BCI = 1.41) and juveniles (BCI = 1.36). This is consistent with the high growth rate values obtained for an adult individual in the present study, which means that healthy turtles will grow faster than the ones in bad shape. As reported by Bolger & Connolly (1989), condition indices can be indicators of changes in the food supply. This could also explain the differences in BCI at each life stage. It is possible that adult green turtles would be feeding better quality food than immature individuals.

The visual method was adequate for the use in the field. However was not possible to compare these data with other green turtle populations in the Pacific given that the method is not broadly used in feeding areas and no information could be found in the literature.

VI.2 Anthropogenic-derived threats

VI.2.1 Boat strikes

Based on the stranding information, the present study reports that anthropogenic activities are affecting the sea turtle population at Virrila Estuary mainly by boat strikes and illegal direct captures.

This is consistent with previous studies that identified boat strikes as an important threat for turtles. Studies performed in the US Gulf of Mexico, the Atlantic coast of Puerto Rico and the US Virgin Islands during the period 1986 – 1993, showed that vessel traffic caused injuries in 9 % of the living and dead stranded sea turtles (Schroeder, 1987; Teas, 1994). At Canary Islands 23.66 % (n = 22) turtles were reported dead with injuries produced by boat-strike (Orós et al., 2005). As reported by Hazel & Gyuris (2006), at least 65 turtles were killed annually as a result of collisions with vessels on the Queensland east coast during the period 1999 – 2002. Likewise, at the Hawaiian Archipelago, boat strike was reported as cause of death of 2.5 % (n = 93) of green turtles in over a 22-year period study (1982 – 2003) and together with shark attack were the hazards most likely to result in dead stranded green turtles (Chaloupka et al., 2008). Additionally, the increase of tourism in Galapagos Islands poses a significant risk of boat collision (Denkinger et al., 2013). The same was reported in Paracas (central Peru) due to the increase of nautical sports and tourism (Quiñones et al., 2017).

Figure 14. East Pacific green turtles (*Chelonia mydas*) with severe injury in the carapace caused by boat strike at Virrila Estuary (Peru). Fractures caused by the propeller of an outboard motor boat typical for the Parachique dock.

Given that the Parachique artisanal dock is located at the mouth of the estuary, there is a dense vessel traffic going in and out of Sechura Bay, which is one of the most important areas for Peruvian scallop aquaculture in Peru (Mendo et al., 2016). Boats with outboard motor ranging from 45 – 60 hp and speed ranging from 6 – 7 kts (11 – 13 km/h) transit every day from and to the Parachique dock. Thus, hundreds of boats are moving daily from Parachique to Sechura Bay and several boats even enter in the estuary around 10 km upstream. Due to the reasons aforementioned, interaction between turtles moving in and out of the estuary and boats are likely to occur. This is consistent with a study conducted by Work et al. (2010), who stated that vessel speed significantly influences the likelihood of catastrophic damage and Hazel et al., (2007), who proposed that vessel speed exceeding 4 km/h increases collision risk with turtles.

During a strike the injuries are produced by both the propeller and the keel, evidenced as fractures and hematoma at the carapace, head and limbs (Figure 14). Several alternatives have been proposed in order to mitigate boat strikes with marine vertebrates such as (1) speed regulation and *go slow zones* (areas with speed limit regulation) (Laist & Shaw 2006, Calleson and Frohlich 2007, Hazel et al. 2007, Shimada et al., 2017), (2) the use of jet propulsion and propeller guards (Work et al., 2010) and (3) limited access to certain areas (Vanderlaan & Taggart, 2009). A detailed analysis of the effectiveness of those alternatives will be discussed in the conservation and management implications section.

VI.2.2 Illegal capture

Illegal capture has been identified as the second main threat affecting green turtles at Virrila Estuary and could be defined as the illicit harvesting of legally protected turtle species in order to use and benefit from the products and by-products. This bad practice has been reported in aggregation areas in Peru (de Paz et al., 2002; 2004; Paredes-Coral et al., 2016; Quiñones et al., 2017), Mexico (Mancini et al., 2009; 2011; Koch et al., 2006; Senko et al., 2014), Cape Verde Archipelago (Hancock et al., 2017) and Gulf of Venezuela (Barrios-Garrido et al., 2017).

Figure 15. East Pacific green turtle (*Chelonia mydas*) illegally captured and butchered at Virrila Estuary (Peru). The undercover plastron indicates that the meat was extracted for human consumption.

In Peru, a traditional turtle fishery has been reported in Pisco (Quiñones et al., 2017). However, this is the first study reporting illegal captures at Virrila Estuary. Some fishermen enter in the estuary specifically to capture turtles, using gillnets set as beach-seines and hauled to the shore by hand, herding the turtles into the net. The operation continues until the net and turtles are dragged onto the shore. This was evidenced during the stranding surveys, when turtles were found with the plastron opened and without flesh (Figure 15). Turtle meat is then commercialized at the central market “Mercado de Sechura” (*Sechura market*) in the seafood section (Figure 16), however, traders hide the meat because they are aware that its commercialization is prohibited.

Figure 16. Illegal trade of East Pacific green turtle (*Chelonia mydas*) meat at the seafood section of Mercado de Sechura (Peru). Price per kg: about 2.5 US$. Photography: Sixto Quispe.

Another method used by fishermen is the capture with retention. If a turtle get entangled in the net and is sighted by the fishermen, they do not disentangle the turtle, instead, they let the turtle drown and keep it in order to butcher it. The price per kg is around 2.5 US$ but could vary according with the demand. Apparently, this practice occurs seasonally, associated with the closure of the anchovy (*Engraulis ringens*) fishery and after the jumbo squid (*Dosidicus gigas*) fishery season, when fishermen target other resources such as the stripped mullet (*Mugil cephalus*) in the estuary, increasing the risk of interaction with green turtles.

VI.3 Climate-driven occurrence of green turtles at the Virrila Estuary

Green turtle abundance, expressed as CPUE, showed a decreasing tendency among the sampling years with the lowest abundances in 2015 and 2017 (Figure 5). This seems to be associated with climate variability during El Niño 2015/2016 and coastal El Niño 2017 events. The decrease in the turtle occurrence during periods of extreme rainfall could be explained due to the decrease in salinity at the estuary caused by the freshwater input by the Piura River.

It is important to remark that the impact of a given EN event on the Peru ecosystem depends on its intensity and spatial structure (Espinoza-Morriberón et al., 2017). For instance, the 'central Pacific' EN events are not likely to have the same strong impact near the Peruvian coast compared to the 'Eastern Pacific' EN or the 'coastal' EN events. The ENSO is the dominant mode of interannual climate variability across the Pacific Ocean basin, with influence on the global climate (Barnard et al., 2017). Rather, the 'coastal' EN is restricted to the territories of Peru and Ecuador. Warm water is pooled off the coast of southern Ecuador and northern Peru and torrential rains fell in both countries with catastrophic consequences such as flooding and landslides (Fraser, 2017).

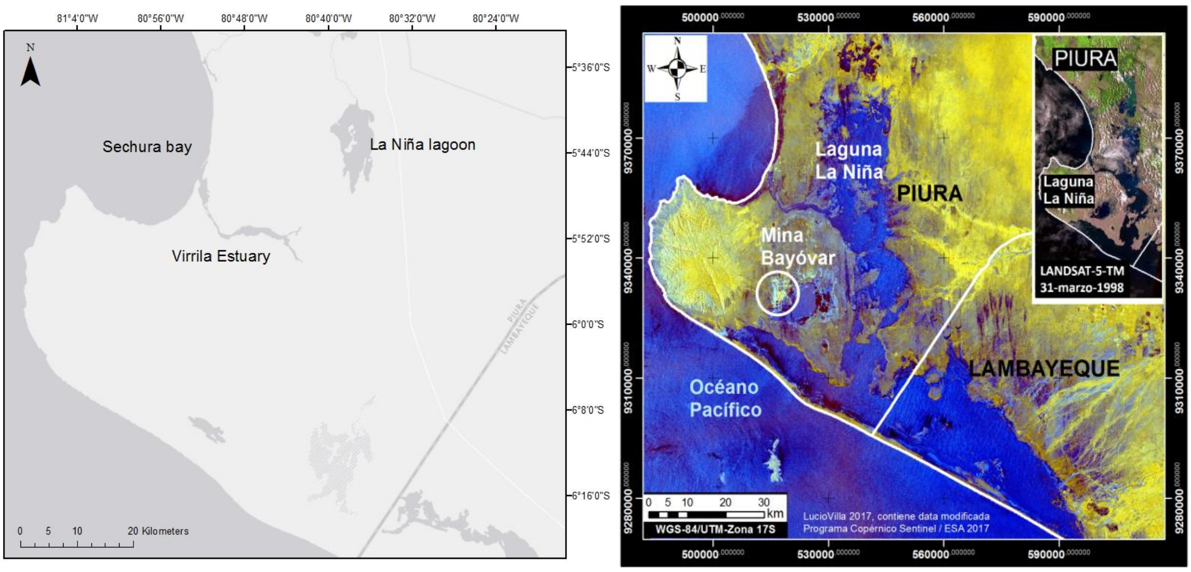


Figure 17. (Left) La Niña lagoon and Virrila Estuary (Peru) during neutral conditions. (Right) La Niña lagoon formation (in blue) after extreme rainfall during El Niño 2017 connected to Virrila Estuary. The figure in the upper right corner indicates the effects of the very strong EN 97/98 in La Niña lagoon formation. Image obtained from a radar image Sentinel-1B Dual-Polarimetry from March 23, 2017. Source: Villa L, 2017.

