ANALYSIS OF SEA TURTLE AND MARINE MAMMAL STRANDINGS ALONG THE NORTHERN COAST OF PERU BETWEEN 2003 AND 2016: PATTERNS AND UNDERLYING CAUSES

Thesis to obtain the Academic Degree of Master in Veterinary Science with mention in Conservation Medicine

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"What we do makes a difference, and you have to decide what kind of difference you want to make".

Jane Goodall

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ABREVIATIONS

AOAC	Association of Official Analytical Chemists
ASP	Amnesic Shellfish Poisoning
CBD	Convention on Biological Diversity
CCL	Curve Carapace Length
CCW	Cold Coastal Waters
CICOTOX	Centro de Información y Control Toxicológico
CMS	Convention of Migratory Species
CMV	Cetacean Morbilivirus
CPPS	South Pacific Permanent Commission
DA	Domic Acid
DMV	Dolphin Morbillivirus
DSP	Diarrheic Shellfish Poisoning
ENFEN	Estudio Nacional del Fenómeno El Niño
EN	El Niño
ENSO	El Niño Southern Oscilation
ESW	Equatorial Superficial Waters
FVM	Faculty of Veterinarian Medicine
ICEN	Índice El Niño Costero
IMARPE	Instituto del Mar del Perú
ITP	Instituto Tecnológico de la Producción
IWS	International Whaling Commission
KTS	Knots
LN	La Niña
LC-MS/MS	Liquid Chromatography-Tandem Mass Spectrophotometry
LCSR	Laboratorio Costero de Santa Rosa – IMARPE
NE	Neutral conditions
NM	Nautical miles
ND	Not Determine
MESC	Subtropical and Coastal waters

OA	Okadaic Acid
OIS	Oficina de Investigaciones en Depredadores Superiores - IMARPE
PCR	Polymerase Chain Reaction
PSP	Paralytic Shellfish Poisoning
PSU	Practical Salinity Units
RT-PCR	Real Time Polymerase Chain Reaction
SAM	Sub adult Males
SEW	Surface Equatorial Waters
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SSW	Superficial Subtropical Waters
STX	Saxitoxins
TL	Total Length
TWS	Tropical Surface Waters
UMES	Unusual Mass Stranding Episodes
UNMSM	Universidad Nacional Mayor de San Marcos
UPCH	Universidad Peruana Cayetano Heredia

ABSTRACT

Over the last two decades, the coast of Peru had registered significant mass mortality events of marine vertebrates; however, the underlying causes of certain events remain undetermined. Marine megafauna is considered as sentinels of the environments they inhabit; therefore, by assessing the main factors related to these events is possible to understand the existing problems of coastal environments that can ultimately affect animals and humans living in proximity to the oceans. The aim of the study was to characterize sea turtle and marine mammal mortality events occurred in the northern coast of Peru between 2003 and 2016, as well as to evaluate the association of mortality events and unusual oceanographic conditions. During this period 5,464 stranded animals were recorded, and the main affected species were the South American sea lion *Otaria flavescens* (n =2,745), long-beak common dolphin *Delphinus capensis* (n = 2,046) and green turtle *Chelonia mydas* (n = 382), followed by Burmeister's porpoise *Phocoena spinipinnis* (n = 140), olive ridley sea turtle *Lepidocheys olivacea* (n = 64), bottlenose dolphin *Tursiops truncatus* (n = 31), humpback whale *Megaptera novaeangliae* (n = 25), leatherback sea turtle *Dermochelys olivacea* (n = 9), Bryde's whale *Balaenoptera edeni* (n = 2) and sperm whale *Physeter macrocephalus* (n =1). Our results revealed stranding hotspots for sea turtles in Tumbes, for pinnipeds in Piura and for cetaceans in Lambayeque. An overall increase of mortality of these species was registered toward the end of the studied period, from 2012 to 2016. Regarding to life stage of stranded animals, green turtles were primarily juveniles (76%), sea lions were largely composed by adults (48%) and sub-adults (44%), and long-beak common dolphins were mainly adults (80%). An 11% of the causes of death identified were related to human interaction. For instance, the principal cause of death of sea turtles was capture and butchered for human consumption, follow by vessel collision, interaction with fishing gear and blunt trauma cause by fishermen; whereas the main cause of death of sea lions was associated with intentional pesticide poisoning, and in a lesser extent blunt trauma, and entanglement. Analyses of cetacean mortalities revealed that the principal cause of death was entanglement in fishermen nets and subsequent butchered for meat use. The evidence generated in this study suggests that mortality peaks of green turtles (2007, 2014, 2015, and 2016), long-beaked common dolphins (2012 and 2014) and South American Sea lions (2009, 2013, 2014, 2015 and 2016) occurred during years with oceanic anomalous conditions. In addition, El Niño events appears to be associated with an increase of interactions between fisheries and marine megafauna due to variation in the distribution and availability of prey.