During an EN event, the conditions at Sechura Bay are characterised by the increase in water temperatures and sea level, as well as severe rainfall. The production of commercial Peruvian scallop dramatically decreases due to the increase of sedimentation rates and riverine inputs diminishing salinity to levels lower than tolerated (Mendo et al., 2016).

Particularly for the Virrila Estuary, the connection with La Niña lagoon could be re-established and the estuary receives high freshwater input, thus increasing its water level and decreasing its salinity.

During the present study, one EN event occurred from September 2015 to March 2016, which was characterised for being one of the three strongest events in the historical record (Huang et al., 2016; L'Heureux et al., 2016) and one coastal EN event from January to May 2017. However, the very strong EN 2015/2016 did not have the same catastrophic effects as the coastal EN 2017 along the Peruvian northern coast and Ecuador.

In March 2017 extreme rainfall across Peru led to flooding and landslides. In Piura 51.3 mm of rainfall was measured, resulting in flooding, which affected 12,000 people. In relation with the latter, severe rainfall increased the Piura river flow and La Niña lagoon extension, allowing the connection with the Virrila Estuary. Consequently, the estuary received abundant influx of freshwater and decreased its salinity to very low levels (e.g. 0.04 psu at the main island in February 2017), thus, producing changes in the biota that inhabits the estuary.

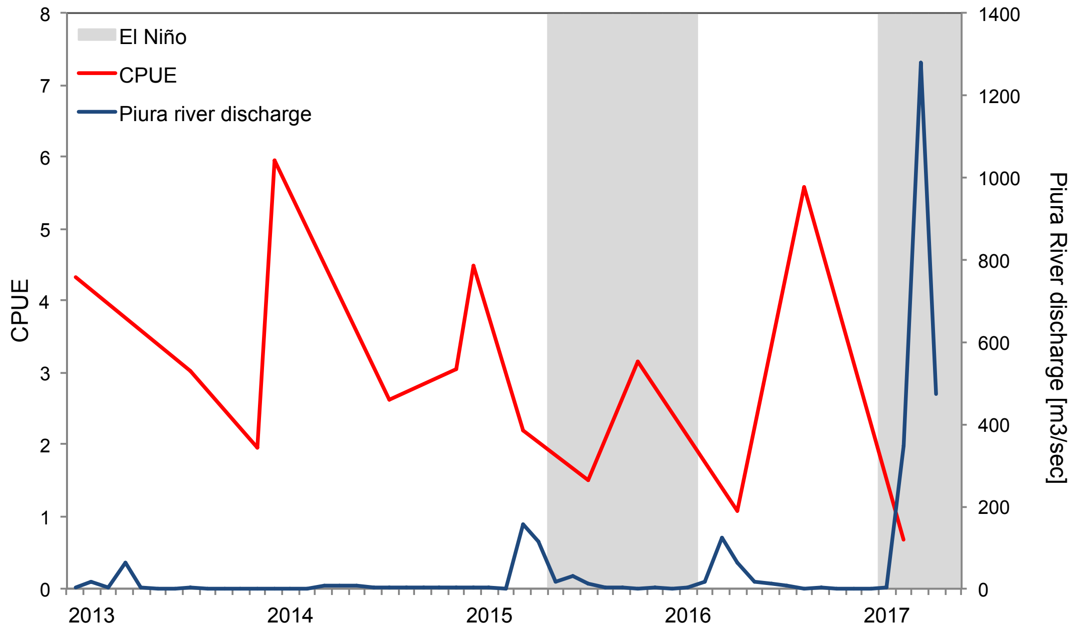


Figure 18. Time series of monthly Piura River discharge values (blue line) and abundance of the East Pacific green turtles (*Chelonia mydas*) as catch per unit effort (CPUE, red line). Shaded grey boxes represent the very strong El Niño 2015/2016 and the Coastal El Niño 2017.

We suggest that green turtles emigrate from Virrila Estuary during EN events due to salinity changes and also due to changes in the prey availability. We hypothesise that changes in fish, seaweed, and benthonic community composition at the estuary and at Sechura Bay may influence the migration of green turtles, seeking for other feeding areas with better quality food. In line with these, diet studies in the Galapagos Islands suggested that EN events may profoundly influence green turtle nutrient intake, with a consequently decline of growth rates and a delay of the size-at-maturity. Furthermore, studies at the Galapagos nesting beaches support the idea that EN does not favour the green turtle occurrence given that the lowest number of nesting green turtles were reported during EN events (e.g. EN 1982/83) (Hurtado, 1989). Moreover, low quality food during EN would not allow nesting females to reach the required body condition to breed, which may drive interannual variation in nesting numbers, as has been reported at the northern coast of Australia (Limpus & Nicholls, 1988; Carrión-Cortez et al., 2010).

Additionally, massive mortality of stripped mullet (*Mugil cephalus*) was reported at Sechura Bay and Virrila Estuary during the last coastal EN 2017 due the warm waters (Javier Quiñones, *personal communication*). Given that green turtles consume the stripped mullet as part of their regular diet at Virrila, the mortality of this fish could favour their emigration.

Conversely to the turtle response at Virrila, Quiñones et al. (2010) reported exceptionally large numbers of green turtle landings during EN events in Pisco (central Peru). The author stated that warmer waters facilitate green turtle access to the area. Similarly, an increase in sea turtle bycatch was reported during EN 1997/1998 in Lambayeque (northern Peru), which was associated with the increment in SST (Castro et al., 2012). This could be due to the fact that Pisco and Lambayeque are important coastal upwelling areas with more influence from the Humboldt Current, where the drastic temperature variations (SST and aSST) would be more noticeable. Additional, it is possible that at those areas, EN conditions may enhance seagrass and algal growth with positive consequences for feeding green turtles (Poloczanska et al., 2009).

VI.4 Conservation and management implications

In order to implement conservation strategies it is important to identify and prioritise the main threats and to be able to allocate scarce resources in threat-mitigation programs (Hazel & Gyuris, 2006). In most of the cases, active management intervention is needed. The following section presents an analysis of the major anthropogenic-derived threats identified and ranked at Virrila Estuary, potential threats and the alternatives suggested for managers.

VI.4.1 Boat strikes

As mentioned in section VI.2.1, boat strikes constitute the first major anthropogenic-derived threat at Virrila Estuary. The need for minimise the interactions and reduce the consequences of these interactions is an urgent conservation issue.

Avoindance of specific areas as a voluntary conservation initiative showed to be effective in the Roseway Basin Area (Southwest Scotian Shelf, Canada) to reduce the risk of lethal vessel strikes to right whales (Vanderlaan & Taggart, 2009). However, closure of areas is not always feasible, so it is important to also identify methods to reduce the impacts of vessel strikes. A study reported by Work et al. (2010) suggested that changes in both vessel operation and configuration could reduce this threat. According to their results, vessel speed influences significantly the probability of catastrophic damage. Also, they proposed that the use of jet propulsion systems bring dramatic improvements in animal safety compared to the traditional outboard and propeller arrangement. However, even if jet propulsion system is less expensive than the traditional outboard and propeller arrangement, it consumes much more fuel than the outboard making it less attractive for fishermen.

In areas subject to vessel traffic, speed limit regulations appeared to be effective for manatees in Florida. However, the effectiveness depends in the design and enforcement, those regulations will favour animals by given them more time to detect and avoid approching boats (Laist & Shaw 2006; Calleson & Frohlich 2007). Management zoning based on the species habitat use has been suggested to mitigate boat strikes in Australia. The authors stated that the creation of *go slow zones* must consider the habitat use of the species, otherwise, the effectiveness will be limited (Shimada et al., 2017).

According to the present results, urgent management measures are needed to be implement at Virrila Estuary and Sechura Bay, given that those areas do not have regulations regarding speed limits, propeller protection or restricted zones to mitigate boat strikes. Speed limit regulation aligned with turtle habitat use seem to be the most adequate measure for the study area. For that, studies on habitat use using satellite tracking are necessary in order to reveal the movements, home range and hotspots of turtles. Moreover, in line with the regulations, it is also necessary to execute continuous controls and to apply sanctions at the dock and at sea. The effectiveness of the aforementioned regulations has to be measured and monitored.

VI.4.2 Illegal capture

The present study identifies illegal captures as the second main anthropogenic-derived threats at Virrila Estuary. According to our findings, the main reasons for illegal capture at Virrila Estuary were direct economic benefits, strong family tradition and vengeful attitude when turtles feed on the catch in their nets and lack of law enforcement (inspections and sanctions).

During the closure of the anchovy (*Engraulis ringens*) fishery season and after the jumbo squid (*Dosidicus gigas*) season, fishermen at Parachique change the target species and fish on striped mullet (*Mugil cephalus*). Thus, when stripped mullet is abundant at the estuary, fishermen enter to fish and to capture also turtles. Some of them kill turtles, because these are attracted to their nets and feed on the catch in the nets. Moreover, some of the fishermen that temporary inhabit the estuary shores benefit directly from turtles by poaching and trading turtle meat at the Sechura market.

The Parachique and Constante coastal communities consume other turtle by-products such as turtle oil and turtle blood. As a family tradition, they believe that those by-products have healing properties against asthma and respiratory diseases and will make them live longer.

Last but not least, the lack of legislation enforcement is evidenced by the absence of control, inspections and sanctions by the authorities. Control is necessary at the dock, however, many fishermen land illegally captured turtles on the estuary shores, where there is no control and are no witnesses. Another practice of fisherman at Virrila is to land turtles at night.

According to the fishermen's *modus operandi* at the study area, we strongly suggest the interinstitutional and active collaboration between the stakeholders (lead by the National Forest and Wildlife Service - SERFOR). Control at the dock and at sea (by Coat guard - DICAPI, Public Ministry inspectors, Ministry of Production - PRODUCE, Peruvian Institute for Marine Research - IMARPE, National Police of Peru), inspections at markets and restaurants (by Public Ministry inspectors and PRODUCE) together with awareness campaigns in the media in order to spread the legislation that protect turtles (PRODUCE, Ministry of the Environment - MINAM). Continuous education campaigns on the ecological importance of turtles by NGOs directed to fisherman guilds and coastal communities are also very important. The results of the present study provide both qualitative and quantitative data to gain a better understanding of illegal turtle captures at Virrila Estuary.

VI.4.3 Others potential threats

The effects of potential threats like pollution causing habitat degradation remain unclear at Virrila Estuary. However, discards and waste from fishing activities at Parachique dock and the Peruvian scallop aquaculture at Sechura Bay put at risk the turtles that inhabit the area. During all the surveys, abundant presence of plastic waste such as oil bottles from boats, plastic bags, plastic bottles, net remnants and pieces of wood was noticeable, primarily at the estuary entrance (La Bocana). Moreover, other threats such as sudden tidal changes, entanglement and hook-and-line ingestion (Paredes-Coral et al., 2015) and parasitic infections (Gomez-Puerta et al., 2017) could be causing turtle deaths, however, the magnitude of those impacts is still undetermined.

It is necessary to continue recording information at Virrila Estuary and other coastal areas along the Peruvian coast. The present study suggests that the implementation of health assessment programs are necessary in order to discard fibropapilloma and quantify the levels of contaminants in turtles inhabiting the Estuary, given that during the coastal EN 2017, the rains have washed rubbish, metals and chemicals from towns, mining operations and farmlands into the ocean. Additionally, genetic studies to reveal the degree of connectivity between aggregation sites should be conducted together with satellite tracking.

In order to provide decision-makers with alternative management and policy options and in order to assess the possible impacts of these options, is necessary to propose a range of management options/scenarios regarding the conservation of turtles. This includes analysing the socio-ecological processes that generate the main threats to turtles, such as illegal captures and bycatch, as well as using participatory techniques that involves the coastal community, scientists, managers and politicians. This would allow to assess and improve the effectiveness of national and regional conservation strategies to restore turtle populations such as the ongoing Peruvian Action Plan for the conservation of sea turtles.

VII. CONCLUSIONS

- According to the results shown in the present study, Virrila Estuary is an important developmental area for the East Pacific green turtle (*Chelonia mydas*), harbouring mainly juvenile individuals (68.7 %; n = 765), followed by sub-adults (26.5 %; n = 295) and few adult individual (4.8 %; n = 53).

- Green turtles at Virrila Estuary showed a low recapture rate (4.9%) indicating that it is a large population.

- Residence time at the estuary was relatively low. However, some individuals inhabit the area around 2.9 years.

- Somatic growth rate was one of the highest at the East Pacific, with larger turtles growing faster than juvenile individuals.

- Both somatic growth rate and body condition indicated that individuals at the study area are healthy probably due to the ingestion of high quality food.

- Stranding data allowed to obtain valuable information about anthropogenic-derived threats, identifying boat strikes as the major threat (57.7 %; n = 45) followed by illegal captures (42.3 %; n = 33).

- El Niño events have negative effects on green turtle abundance in the estuary.

- This study indicates the necessity of management efforts to prevent and reduce anthropogenic-derived threats on turtles at the estuary and the need of an active management intervention and law enforcement in Peru.

VIII. REFERENCES

- Alfaro- Shigueto, J., Mangel, J. C., Bernedo, F., Dutton, P. H., Seminoff, J. A., & Godley, B. J. (2011). Small- scale fisheries of Peru: a major sink for marine turtles in the Pacific. *Journal of Applied Ecology, 48*(6), 1432-1440.

- Alvarado-Díaz, J.; Delgado-Trejo, C. & I. Suazo-Otuño. (2001). Evaluation of the black turtle project in Michoacan, Mexico. Marine Turtle Newsletter, 92, 4-7.

- Álvarez-Varas, R., Contardo, J., Heidemeyer, M., Forero-Rozo, L., Brito, B., Cortés, V., Brain, M.J., Pereira, S. & J. A. Vianna. 2017. Ecology, health and genetic characterization of the southernmost green turtle (Chelonia mydas) aggregation in the Eastern Pacific: implications for local conservation strategies. Lat. Am. J. Aquat. Res., 45(3): 540-554

- Amorocho, D. & R. Reina. (2007). Feeding ecology of the East Pacific green sea turtle Chelonia mydas agassizii at Gorgona National Park, Colombia. Endangered Species Research, 3(1), 43–51.

- Apaza, M., Pesantes, M. A., Tovar, C. (2005). Plan de Manejo Participativo de los Recursos Naturales del Estuario de Virrilá. Asociación Perú Verde y Comité Holandés de la IUCN. 54 p.

- Aranda, C.A. & M.W. Chandler. (1989). Las tortugas marinas del Perú y su situación actual. Boletín de Lima, 11(62), 77-86.

- Arauz, R., Steiner, T., Amorocho, D. & J. Carrión-Cortez. (2013). Home Range and Migration of East Pacific green turtles (Chelonia mydas) tagged in Cocos Island National Park, Costa Rica. In Proceedings of the International Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC- 640:122.

- Arthur, K.E., McMahon, K.M., Limpus, C.J. & W.C. Dennison. (2009). Feeding ecology of green turtles (Chelonia mydas) from Shoalwater Bay, Australia. Mar Turt Newsl, 123, 6-12.

- Ayón, P., Purca, S., & Guevara-Carrasco, R. (2004). Zooplankton volume trends off Peru between 1964 and 2001. ICES Journal of Marine Science, 61(4), 478-484.

- Barber, R. T. & F. P. Chavez, (1983). Biological consequences of El Nin˜o. Science 222: 1203–1210.

- Barnard, P. L., Hoover, D., Hubbard, D. M., Snyder, A., Ludka, B. C., Allan, J., ... & McCandless, D. (2017). Extreme oceanographic forcing and coastal response due to the 2015–2016 El Niño. *Nature Communications*, *8*.

- Barrientos-Muñoz, K. G., Ramírez-Gallego, C., & Rivas, L. (2013). First Report of Nesting of the Black Sea Turtle (Chelonia mydas) on the North Pacific Coast of Colombia. Marine Turtle Newsletter, (138), 19

- Barrios-Garrido, H., Espinoza-Rodríguez, N., Rojas-Cañizales, D., Palmar, J., Wildermann, N., Montiel-Villalobos, M. G., & Hamann, M. (2017). Trade of marine turtles along the Southwestern Coast of the Gulf of Venezuela. *Marine Biodiversity Records*, *10*(1), 15.