Keywords: *mortality events, marine mammals, sea turtles, human interaction, El Niño*

RESUMEN

La costa peruana ha registrado numerosas mortandades masivas de vertebrados marinos en las últimas dos décadas; sin embargo, las causas subyacentes de diversos eventos continúan sin determinarse. Las tortugas y mamíferos marinos son considerados especies centinelas de los ecosistemas que habitan, razón por la cual el estudio de sus poblaciones proporciona información sobre lo que sucede en zonas marino costeras, y cuyos problemas de salud finalmente pueden afectar a la población humana. El objetivo del estudio fue la caracterización de los eventos de mortandad de tortugas y mamíferos marinos en la costa norte de Perú en el periodo comprendido entre el 2003 y 2016, así como evaluar la asociación de estos eventos y las condiciones oceanográficas anómalas. Durante el periodo de estudio se registró el varamiento de 5,464 animales, las principales especies afectadas fueron el lobo marino de un pelo Sudamericano *Otaria flavescens* (n = 2745), el delfín común de hocico largo *Delphinus capensis* (n =2046) y la tortuga verde del Pacífico este *Chelonia mydas* (n = 382); seguido de la marsopa espinosa *Phocoena spinipinnis* (n = 140), tortuga pico de loro *Lepidochelys olivacea* (n = 64), delfín mular *Tursiops truncatus* (n = 31), ballena jorobada *Megaptera novaeangliae* (n = 25), tortuga dorso de cuero *Dermochelys olivacea* (n = 9), ballena de Bryde *Balaenoptera edeni* (n = 2) y cachalote *Physeter macrocephalus* (n =1). Nuestros resultados muestran que la principal zona de ocurrencia para tortugas marinas fue Tumbes, para pinnípedos Piura y para cetáceos Lambayeque. Se registró un incremento de mortandad de estas especies hacia el final del periodo de estudio, del 2012 al 2016. En relación a la etapa de vida, las tortugas verdes afectadas fueron principalmente juveniles (76%), los lobos marinos adultos (48%) y sub-adultos (44%), y los delfines comunes de hocico largo estuvieron compuestos esencialmente por ejemplares adultos (80%). El 11% de las causas de muerte de tortugas y mamíferos marinos estuvo relacionada a interacción humana. La principal causa de muerte para las tortugas marinas fue captura ilegal para el consumo humano, seguida por colisión con embarcaciones, interacción con artes de pesca y traumas causados por objeto contundente; mientras que los lobos marinos murieron por envenenamiento intencional con pesticidas, seguido por trauma con objetos contundentes y enredo en artes de pesca. En cetáceos, el enmallamiento en redes de pesca fue la causa predominante y el subsecuente uso de su carne como carnada. La evidencia obtenida por este estudio revela que los picos de mortandad de tortuga verde (2007, 2014, 2015 y 2016), delfín común hocico largo (2012 y 2014) y el lobo marino de un pelo (2009, 2013, 2014, 2015 y 2016) se dieron en años con condiciones oceanográficas anómalas. Adicionalmente, El Niño parece estar asociado a un incremento en las interacciones entre las actividades pesqueras y megafauna marina a causa de la variación en la distribución y disponibilidad de sus presas.

Palabras clave: *eventos de mortandad, tortugas marinas, mamíferos marinos, interacción pesquera, El Niño.*

1. INTRODUCTION

Mortality events involving marine wildlife have increased at an alarming rate over the past 30 years (Gulland 2006, Camphuysen et al. 2008, Fernández et al. 2012, Imarpe 2012), and the Southeastern Pacific is not exemption (Van Waerebeek & Reyes 1994, Palacios et al. 2004, Alava et al. 2005, Galletti y Cabrera 2007, Rosales et al. 2010, Pizarro-Neyra 2010, García-Godos et al. 2013, Haussermann et al. 2017). During the last two decades the Peruvian coast had registered several stranding events involving marine invertebrates, fish, sea turtles, seabirds and marine mammals (Lopez et al. 2008, Hernandez-Miranda et al. 2010, Jessup et al. 2009, Peckham et al. 2008, Pizarro-Neyra 2010, Imarpe 2012, 2013, García-Godos et al. 2013). Unfortunately, the underlying causes of the majority of the events in Peru have not been determined, mainly because of the non-existence of a local stranding network with skilled professionals and economic resources to rapidly respond and document these mortalities. A systematic collection of data is therefore crucial to characterize strandings of marine animals, including information on species and age/group involved, spatio-temporal patterns of occurrence and associated anthropogenic activities or climate events.

Stranded whales had been documented since ancient times (Aristotle 350 BC) and even several marine mammal species have been described for the first time due to mortality events (Geraci 1978). Moreover, the knowledge on many biological and natural history aspects of marine species had been acquired from stranded animals since these events provide a unique access to valuable information of cryptic species that are difficult to study in their natural habitats (Wilkinson 1991). Numerous causes have been associated with marine stranding events including, extreme climate conditions (Reyes 2009), starvation (Reyes 2009), infectious diseases (Bossart 2011, Browning et al. 2015), toxic algal blooms (Bossart 2011, Torres de la Riva et al. 2009), habitat loss and degradation (Bossart 2011, Moore et al. 2008), wastewater and industrial contamination (Bossart 2011, Moore et al. 2008), marine debris (Moore & Van der Hoop 2012, Moore et al. 2018), noise pollution (Moore et al. 2008, Jepson et al. 2013), fisheries interaction (human and animal conflicts, poisoning, bycatch, direct consumption), boat strikes, unregulated tourism (Van Waerebeek et al. 2007, Van Waerebeek & Reyes. 1994, Pizarro-Neyra 2010, García-Godos et al. 2013, Reyes 2009, Bugoni et al. 2001, Paredes et al. 2015, Paredes & Quiñones 2016, Quiñones & Quispe 2017) and climate change (Poloczanska et al. 2009, McLeod 2009).

The coastline of Peru is situated between 03°24'S latitude in the border with Ecuador (Punta Capones) and 18°20,8'S limiting with Chile (La Concordia point); its length encompasses more than 3000 km (Silva & Pacheco 2016). The marine area in front the Peruvian coast had special features mainly caused by the complex system of superficial and sub-superficial currents, associated with spatial and temporal coastal upwelling, which are favored by the intensification of southern trade winds (Moron 2000). These characteristics could drastically change due to warm El Niño Southern Oscillation (ENSO) phase that could cause sea surface anomalies up to +10 °C above the multiannual average, depending on its intensity. On the other hand, the cold phase (La Niña) acts in the opposite way, with upwelling cold waters rich in nutrients that fertilized the environment and increased the productivity, enabling the development of fish population, expanding the productivity zone (Moron 2000).

The marine ecosystem off coast of northern Peru has particular characteristics due to the convergence of cold waters through the Humboldt Current, and warm waters trough the Equatorial Superficial (ESW) and Tropical Superficial Waters (TSW) (Clarke 1962, Félix & Haase 2005). This singularity enhances the great diversity of hydrobiological resources and allows the concurrent presence of cetaceans, pinnipeds and marine turtles (Rosales et al. 2010). Five species of sea turtles (Aranda 1989, Kelez et al. 2003a), 30 cetacean species, seven baleen whales and 23 odontocetes (Reyes 2009), and two species of pinnipeds (Majluf & Thrillmich 1981) are known to inhabit the Peruvian ocean. A summary of the species that occurs in the Northern Peru marine waters are detailed on the Appendix I. Sea turtles and marine mammals are protected by national legislation (DS N˚02-1996-PE, Ley 26585, DS N˚ 026-2001-PE, DS N˚004-2014-MINAGRI) and international agreements (South Pacific Permanent Commission CPPS, International Whaling Commission IWC, Inter-American Sea Turtle Convention CIT, Convention of

Migratory Species Conservation CMS, and the Convention on Biological Diversity CBD). Despite official protection, many populations of marine vertebrates continue to decline in recent years (Seminoff 2004, Abreu-Grobois & Plotkin 2008, Wallace et al. 2013) or its population trend remain unknown (Hammond et al 2008, Félix et al. 2018, Hammond et al. 2012, Taylor et al. 2008, Cooke & Brownell 2018).

Locally, the main threat faced by sea turtles in the past was direct catch for human consumption until 1995, when this practice was banned by Peruvian legislation (Ministerial Resolution N˚103-95-PE). Nevertheless, overexploitation for human consumption is still a problem in Peru, as well as habitat degradation, bycatch and boat strikes (De Paz et al*.* 2002, Quiñones & Quispe 2017, Velez-Zuazo et al*.* 2014, Alfaro-Shigueto et al*.* 2011, Paredes 2015, Paredes et al*.* 2015, Kelez et al*.* 2003b, Seminoff 2004). In cetaceans, the causes of the population declines have been mainly associated with commercial whaling.

Commercial whale hunting on Peruvian waters was initiated during the Viceroyalty (Flores 2010). Through the 20th century, about 38,289 individuals were captured until 1981 when this practice was banned (Ramirez 2001, Aguirre & Paz 1964, Saeterdal et al*.* 1963). At present, bycatch in drift and set gillnets, vessel collision and marine noise, are important threats to cetacean populations (Van Waerebeek & Reyes 1994, Van Waerebeek 2007, García-Godos et al*.* 2013, Jepson et al*.* 2013, Browing et al*.* 2015, Fernandez et al*.* 2005, Fernandez et al*.* 2012). Otariid populations have also declined in the coast of Peru due to overexploitation for pelt and oil beginning at the early 20th century (Murphy 1925) and until the exportation of otariid products was banned in 1976 (Vasquez et al*.* 1996). Nowadays, the main threat faced by sea lions and fur seals are the artisanal and industrial fisheries that compete for the same resources and generate conflicts between fishermen, including certain individuals of pinnipeds that have learned to take fish from nets and damage fishing gears (Arias-Schereiber & Rivas 1998, Imarpe 2013). This problem has been increased those years with El Niño Southern Oscilation (ENSO) events that impact prey availability (De Oliveira 2011, Majluf 1991). Warm sea surface temperature during ENSO years produce the deepening of the thermocline, less upwelling and a decrease the primary marine productivity (Trillmich 1993, Fieldler 2002). This has caused a severe scarcity of anchovy (*Engraulis ringes*) and other prey for South American sea lions (Soto et al. 2004).

Marine mammals and sea turtles are considered as important sentinels of marine environments due to their long lifespan, bioaccumulating potential contaminants from their food webs, and with many species being near-shore coastal water inhabitants (Duignan et al. 1996, Lutz 1998, Caro & O'Doherty 1999, Aguirre & Lutz 2004, Gulland & Hall 2007, Moore 2008, O'Shea & Odell 2008, Boresma 2008, 2006, Bossart 2011). Furthermore, charismatic species can enhance public attention in order to take action for marine conservation (Aguirre & Tabor 2004). Thus, sea turtles, pinnipeds and cetaceans provide early warnings of the current negative impacts occurring on marine ecosystems (Bossart 2006, Readdy et al. 2001, Bossart 2006). Nevertheless, beached carcasses represented an unknown fraction of at-sea mortalities (Hart et al. 2006), assessing the causes and factors contributing to marine vertebrate strandings enable the identification of processes determining health of marine ecosystems that can ultimately affect animals and humans living in proximity to the oceans (Berrow & Rogan 1997, Goldstain et al. 1999, García-Godos et al. 2013).

Stranding events are incidents in which cetaceans, sea turtles, sharks, other fish and marine invertebrates appear dead or alive on the seashore or shallow waters, in helpless position, ill, weak or lost (Geraci & Lounsbury 2005, Hernandez-Miranda et al. 2010, Lopez et al. 2008). These findings could involve one, dozens or thousands of individuals of the same or different species at the same time, in which case they are known as mass strandings (Geraci & Lounsbury 2005, Reyes 2009). Pinnipeds are consider stranded when an animal is dead at the beach or is unable or unwilling to leave the shore because of injury or poor health (Wilkinson 1991). A mass stranding episode may span one or more days, and range over miles of shoreline connecting multiple regions, or sandbars and distant islands. They remain hard to manage as they are often logistically overwhelming, and the reasons for their occurrence remain hard to identify in most cases (Gulland 2006). Unusual Mortality events may involve a few animals dying under unusual circumstances, or death on a large scale, the latter related with diseases, prey depletion associated with climatic anomalies, among other causes. Such events can bring hundreds or thousands of animals ashore and demand an immediate response (Geraci & Lounsbury 2005, Gulland 2006).