- Bertrand, A., M. Segura, M. Gutierrez & L. Vasquez, (2004). From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish and Fisheries 5: 296–316.

- BirdLife International (2017) Important Bird Areas factsheet: Estuario de Virrila. Downloaded from http://www.birdlife.org on 09/07/2017.

- Bjorndal, K.A. & J.B. Jackson. (2003). Roles of Sea Turtles in Marine Ecosystems: Reconstructing the Past. The Biology of Sea Turtles, 2, 261.

- Bjorndal, K. A., Bolten, A. B., & Chaloupka, M. Y. (2000). Green turtle somatic growth model: evidence for density dependence. Ecological Applications, 10(1), 269-282.

- Bjorndal, K.A. (1980). Nutrition and grazing behavior of the green turtle Chelonia mydas. Marine Biology, 56(2), 147-154.

- Blanco, G.S., Morreale, S.J., Bailey, H., Seminoff, J.A., Paladino, F.V. & J.R Spotila. (2012). Post-nesting movements and feeding grounds of a resident East Pacific green turtle Chelonia mydas population from Costa Rica. Endangered Species Research, 18, 233-245.

- Bolger, T., & Connolly, P. L. (1989). The selection of suitable indices for the measurement and analysis of fish condition. Journal of Fish Biology, 34(2), 171-182.

- Calleson, C. S., & Frohlich, R. K. (2007). Slower boat speeds reduce risks to manatees. *Endangered Species Research*, *3*(3), 295-304.

- Carr, A. (1987). New perspectives on the pelagic stage of sea turtle development. Conservation Biology, 1(2), 103-121.

- Carr, A. & A.B. Meylan. (1980). Evidence of passive migration of green turtle hatchlings in Sargassum. Copeia, 366-368.

- Carrión-Cortez, J.A.; Zárate, P. & J.A. Seminoff. (2010). Feeding ecology of the green sea turtle (Chelonia mydas) in the Galapagos Islands. Journal of the Marine Biological Association of the United Kingdom, 90(5), 1005-1013.

- Casale, P., Affronte, M., Insacco, G., Freggi, D., Pino d' Astore, P., Basso, R., Paolillo, G., Abbate, G., (2010). Sea turtle strandings reveal high anthropogenic mortality in Italian waters. Aquatic Conservation: Marine and Freshwater Ecosystems 20 (6), 611e620.

- Castro, J., de la Cruz, J., Ramírez, P., & Quiñones, J. (2012). Captura incidental de tortugas marinas durante El Niño 1997-1998, en el norte del Perú. Latin american journal of aquatic research, 40(4), 970-979.

- Chacón-Chaverri, D., Martínez-Cascante, D. A., Rojas, D., & Fonseca, L. G. (2015). Captura por unidad de esfuerzo y estructura poblacional de la tortuga verde de Pacífico (Chelonia mydas) en el Golfo Dulce, Costa Rica. Rev. Biol. Trop, 63(Supl 1), 363-373.

- Chaloupka, M., Work, T. M., Balazs, G. H., Murakawa, S. K., & Morris, R. (2008). Cause-specific temporal and spatial trends in green sea turtle strandings in the Hawaiian Archipelago (1982–2003). *Marine Biology*, *154*(5), 887-898.

- Chaloupka, M., Limpus, C., & Miller, J. (2004). Green turtle somatic growth dynamics in a spatially disjunct Great Barrier Reef metapopulation. Coral Reefs, 23(3), 325-335.

- Chaloupka, M., & Limpus, C. (2001). Trends in the abundance of sea turtles resident in southern Great Barrier Reef waters. Biological Conservation, 102(3), 235-249.

- Chaves, J. A., Peña, M., Valdés-Uribe, J. A., Muñoz-Pérez, J. P., Vallejo, F., Heidemeyer, M., & Torres-Carvajal, O. (2017). Connectivity, population structure, and conservation of Ecuadorian green sea turtles. Endangered Species Research, 32, 251-264.

- Chavez, F. P., Bertrand, A., Guevara-Carrasco, R., Soler, P., & Csirke, J. (2008). The northern Humboldt Current System: Brief history, present status and a view towards the future.

- Chavez, F. P., P. G. Strutton, G. E. Friederich, R. A. Feely, G. C. Feldman, D. G. Foley & M. G. McPhaden. (1999). Biological and chemical response of the equatorial Pacific Ocean to the 1997–

1998 El Niño. Science 286: 2126–2131.

- Convention on International Trade in Endangered Species of Wild Fauna and Flora, March 3rd, 1973, 993 U.N.T.S. 243.

- Csirke, J., (1989). Changes in the catchability coefficient in the Peruvian anchoveta (Engraulis ringens) fishery. In Pauly, D., P. Muck, J. Mendo & I. Tsukayama (eds), The Peruvian Upwelling Ecosystem: Dynamics and Interactions, Vol. 18. ICLARM Studies and Reviews, Manila: 207–219.

- De Paz, N. & J. Alfaro-Shigueto. (2008). "Foraging grounds for sea turtles in inshore Peruvian waters". In: Kalb H., Rhode A., Gayheart K., Shanker K. (Eds.) Proceedings of the Twenty-Fifth Annual Symposium on Sea Turtle Biology and Conservation. USA: NOAA Technical Memorandum NMFS-SEFSC-582, 88.

- De Paz, N., J.C. Reyes & M. Echegaray. 2004. Capture and trade of marine turtles at San Andrés, Southern Peru. In M.S. Coyne & R.D. Clark (eds.). Proceedings of the Twenty-First Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS–SEFSC, 528: 52-54.

- De Paz, N., J.C. Reyes & M. Echegaray. 2002. Datos sobre captura, comercio y biología de tortugas marinas en el área de Pisco-Paracas. Memorias I Jornada Científica Reserva Nacional de Paracas, Universidad Nacional Agraria La Molina, Lima, pp. 125-129.

- Denkinger, J., Parra, M., Muñoz, J. P., Carrasco, C., Murillo, J. C., Espinosa, E., Koch, V. (2013). Are boat strikes a threat to sea turtles in the Galapagos Marine Reserve? Ocean & coastal management, 80, 29-35.

- Eguchi T, Seminoff JA, LeRoux RA, Prosperi D, Dutton DL, et al. (2012) Morphology and growth rates of the green sea turtle (Chelonia mydas) in a northern-most temperate foraging ground. Herpetologica 68: 76–87.

- Espinoza- Morriberón, D., Echevin, V., Colas, F., Tam, J., Ledesma, J., Vásquez, L., & Graco, M. (2017). Impacts of El Niño events on the Peruvian upwelling system productivity. *Journal of Geophysical Research: Oceans*.

- ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

- FAO species catalogue. Vol.11: Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. FAO Fisheries Synopsis No. 125, Vol. 11. Rome, FAO. 1990. 81 p.

- Fernandez, E. C., C. Cordova & J. Tarazona, (1999). Condiciones del bosque submareal de Lessonia trabeculata en la Isla Independencia durante el evento El Nin˜o 1997–1998. In Tarazona, J. & E. Castillo (eds), El Nin˜o 1997–98 y su impacto sobre los ecosistemas marino y terrestres. Revista PeruanadeBiolog´ıa,VolumenExtraordinario,Lima:47– 59.

- Fiedler, P. C., V. Philbrick & F. P. Chavez, (1991). Oceanic upwelling and productivity in the eastern tropical Pacific. Limnology and Oceanography 36: 1834–1850.

- Fish, M. R., Cote, I. M., Gill, J. A., Jones, A. P., Renshoff, S., & Watkinson, A. R. (2005). Predicting the impact of sea- level rise on Caribbean Sea turtle nesting habitat. Conservation biology, 19(2), 482-491.

- Flint M., Patterson-Kane J., Mills P. & Limpus C. (2009). A veterinarian's guide for sea turtle post mortem examination and histological investigation. The University of Queensland.

- Fraser, Barbara. "Peru's floods teach tough lessons." (2017) Nature news: 405-U507.

- Frazer, N. B., & Ehrhart, L. M. (1985). Preliminary growth models for green, Chelonia mydas, and loggerhead, Caretta caretta, turtles in the wild. Copeia, 73-79.

- Fuentes, M.M.P.B., Limpus, C.J. and Hamann, M. (2011), Vulnerability of sea turtle nesting grounds to climate change. Global Change Biology, 17: 140–153. doi:10.1111/j.1365-2486.2010.02192.x

- Garcia-Martínez, S. & W.J. Nichols. (2001). Sea turtles of Bahía Magdalena, BCS, Mexico: demand and supply of an endangered species. 10th Conf Int Inst Fish Econ Trade, Oregon State University, Corvallis, OR.