The Peruvian Ocean Institute (IMARPE) had registered sea turtle, sea lions, odontocetes, and baleen whales stranding events through the coast of Peru since early 2000s. The information gathered shown an increased in number of stranded sea turtles and marine mammals during the last two decades, a trend more notorious in the region of northern Peru. Unfortunately, there is not an immediate and effective response to these events. For this reason, IMARPE had taken the main role in the assessment and documentation of stranded marine wildlife in the coasts of Peru. IMARPE has been recording systematically the main affected areas, as well as the species involved through the Top Predator Investigation Office and coastal laboratories. The aim of this study is to characterize sea turtles and marine mammal mortality events in the northern coast of Peru during 2003 to 2016, and assess its relation with anthropogenic activities, anomalous oceanographic conditions and other causes.

2. OBJECTIVES

2.1 GENERAL OBJECTIVE

Characterize sea turtle and marine mammal mortality events and its causes in the northern coast of Peru in the period between 2003 and 2016.

2.2 SPECIFIC OBJECTIVES

1. Determine species involved, age group affected and anthropogenic causes of sea turtle and marine mammal mortality events occurring in Northern Peru.
2. Determine spatial occurrence of marine megafauna stranding along the northern coast of Peru.
3. Evaluate the association between sea turtle and marine mammal mortality events with anomalous oceanographic conditions in northern Peru.

3. MATERIAL AND METHODS

3.1. Study Area

The survey was conducted in area of about 250 km of the northern coast of Peru. The regions evaluated were Tumbes, Piura and Lambayeque. The study area with the main villages and fishermen towns are shown in Figure 1.

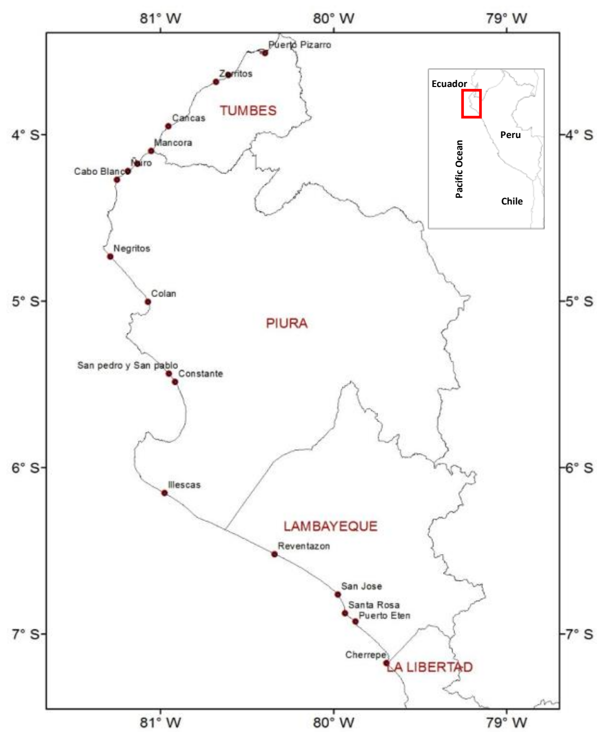

Figure 1. The study area in northern Peru. These includes the departments of Tumbes, Piura and Lambayeque. Red dots represent the main fishing ports and coves.

3.2 Data Collection

Mass mortality events along the coast of Tumbes, Piura and Lambayeque were recorded between 2003 and 2016 by IMARPE coastal laboratories and Top Predator Investigation Office professionals, the information was gathered in a Stranding database of IMARPE. Each individual was georeferenced; species composition and sex were identified whenever possible. Photographs were taken from each animal at different views. Sea turtle and marine mammal species identification was based on morphological characteristics (Marquez 1990, Knopf 2002, Reyes 2009). The carcasses of stranded animals were marked with spray paint in order to avoid animal recount.

3.3 Biometric measurement

3.3.1. Sea turtles: curved Carapace Length (CCL) and Carapace Curve Width were obtained for each stranded marine turtle. Characterization of life stage of dead sea turtles is shown on table 1.

Table 1. Life stage characterization of sea turtles.

Species	Juveniles	Sub-adults	Adults	Author
Green turtles (*Chelonia mydas agassizii)*	CCL is <69 cm	CCL >69 cm <85 cm	CCL >85 cm	Zarate et al. 2013
Olive ridleys (*Lepidochelys olivacea*)	CCL<57 cm	Not specified	CCL >57 cm	Márquez 1990
Leatherback sea turtles (*Dermochelys coriacea*)	CCL<123 cm	Not specified	CCL>123 cm	Reina et al. 2002

3.3.2. Marine mammals: total length (TL) of stranded marine mammals was measured. Marine mammal size structure was defined by the measurements stablished in Folkens et al. (2002) and Reyes (2009) (Table 2), based on the characteristics of the species involved on the stranding event.

Table 2. Life stage characterization of marine mammals.

Species	Calf	Juveniles	Sub-adults/ Immature	Adults	Author
Long-beaked common dolphin (*Delphinus capensis*)	0.85 m	Not specified	Less than 2.00 m	Females 1.99-2.20 m Males 2.54 m	Reyes 2009, Folkens et.al 2002
Bottlenose dolphin (*Tursiops truncatus*	0.84-1.40 m	Not specified	Less than adults length	Females 2.40-3.70 m Males 2.45-3.80	Folkens et.al 2002
Burmeister's porpoise (*Phocoena spinipinnis*)	86 cm	Not specified	Less than adults length	Females 1.83 m Males 1.82 m	Reyes 2009, Folkens et.al 2002
Sperm whale (*Physeter macrocephalus*	3.50-4.50 m	Not specified	Less than adults length	Females 12.00 m Males 18.00 m	Reyes 2009
Humpback whales (*Megaptera novaeangliae)*	4.00-4.6 m	Not specified	Less than adults length	14.00-17.00 m	Reyes 2009 Folkens et.al 2002
Bryde's whale (*Balaenoptera edeni)*	4.00 m	Not specified	Less than adults length	Females 12.00-12.80 m Males 11.60-12.40 m	Reyes 2009 Folkens et.al 2002
South American sea lion (*Otaria flavescens*)	0.85 m	Not specified	Females less than 2.20 m Males 2.50	Females 2.20 m Males 2.8 m	Folkens et al. 2002

3.4 Carcass Classification

An adaptation of Flint et al*.* (2009) characterization was done for marine turtles in order to unify criteria. Marine mammal carcass condition was determined according to its decomposition stage (Geraci & Lounsbury 2005, Pugliares et al*.* 2007). See Table 3.

Table 3. Carcass of sea turtle and marine mammal classification according to their decomposition stage

Code	Carcass Description	
Code 1	Moribund	Alive and subsequent death.
Code 2	Carcass in good condition (Fresh)	Normal appearance, with little scavenger damage; fresh odor; minimal drying and wrinkling of skin, or mucous membranes; eyes clear; carcass not bloated, tongue and penis no protruded, blubber firm, white and semi-translucent blubber; muscles firm, dark and red, well-defined; viscera intact and well-defined; gut with little or no gas; brain firm with no discoloration, easily removed intact.
Code 3	Fair (Moderate decomposition)	Carcass intact, bloating evident (tongue and penis protruded) and skin cracked and sloughing; possible scavenger damage; characteristic mild odor; mucous membranes dry, eyes sunken or missing; blubber with blood-tinged and oily; muscles soft and poorly defined; viscera soft, friable, mottled, but still intact; gut distended by gas; brain soft, features distinct, dark reddish cast, fragile but can usually be removed intact.
Code 4	Poor (Advanced decomposition)	Carcass may be intact but collapsed; skin sloughing; often severe scavenger damage; strong odor; blubber and muscle easily torn or falling off from bones; liquefied internal organs.
Code 5	Mummified/ Skeletal remains	Often with dried skin draped over bones; completely desiccated.

3.5 Nutritional Condition Assessment

The nutritional condition of recent stranded (fresh condition carcasses) individuals was assessed using a visual-assessment. For this, the evaluation of sea turtles body condition was determined according to the concavity or convexity of the plastron and the condition of the forelimbs and hind limbs muscle mass (Flint et al*.* 2009). The evidence of pelvic, rib cage and neck regions of the animal (Pugliares et al. 2007) permitted the assessment of the condition of pinnipeds. Whereas, cetacean's body condition was evaluated by means of loss of dorsal epaxial muscle mass and level of evidence of pronounced vertebrae (Pugliares et al*.* 2007). Three categories of evaluation were established: 1) Good, 2) Fair and 3) Poor (see Table 4).

Table 4. Sea turtles and marine mammals body condition criteria.

Animal Group	Good	Fair	Poor	Reference
Sea Turtles	Convex plastron	Flat plastron	Concave plastron and evident bones	Flint et al. 2009
Sea Lions	Fusiform body shape, mass muscles cover the bones which are not evident	Light evidence of pelvic and neck bones	Pelvic and rib cage bones evident, marked Difference between the neck and the rest of the body	Pugliares et al. 2007
Cetaceans	Convex epaxial muscular mass in both sides of the dorsal fin. Rounded body	Slight loss of epaxial muscular mass	Significant loss of epaxial muscular mass with an evident convex appearance over the dorsal part of the body	Pugliares et al. 2007

3.6 Cause of Death

Stranded animals showing evidence of interaction with humans were registered. These included, hooks inserted in different body parts, injuries caused by sharp objects, loss of pectoral or caudal fin, injuries caused by fishing gear, individuals with the plastron and carapace separated with evidence of cuts, bone or carapace fractures, scars or wounds caused by bullets. Additionally, presence of fishery activities near coast were registered. Opportunistic post mortem analysis was performed in fresh carcasses.

According to the findings the causes of death were classified as: a) entanglement, b) vessel collision, c) butchered for human consumption (in the case of sea turtles when the plastron was opened and move aside; in cetaceans when the skin was removed and the epaxial muscles were absent), d) pesticide intoxication, e) trauma caused by blunt object, f) infectious disease, and g) undetermined.

3.7 Oceanographic conditions

Information of Sea Surface Temperature (SST), Sea Surface Temperature Anomalies (SST anomalies) and Sea Surface Salinity (SSS) was obtained from IMARPE oceanographic stations located in Tumbes, Paita (Piura) and San Jose (Lambayeque).

Historical ENSO and La Niña events on the region 1+2 (90°- 80°W, 10°- 0°S) based on the variability of sea surface temperature anomalies (Takahashi et al. 2014) are detailed on Table 4 and 5, based on the ICEN index (Indice El Niño Costero) (ENFEN 2018).