- García-Olaechea, A. y C. M. Hurtado. 2016. Pampas cat conservation in northwestern Peru. Small Wild Cat Conservation News 02: 18.

- Gomez-Puerta L.A., V. Bachmann, J. Quiñones, S. Quispe, D. Torres, J. Macalupu. 2017. Primer reporte de Cricocephalus albus (Digenea: Pronocephalidae) en el Perú, parásito de la tortuga verde del Pací co Este (Chelonia mydas agassizii). Revista peruana de biología 24(2): 217 - 222 (Julio 2017). doi: http://dx.doi.org/10.15381/rpb.v24i2.13501

- Green, D. (1984). Long-distance movements of Galapagos green turtles. Journal of Herpetology, 18, 121-130.

- Hancock, J. M., Furtado, S., Merino, S., Godley, B. J., & Nuno, A. (2017). Exploring drivers and deterrents of the illegal consumption and trade of marine turtle products in Cape Verde, and implications for conservation planning. *Oryx*, *51*(3), 428-436.

- Hawkes, L. A., Broderick, A. C., Godfrey, M. H. & B. J. Godley (2007) Investigating the potential impacts of climate change on a marine turtle population. Global Change Biology 13, 1–10, doi: 10.1111/j.1365-2486.2006.01320.x

- Hazel, J., Lawler, I. R., Marsh, H., & Robson, S. (2007). Vessel speed increases collision risk for the green turtle Chelonia mydas. *Endangered Species Research*, *3*, 105-113.

- Hazel, J., & Gyuris, E. (2006). Vessel-related mortality of sea turtles in Queensland, Australia. *Wildlife Research*, *33*(2), 149-154.

- Heidemeyer, M., Arauz-Vargas, R., & López-Agüero, E. (2014). New foraging grounds for hawksbill (Eretmochelys imbricata) and green turtles (Chelonia mydas) along the northern Pacific coast of Costa Rica, Central America. Revista de Biologia Tropical, 62, 109-118.

- Heppell, S.S., Snover, M. L., & Crowder, L. B. (2002). Sea Turtle Population Ecology. The biology of sea turtles, 2, 275.

- Holroyd, G.L. & H.E. Trefry. (2010). The importance of Isla Clarión, Archipelago Revillagigedo, Mexico, for green turtle (Chelonia mydas) nesting. Chelonian Conservation and Biology, 9, 305-309.

- Hooker, Y., Prieto-Rios, E. & Solís-Marín, F.A. (2013) Echinoderms of Peru. Echinoderm research and diversity in Latin America (ed. by J.J. Alvarado and F.A. Solis-Marin), pp. 277-299. Springer, Berlin.

- Huang, B., L'Heureux, M., Hu, Z. Z., & Zhang, H. M. (2016). Ranking the strongest ENSO events while incorporating SST uncertainty. *Geophysical Research Letters*, *43*(17), 9165-9172.

- Hurtado M. (1989). Manejo de las tortugas marinas y su vinculacion con las variaciones de las condiciones ambientales. Instituto Nacional de Pesca, Ecuador.

- Ibañez Erquiaga, B. (2016). Zonación biogeográfica del macrobentos del intermareal rocoso del Norte y Centro del Perú (3.5-13.5° S).

- IMARPE. (2011). Informe Nacional sobre la Situación de las Tortugas Marinas en el Perú. Lima, Perú. 72 p.

- Jahncke, J., D. Checkley & G. L. Hunt Jr. (2004). Trends in carbon flux to seabirds in the Peruvian upwelling. Fish- eries Oceanography 13: 208–223.

- Ji, M. & A. Leetmaa, 1997. Impact of data assimilation on ocean initialization and El Niño prediction. Monthly Weather Review 125: 742–753.

- Jiménez, A, Pingo, S, Alfaro-Shigueto, J, Mangel, J.C. & Y. Hooker (2017) Feeding ecology of the green turtle Chelonia mydas in northern Peru. Lat. Am. J. Aquat. Res., 45(3): 585-596.

- Kelez, S. & X. Velez-Zuazo (2014) Sea turtle nesting expansion into Peru brings new management challenges. SWOT report, Vol. IX. .p 20-21

- Koch, V., Nichols, W. J., Peckham, H., & de la Toba, V. (2006). Estimates of sea turtle mortality from poaching and bycatch in Bahia Magdalena, Baja California Sur, Mexico. Biological Conservation, 128(3), 327-334.

- Kubis S, Chaloupka M, Ehrhart L, Bresette M (2009) Growth rates of juvenile green turtles Chelonia mydas from three ecologically distinct foraging habitats along the east central coast of Florida, USA. Mar Ecol Prog Ser 389:257–269. doi:10.3354/meps08206

- Laist, D.W., and Shaw, C., 2006. Preliminary evidence that boat speed restrictions reduce deaths of Florida manatees. Mar. Mammal Sci., 22(2), 472-479.

- Lester-Coll, A., Velez-Zuazo, X., Quiñones, J.A. & J. Alfaro-Shigueto. (2016) Genetic diversity, structure and origin of green sea turtles foraging along the coast of Peru. Proceedings of the Thirty-Fourth Annual Symposium on Sea Turtle Biology and Conservation. New Orleans, USA.

- L'Heureux, M. L., Takahashi, K., Watkins, A. B., Barnston, A. G., Becker, E. J., Di Liberto, T. E., ... & Mosquera-Vásquez, K. (2016). Observing and predicting the 2015-16 El Niño. *Bulletin of the American Meteorological Society*, (2016).

- Limpus, C., & Nicholls, N. (2000). ENSO Regulation of Indo-Pacific Green Turtle Populations. In G. L. Hammer, N. Nicholls, & C. Mitchell (Eds.), Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems (pp. 399-408). Dordrecht: Springer Netherlands.

- Limpus, C., & Chaloupka, M. (1997). Nonparametric regression modelling of green sea turtle growth rates (southern Great Barrier Reef). Marine Ecology Progress Series, 23-34.

- Limpus, C. J. (1993). The green turtle, Chelonia mydas, in Queensland: breeding males in the southern Great Barrier Reef. Wildlife Research, 20(4), 513-523.

- Limpus, C. J., & Nicholls, N. (1988). The Southern Oscillation Regulates the Annual Numbers of Green Turtles (Chelonia-Mydas) Breeding Around Northern Australia. Wildlife Research, 15(2), 157-161.

- López-Castro MC, Koch V, Marical-Loza A, Nichols WJ (2010) Long-term monitoring of black turtles Chelonia mydas at coastal foraging areas off the Baja California Peninsula. Endang Species Res 11: 35–45.

- López-Mendilaharsu, M., Gardner, S.C., Seminoff, J.A. & R. Riosmena-Rodriguez. (2005). Identifying critical foraging habitats of the green turtle (Chelonia mydas) along the Pacific coast of the Baja California peninsula, Mexico. Aquatic Conservation: Marine and Freshwater Ecosystems, 15(3), 259-269.

- Luschi, P.; Hays, G.C. & F. Papi. (2003). A review of long-distance movements by marine turtles, and the possible role of ocean currents. Oikos, 103(2), 293-302.

- Mancini, A., Senko, J., Borquez-Reyes, R., Póo, J. G., Seminoff, J. A., & Koch, V. (2011). To poach or not to poach an endangered species: elucidating the economic and social drivers behind illegal sea turtle hunting in Baja California Sur, Mexico. Human ecology, 39(6), 743-756.