ICEN index consist in the estimation of the media of the sea surface anomalies of three consecutive months in the El Niño 1+2 region, obtained of the SST absolute data in real time NOAA ERSST 3b, using the climatology of 1981-2010 period (Table 7) (ENFEN 2012). This index reflects better the Peruvian coast conditions in relation with global index. Whereas, LABCOS index is statistical indicator that reflex the range of variability of SST in the Peruvian littoral (Quispe & Vásquez 2015). The estimation of this index is based on monthly averages of SST anomalies obtained by Coastal Laboratories of IMARPE stations (Paita, Chicama, Chimbote, Callao, Pisco and Ilo) and the San Juan Navy station of the Hydrography and Navigation since 1976. LABCOS index is determined by the moving quarterly average of the SST anomalies (Table 8) (Quispe & Vásquez 2015).

Table 5. Coastal El Niño events and its duration based on ICEN Index for 1+2 region (Peruvian coast)

Initial year	Initial month	Final year	Final month	Duration (months)	Magnitude
2003	11	2004	1	3	Weak
2004	10	2004	12	3	Weak
2006	8	2007	2	7	Moderated
2008	7	2008	9	3	Weak
2009	5	2009	9	5	Weak
2012	3	2012	7	5	Weak
2014	5	2014	10	6	Moderated
2015	4	2016	6	15	Strong
2016	12	2017	4	5	Weak

Table 6. Coastal La Niña and its duration base on ICEN Index for 1+2 region

Initial year	Initial month	Final year	Final month	Duration (months)	Magnitude
2007	5	2007	12	8	Strong
2010	8	2010	11	4	Moderated
2013	4	2013	8	5	Strong

Table 7. Intervals of ICEN obtained for the classification of EN and LN events according categories (ENFEN 2012)

Condition	Category	SST max anomaly	SST min anomaly
La Niña	Strong		< -1.40
	Moderated	≥ -1.40	< -1.20
	Weak	≥ -1.20	< -1.00
Neutral		≥ -1.00	< 0.40
El Niño	Weak	> 0.40	≤ 1.00
	Moderated	> 1.00	≤ 1.70
	Strong	> 1.70	≤ 3.00
	Very Strong	> 3.00	

Table 8. Intervals of LABCOS obtained for the classification of EN and LN events according categories (Quispe & Vásquez 2015)

Condition	Category	SST max anomaly	SST min anomaly
La Niña	Strong	-1.31	< -1.31
	Moderated	-1.31	-1.10
	Weak	-1.10	-0.78
Neutral		-0.78	0.27
El Niño	Weak	0.27	0.78
	Moderated	0.78	1.37
	Strong	1.37	2.77
	Very Strong	2.77	> 2.77

3.8 Statistical Analysis

Co-variables evaluated were classified as detailed below:

X_1 = Sea turtles (discrete quantitative variable)

X_2= Pinnipeds (discrete quantitative variable)

X_3 = Odontocetes (tooth whales) (discrete quantitative variable)

X_4 = Mysticetes (baleen whales) (discrete quantitative variable)

X_5 = Sea Surface Temperature Anomalies of the time series (quantitative continuous variable)

X_6 = Sea Surface Salinity (SSS) (quantitative continuous variable)

X_7 = ICEN Category (EN, LN, NE) (nominal variable)

X_8 = ICEN index values (quantitative continuous variable)

X_9 = LABCOS index values (quantitative continuous variable)

X_{10} = Death causes (nominal variable)

Chi-square (X^2) statistical test was used to verify univariate significant differences in strandings frequency between zones using Microsoft Excel (2013). Chi-square (χ^2) statistics were also used to test differences in stranding frequencies between years, age class and sex categories. Spearman correlation was employed in order to determinate association between co-variables (taking into account each stranded species and SSS, SST and SST anomalies).

Principal component analysis (PCA) was performed in order to evaluate relation between quantitative variables (sea turtle, pinnipeds, odontocetes and mysticetes strandings, SST anomalies, SSS, ICEN categories, ICEN index value, LABCOS index values and death causes) previous normal distribution standardization of variables. Correspondence Analysis (AC) were done for relations between qualitative variables (ICEN categories, death cause, and frequency of occurrence of animal group strandings).

The statistical methodology was applied using Ade4 and FactorMiner library of R program (R Core Team 2014, Dray et al. 2018, Husson et al. 2018). All maps were done using the software ArcGis 10.4 (Esri 2011).

4. RESULTS

4.1 Species affected

A total of 5,464 stranded animals belonging to 10 species among sea turtles and marine mammals were recorded along the coasts of Northern Peru between 2003 and 2016. South American sea lion (*Otaria flavescens*) was the most frequent species found dead (n=2,745), followed by long beak common dolphin (*Delphinus capensis*; n=2,045), green turtle (*Chelonia mydas agassizii*; n=382) and Burmeister's porpoise (*Phocoena spinipinnis*; n=140). Less frequent strandings were comprised by olive Ridley turtle (*Lepidochelys olivacea*; n=64), bottlenose dolphin (*Tursiops truncatus*; n=31), humpback whales (*Megaptera novaeangliae*; n=25), leatherback turtle (*Dermochelys coriacea*; n=9), Bryde's whale (*Balaenoptera edeni*; n=2), and sperm whale (*Physeter macrocephalus*; n=1). Three whales and 17 dolphins stranded individuals were identified to the level of Family: Balaenoptea and Delphinidae. See Figure 2.

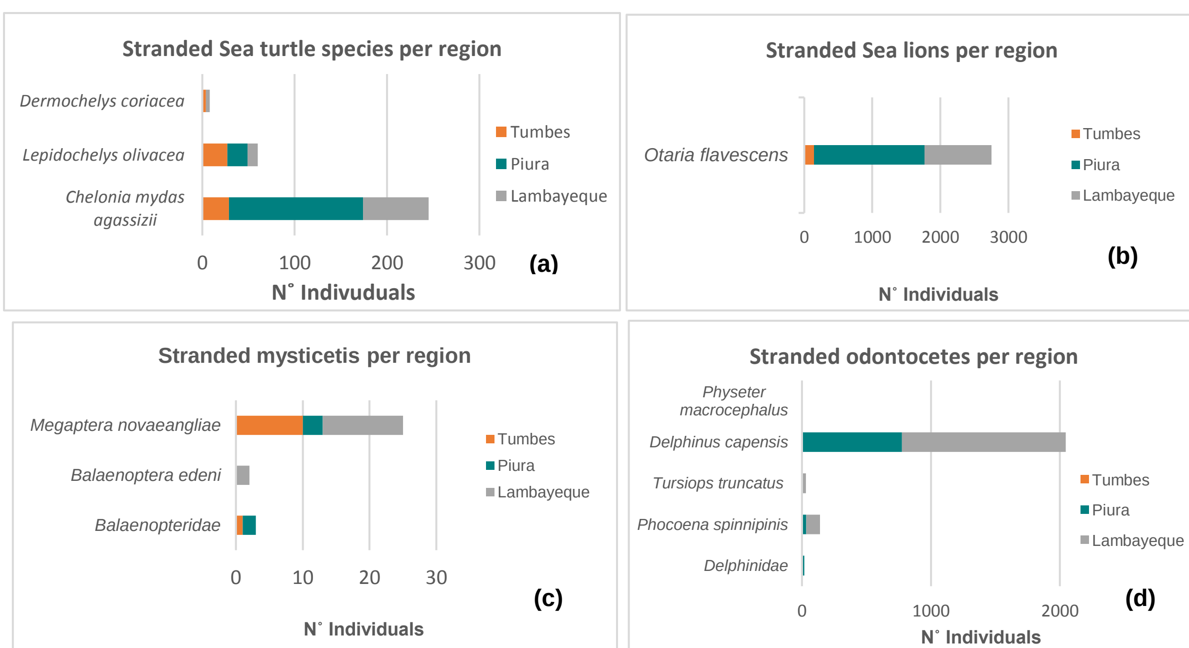

Figure 2. Stranded marine mammal species per geographical zone in northern Peru between 2003 and 2016. **a.** sea turtles, **b.** sea lions, **c.** mysticetes and **d.** odontocetes.

4.2 Area of Occurrence

The majority of sea turtle die-offs were in the coast of Tumbes, whereas for pinniped, and cetacean deaths were located in Piura and Lambayeque respectively. These three Regions showed a statistical significant difference in number of strandings (X^2 test, p-value <0.01) (Fig. 3, Table 9). Green turtles primarily stranded in the coast of Tumbes and Piura, and in a lesser extent in Lambayeque. Olive Ridley turtles stranded mainly in Tumbes and southern Piura, and in a less proportion in Tumbes coast. While stranded Leatherback turtles were located in Lambayeque, Southern Piura and Tumbes coast (Fig. 3a, Appendix 2a).

The occurrence of South American sea lion strandings were mainly located over the littoral of Piura, followed by Lambayeque and in less proportion along the shore of Tumbes (Fig. 3b, Appendix 2b). The seashore of Lambayeque and southern Piura registered the greatest number of long-beak common dolphin strandings. Burmeister's porpoise and bottlenose dolphins mostly stranded over the coast of Lambayeque and southern Piura (Fig. 3c, Appendix 2c). Humpback whales where mainly located over the seashore of Lambayeque and Tumbes, and some did also strand in northern and southern coastline of Piura; whereas Bryde's whales and the single Sperm whale beached in Lambayeque (Fig. 3c, Appendix 2d).