- Mancini, A., & Koch, V. (2009). Sea turtle consumption and black market trade in Baja California Sur, Mexico. Endangered Species Research, 7(1), 1-10.
- Marquez, R. (1996). Las Tortugas Marinas y Nuestro Tiempo. Fondo de Cultura Económica, México, DF, 104 p.
- Mendo, J., Wolff, M., Mendo, T., & Ysla, L. (2016). Scallop Fishery and Culture in Peru. *Scallops: Biology, Ecology, Aquaculture, and Fisheries. Third Edit*, 1089-109.
- Meylan, P.A.; Meylan, A.B. & J.A. Gray. (2011). The ecology and migrations of sea turtles 8. Tests of the developmental habitat hypothesis. Bulletin of the American Museum of Natural History, 1-70.
- MiAmbiente - Ministerio de Ambiente de Panamá. 2017. Diagnóstico de la Situación de las Tortugas Marinas y Plan de Acción Nacional para su Conservación. Edgar A. Araúz A., Lucas Pacheco, Shirley Binder y Ricardo de Ycaza. Ministerio de Ambiente, Ciudad de Panamá. 104 páginas.
- Montecinos, A., S. Purca & O. Pizarro, 2003. Interannual to interdecadal sea surface temperature variability along the western coast of South America. Geophysical Research Letters 30: 1570.
- Mortimer, J.A. (1981). The feeding ecology of the West Caribbean green turtle (Chelonia mydas) in Nicaragua. Biotropica, 13, 49-58.
- Mrosovsky, N. & C.L. Yntema. (1980). Temperature dependence of sexual differentiation in sea turtles: implications for conservation practices. Biological Conservation, 18(4), 271-280.
- Municipalidad Provincial de Sechura. Available online: <http://sialsechura.regionpiura.gob.pe/index.php?accion=verElemento&idElementoInformacion=668&idTipoElemento=3. 7> July 2017.
- Musick, J.A. & C.J. Limpus. (1997). Habitat utilization and migration in juvenile sea turtles. In: LUTZ, Peter L.; MUSICK, John A. and WYNEKEN, Jeanette (edit). The biology of sea turtles. New York: CRC Press. 1, 137-163.
- Nichols, W.J. (2003). “Biology and conservation of the sea turtles of Baja California, Mexico”, Ph.D. Thesis, University of Arizona, Tucson.
- Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R. B., Simpson, G.L., Solymos, P., Stevens, M.H. and H. Wagner (2016). vegan: Community Ecology Package. R package version 2.3-4. http://CRAN.R-project.org/package=vegan
- Orós, J., Torrent, A., Calabuig, P., Déniz, S., (2005). Diseases and causes of mortality among sea turtles stranded in the Canary Islands, Spain (1998-2001). Diseases of Aquatic Organisms 63 (1), 13-24.
- Paredes-Coral, E., Quiñones J. A. & Quispe, S. C. (2016). Sea turtles at the Virrila estuary, northern coast off Peru: threats and implications for conservation. Student Conference on Conservation Science, University of Cambridge, UK.
- Paredes-Coral, E. (2015). Hábitos alimentarios de la tortuga verde del pacífico este Chelonia mydas agassizii (BOUCORT, 1868) en la bahía de Paracas, Ica, Perú, durante el año 2010. Thesis. 61 p.
- Paredes-Coral, E., Quiñones, J.A., Quispe, S.C. & V.M. Bachmann (2015) Black and hawksbill turtle strandings in estuarine waters in the Peruvian northern coast. In: Kaska, Y., Sonmez, B., Turkecan, O., Sezgin, C. (2015). Book of abstracts of 35th Annual Symposium on Sea Turtle

Biology and Conservation. MACART press, 250pp. Turkey.

- Parra, M., Deem, S.L., Espinoza, E., 2011. Green turtle (Chelonia mydas) mortality in the Galápagos Islands, Ecuador during the 2009-2010 nesting season. Marine Turtle Newsletter 130, 10-15.

- Patricio, A. R., Velez-Zuazo, X., Diez, C. E., Van Dam, R., & A. M. Sabat. (2011). Survival probability of immature green turtles in two foraging grounds at Culebra, Puerto Rico. Marine Ecology Progress Series, 440, 217-227.

- Pennington, J.T., Mahoney, K.L., Kuwahara, V.S., Kolber, D.D., Calienes, R., Chavez, F.P., (2006). Primary production in the eastern tropical Pacific: a review. Prog. Oceanogr. 69, 285–317.

- Pingo, S., Jiménez, A., Alfaro-Shigueto, J., & Mangel, J. C. (2017). Incidental capture of sea turtles in the artisanal gillnet fishery in Sechura Bay, northern Peru. *Latin American Journal of Aquatic Research*, *45*(3), 606.

- Poloczanska, E.S, Limpus, C.J and Hays, G.C (2009) Vulnerability of Marine Turtles to Climate Change. In D. W. Sims, editor: Advances in Marine Biology, Vol. 56, Burlington: Academic Press, pp. 151-211. ISBN: 978-0-12-374960-4.

- Quiñones, J.A, Quispe, S., Paredes, E, Romero, C. & O, Galindo. Ecología y parámetros poblacionales de la tortuga negra (*Chelonia mydas agassizii*) en la ensenada de la Aguada, Paracas, Pisco. 2010-2016. Boletín Instituto del Mar del Perú. In Press

- Quiñones, J., Quispe, S., & Galindo, O. (2017). Illegal capture and black market trade of sea turtles in Pisco, Peru: the never-ending story. *Latin American Journal of Aquatic Research*, *45*(3), 615.

- Quiñones, J., García-Godos, I., Llapapasca, M., Ordt, F. V., & Paredes, E. (2015). The black sea turtle (Chelonia mydas agassizii) at Lobos de Tierra Island, Northern Peru: High densities in small areas. South American Journal of Herpetology, 10(3), 178-186.

- Quiñones, J., González Carman, V., Zeballos, J., Purca, S., & Mianzan, H. (2010). Effects of El Niño-driven environmental variability on black turtle migration to Peruvian foraging grounds. Hydrobiologia, 645(1), 69-79. doi:10.1007/s10750-010-0225-8.

- R Core Team (2014) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria, http://www.R-project.org

- Sampson, L., Giraldo, A., Payán, L. F., Amorocho, D. F., Eguchi, T., & Seminoff, J. A. (2015). Somatic growth of juvenile green turtle (Cheloniamydas) morphotypes in the Colombian Pacific. Marine biology, 162(8), 1559-1566.

- Sampson, L., Payán, L. F., Amorocho, D. F., Seminoff, J. A., & Giraldo, A. (2014). Intraspecific variation of the green turtle, chelonia mydas (cheloniidae), in the foraging area of gorgona natural national park (colombian pacific). Acta Biológica Colombiana, 19(3), 461-470.

- Santidrián Tomillo, P., Roberts, S.A., Hernández, R., Spotila, J.R. & F.V. Paladino. (2014). Nesting ecology of East Pacific green turtles at Playa Cabuyal, Gulf of Papagayo, Costa Rica. Marine Ecology.

- Santillán, L.A. (2008). "Análisis de la dieta de Chelonia mydas agassizii "tortuga verde del Pacífico" en la bahía de Sechura, Piura - Perú". Promotor: Martha Williams. Master Thesis. UNALM, Lima.

- Schroeder, B. A. (1987). Sea turtle stranding and salvage network Atlantic and Gulf Coasts of the United States. NMFS-Coastal Resources D iv., Contr. No. CRD-87/88-12.

- Seafood Trade Intelligence Portal (2016). Consulted 19/06/2017. Available online <

https://www.seafood-tip.com/sourcing-intelligence/countries/peru/scallops/>

- SEMARNAT (2011) Ficha de identificación de la tortuga prieta. 8 pp.
- Seminoff, J.A. (Southwest Fisheries Science Center, U.S.). 2004. Chelonia mydas. The IUCN Red List of Threatened Species 2004: e.T4615A11037468.
- Seminoff, J. A., Jones, T. T., Resendiz, A., Nichols, W. J., & Chaloupka, M. Y. (2003). Monitoring green turtles (Chelonia mydas) at a coastal foraging area in Baja California, Mexico: multiple indices to describe population status. Journal of the Marine Biological Association of the UK, 83(06), 1355-1362.
- Seminoff, J.A.; Resendiz, A. & W.J. Nichols. (2002a). Diet of East Pacific green turtles (Chelonia mydas) in the central Gulf of California, Mexico. Journal of Herpetology, 36(3), 447-453.
- Seminoff, J. A., Resendiz, A., Nichols, W. J., & Jones, T. T. (2002). Growth rates of wild green turtles (Chelonia mydas) at a temperate foraging area in the Gulf of California, Mexico. Copeia, 2002(3), 610-617.
- Senko, J., Mancini, A., Seminoff, J. A., & Koch, V. (2014). Bycatch and directed harvest drive high green turtle mortality at Baja California Sur, Mexico. Biological Conservation, 169, 24-30.
- Shimada, T., Limpus, C., Jones, R., & Hamann, M. (2017). Aligning habitat use with management zoning to reduce vessel strike of sea turtles. *Ocean & Coastal Management*, *142*, 163-172.
- Silva, B. M., Bugoni, L., Almeida, B. A., Giffoni, B. B., Alvarenga, F. S., Brondizio, L. S., & Becker, J. H. (2017). Long-term trends in abundance of green sea turtles (Chelonia mydas) assessed by non-lethal capture rates in a coastal fishery. Ecological Indicators, 79, 254-264.
- Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M. A. X., ... & Martin, K. D. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience, 57(7), 573-583.
- Taylor, M. H., Wolff, M., Vadas, F., & Yamashiro, C. (2007). Trophic and environmental drivers of the Sechura Bay Ecosystem (Peru) over an ENSO cycle. Helgoland Marine Research, 62(1), 15.
- Teas, W. G. (1994). Marine turtle stranding trends, 1986-1993. In Bjorndal, KA, AB Bolten, DA Johnson, and PJ Eliazar, compilers. Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-351 (pp. 293-295).
- Thomson, J. A., Burkholder, D., Heithaus, M. R., & Dill, L. M. (2009). Validation of a rapid visual-assessment technique for categorizing the body condition of green turtles (Chelonia mydas) in the field. Copeia, 2009(2), 251-255.
- Trillmich, F., & Ono, K. A. (Eds.). (2012). Pinnipeds and El Niño: responses to environmental stress (Vol. 88). Springer Science & Business Media.
- Vanderlaan, A. S., & Taggart, C. T. (2009). Efficacy of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. *Conservation Biology*, *23*(6), 1467-1474.
- Velez-Zuazo, X., Quiñones, J., Pacheco, A. S., Klinge, L., Paredes, E., Quispe, S., & Kelez, S. (2014). Fast growing, healthy and resident green turtles (Chelonia mydas) at two neritic sites in the central and northern coast of Peru: implications for conservation. PloS one, 9(11), e113068.
- Veliz, D., Salinas, P., Sielfeld, W., Contreras, D., Azocar, C., Tobar, M. & J. Gallardo. (2014). Estudio poblacional y genético de la tortuga Chelonia mydas agassizii (Sauria: Cheloniidae) en la Playa Chinchorro, Arica, Chile. Revista de biología marina y oceanografía, 49(3), 589-593.
- Villa, L. (2017). Radar Sentinel-1: Evaluación Preliminar del Impacto del Niño Costero en Perú (Parte II). Online: http://luciovilla.blogspot.pe/2017/03/radar-sentinel-1-evaluacion-

preliminar_27.html

- Wabnitz, C.C., Balazs, G., Beavers, S., Bjorndal, K.A., Bolten, A.B., Christensen, V. & D. Pauly. (2010). Ecosystem structure and processes at Kaloko Honokhau, focusing on the role of herbivores, including the green sea turtle Chelonia mydas, in reef resilience. Marine Ecology Progress Series, 420, 27-44.

- Wallace, B.P., Kot, C.Y., DiMatteo, A.D., Lee, T., Crowder, L.B. & R.L. Lewison. (2013). Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere, 4(3), 40.

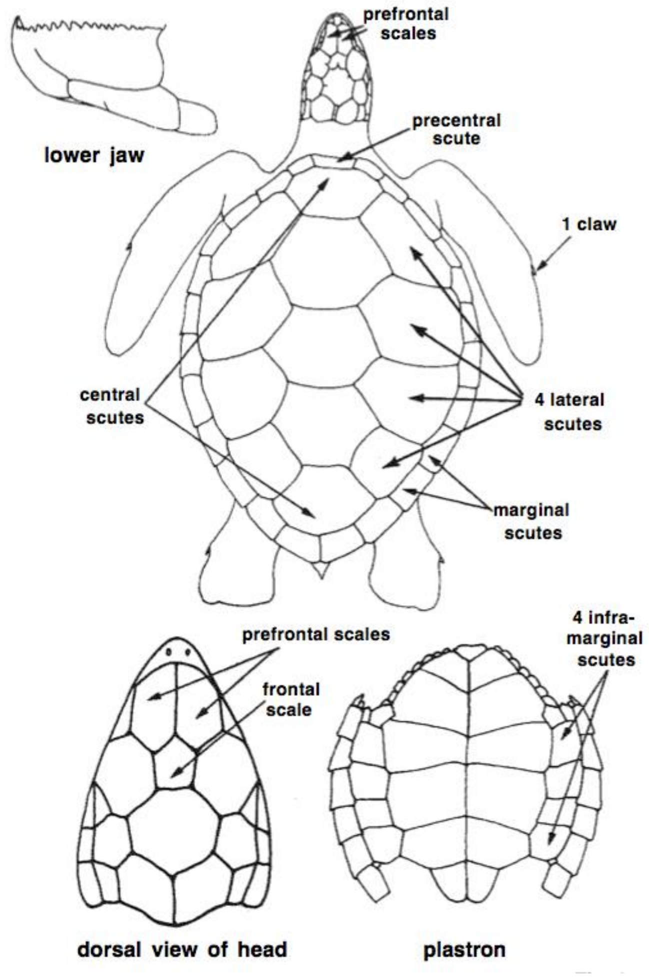
- Work, P. A., Sapp, A. L., Scott, D. W., & Dodd, M. G. (2010). Influence of small vessel operation and propulsion system on loggerhead sea turtle injuries. *Journal of Experimental Marine Biology and Ecology*, *393*(1), 168-175.

- Work, T. M. (2000). Sea turtle necropsy manual for biologists in remote refuges: National Wildlife Health Center, Hawaii Field Station.

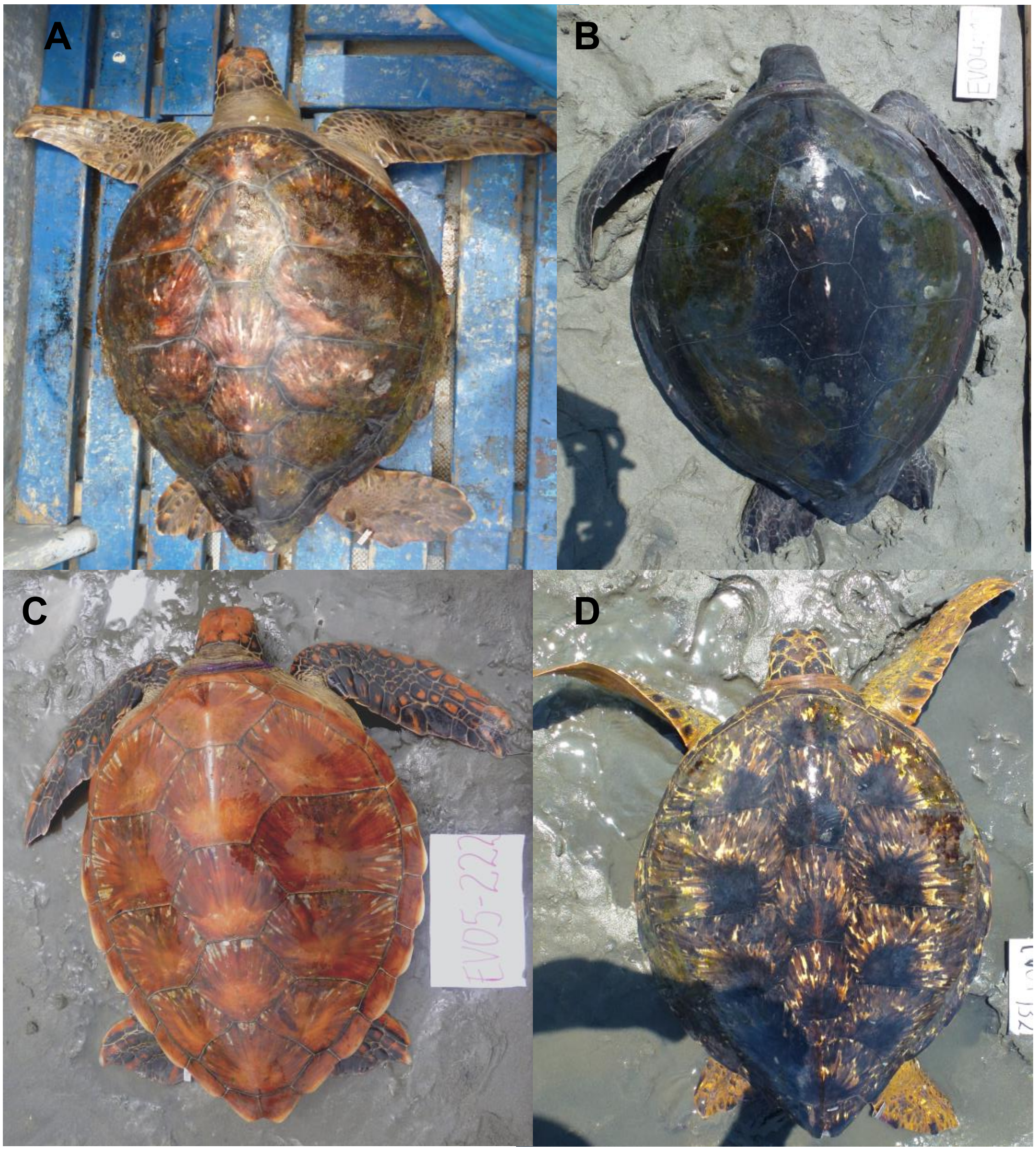
- Zárate, P., Bjorndal, K.A., Parra, M., Dutton, P.H., Seminoff, J.A. & A.B. Bolten. 2013. Hatching and emergence success in green turtle Chelonia mydas nests in the Galápagos Islands. Aquatic Biology, 19(3), 217-229.

- Zárate, P., & Dutton, P. (2002). Tortuga verde. Reserva Marina de Galápagos, línea base de la biodiversidad.

IX. APPENDIX

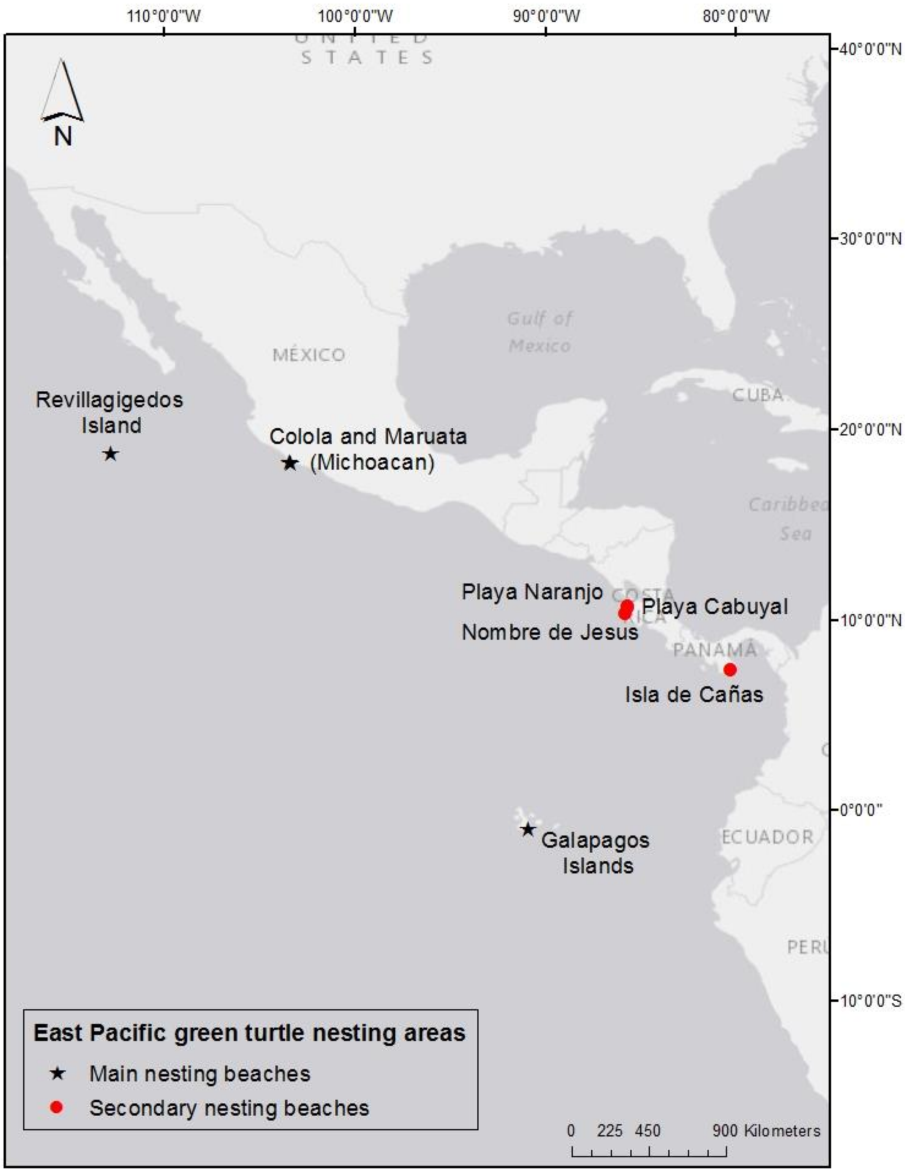


APPENDIX 1. Green turtle (*Chelonia mydas*) morphology including the diagnostic features for its identification. Source: FAO species catalogue, 1990.



APPENDIX 2. East Pacific green turtles (*Chelonia mydas)* colourations at Virrila Estuary (Peru). (A) brownish, (B) black, (C) reddish and (D) yellow.

APPENDIX 3. Distribution of the East Pacific green turtle (*Chelonia mydas*) showed in blue, ranging from San Diego Bay (USA) to Bahia Salado (Chile). Adapted from seaworld.org



APPENDIX 4. East Pacific green turtle (*Chelonia mydas*) nesting areas. Main nesting beaches are showen as black stars and secondary nesting beaches indicated in red circles.

APPENDIX 5. Surveys performed at the Virrila Estuary (Peru) from 2011 – 2017 and the corresponding number of East Pacific green turtles (*Chelonia mydas)* captured and recorded from stranding surveys.

		# turtles	
Survey code	date	# alive	# stranded
pilot survey*	Oct-11	12	13
EV01	Dec-12	30	*not performed*
EV02	Jul-13	45	92
EV03	Nov-13	41	106
EV04	Dec-13	70	46
EV05	Jul-14	53	85
EV06	Nov-14	53	48
EV07	Dec-14	82	28
EV08	Mar-15	53	106
EV09	Jul-15	39	68
EV10	Oct-15	51	65
EV11	Apr-16	27	52
EV12	Aug-16	45	83
EV13	Feb-17	14	46
Total		615	838

** exploratory survey with different fishing gear*

APPENDIX 6. Mean annual CPUE for East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru). Estimates for standard deviation (STD), number of caught turtles (N), coefficient of variance = SD/ Mean CPUE (CV), minimum CPUE (Min) and maximum CPUE (Max).

Year	Mean CPUE	SD	N	CV	Min	Max
2012	4.3	1.32	30	30.5	3.4	5.3
2013	3.5	1.90	156	54.6	1.5	6.4
2014	3.4	0.98	188	29.2	2.2	4.8
2015	2.2	1.39	143	62.6	0.5	4.8
2016	3.3	3.30	72	99.1	1	9.58
2017	0.7	1.11	14	166.2	0	2.32

APPENDIX 7. Size composition of East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) from 2011 to 2017.

Year	No. turtles			Size (cm)	
	Juvenile	Sub-adult	Adult	CCL (± SD)	Range (cm)
2011*	21	4	0	60.5 (± 9.1)	47.2 - 77.2
2012	20	9	1	64.2 (± 11.2)	47.8 - 86.6
2013	200	50	3	60.6 (± 10.4)	30.9 - 98.6
2014	205	71	10	63 (± 10.9)	36.4 - 91.7
2015	195	93	26	66.6 (± 11.8)	38 - 105.1
2016	94	50	11	66.8 (± 12)	39.4 - 104.1
2017**	30	18	2	64.3 (± 12.4)	36.5 - 92.6

**Pilot study **Only one survey in February*

APPENDIX 8. Mean annual body condition index for East Pacific green turtles (*Chelonia mydas*) at Virrila Estuary (Peru) between 2011 and 2017. BCI denotes body condition index (body mass/$SCL^3 * 10^4$) and is classified by life stage (juvenile, sub-adult and adult).

Year	BCI ± SD (n)			Total	
	Juvenil	Sub-adult	Adult	mean (± SD)	Range
2011	1.53 ± 0.17 (11)	1.54 (1)	-	1.53 (± 0.16)	1.34 - 1.95
2012	1.49 ± 0.15 (20)	1.53 ± 0.24 (9)	1.77 (1)	1.51 (± 0.19)	1.27 - 1.92
2013	1.34 ± 0.2 (117)	1.43 ± 0.12 (36)	1.47 ± 0.11 (3)	1.36 (± 0.18)	0.88 - 2.03
2014	1.38 ± 0.4 (134)	1.4 ± 0.17 (49)	1.41 ± 0.27 (5)	1.38 (± 0.35)	0.95 - 5.76
2015	1.32 ± 0.12 (99)	1.34 ± 0.12 (36)	1.35 ± 0.1 (8)	1.33 (± 0.12)	0.85 - 1.65
2016	1.38 ± 0.2 (44)	1.47 ± 0.46 (22)	1.41 ± 0.08 (6)	1.41 (± 0.30)	1.10 - 3.43
2017	1.47 ± 0.1 (8)	1.47 ± 0.11 (5)	1.49 (1)	1.48 (± 0.09)	1.29 - 1.61

APPENDIX 9. East Pacific green turtle (*Chelonia mydas*) strandings at Virrila Estuary (Peru) shorelines and main island from 2011 to 2017.