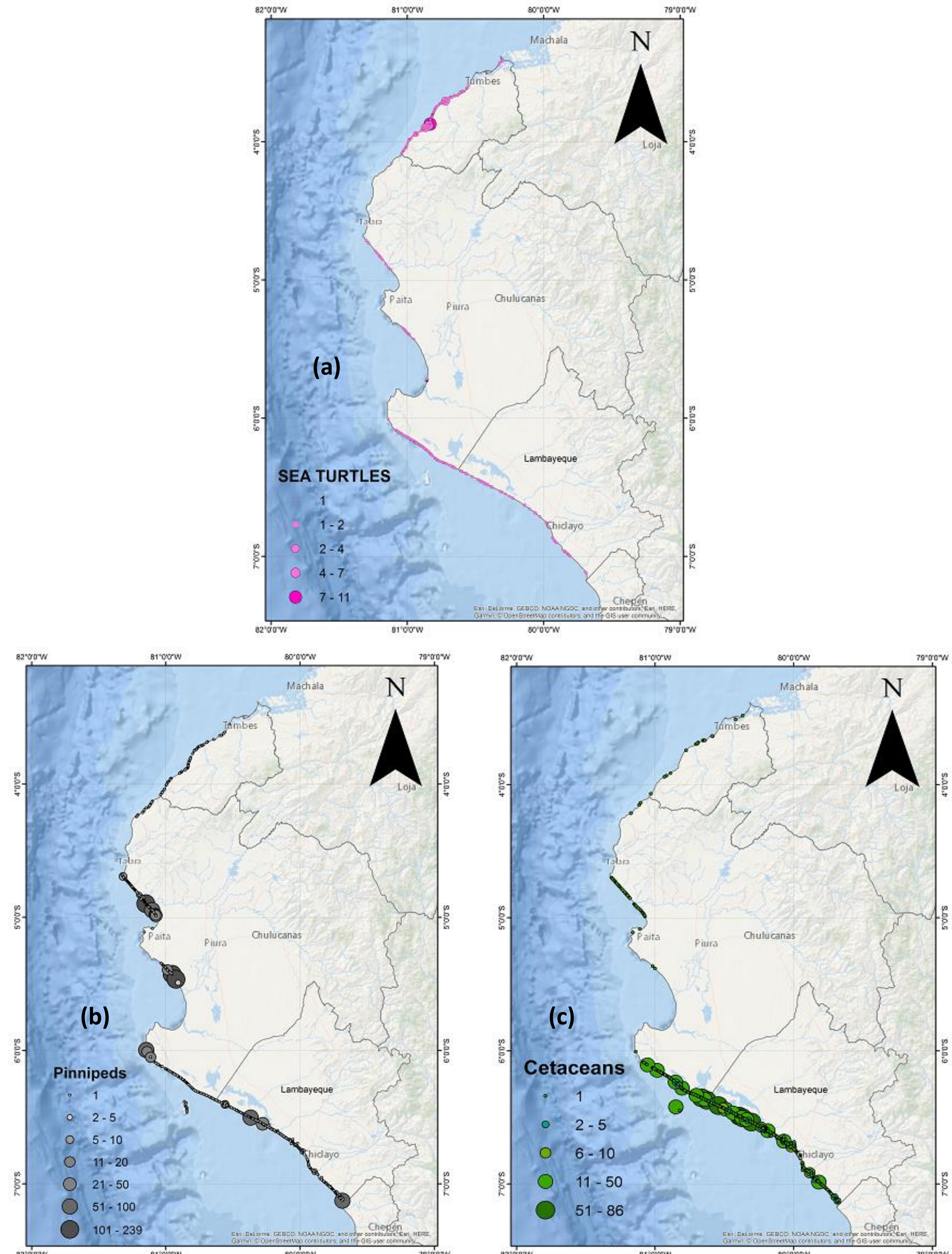

Figure 3. Spatial stranding distribution of **a)** sea turtles, **b)** pinnipeds and **c)** cetaceans, in the coast of northern Peru in the period 2003-2016. **a.** Sea turtle stranding area (pink dots) displaying an important aggregation of carcasses in Tumbes coast. **b.** Stranded Sea lion hotspot (grey dots) showing a significant aggregation of carcasses in Piura shore. **c.** Cetaceans stranding area (green dots) exhibit a major aggregation in Lambayeque littoral.

Table 9. Descriptive analysis of sea turtles and marine mammals stranded per region, age class and sex in northern Peru

	All		Piura		Tumbes		Lambayeque		p-value
	n	%	n	%	n	%	n	%	
Species	**5464**								
Sea Turtles +	455	8%	167	6%	202	55%	86	3%	< 0.01
Sea lions ++	2745	50%	1620	62%	148	40%	977	39%	
Cetaceans ++	2264	41%	829	32%	16	4%	1419	57%	
Sea turtles									
Age Class	**399**								
Juvenile	283	71%	110	81%	108	58%	65	83%	< 0.01
Sub-adult	76	19%	20	15%	45	24%	11	14%	
Adult	40	10%	5	4%	33	18%	2	3%	
Sex	**13**								
Male	5	38%	3	60%	0	0%	2	50%	0.16
Female	8	62%	2	40%	4	100%	2	50%	
Sea lions									
Age Class	**1512**								
Pup	2	0%	1	0%	0	0%	1	0%	< 0.01
Juvenile	125	8%	64	8%	4	9%	52	8%	
Sub-adult	663	44%	203	24%	16	34%	444	71%	
Adult	722	48%	566	68%	27	57%	129	21%	
Sex	**1531**								
Male	1204	79%	601	71%	39	89%	564	88%	< 0.01
Female	327	21%	245	29%	5	11%	77	12%	
Cetaceans									
Age Class	**1106**								
Juvenile	240	22%	55	18%	6	75%	179	22%	< 0.01
Adult	827	75%	232	78%	0	0%	595	74%	
Pup	39	4%	11	4%	2	25%	26	3%	
Sex	**752**								
Male	426	57%	72	50%	7	88%	347	58%	0.04
Female	326	43%	73	50%	1	13%	252	42%	

** p-value (X2-Test)*

+ Chelonia mydas agassizii, Lepidochelys olivacea, Dermochelys coriacea

++ Otaria flavescens

+++ Delphinus capensis, Tursiops truncatus, Phocoena spinipinnis, Physeter macrocephalus Megaptera novaeangliae, Balaenoptera edeni, Delphinidae, Balaenopteridae

4.3 Period of Mass Strandings Occurrence

There is a significant difference in number of animal stradings per year (X^2 test, p-value <0.01) (Table 10), with an increase trend of reported cases in the last three years with a highest frequency achieved in 2014. Altogether, within the assessment period (2003-2016), years with massive mortality events occurred in 2009, 2012, 2014, 2015 and 2016. Peaks of mortality with a total of 934 and 1,021 cetaceans stranded occurred in 2012 and 2014, respectively. Whilst, a total of 293 and 654 pinnipeds stranded in 2009 and 2014, respectively. Moreover, mortality of 940 and 735 sea lions was registered in 2015 and 2016, respectively (Fig.4, Table 9). In the case of sea turtles, 259 stranded animals were recorded in 2016 (Fig. 4, table 9).

Whale carcasses were registered during the total period of study with an important mass stranding of Humpback whales over the coastline of Lambayeque in spring of 2003. Over the course of the last years, 2014 and 2015 were the years when whale strandings peaked. Six whales came ashore death on the coast of Lambayeque and Tumbes in 2014 (five Humpback whales, and one unidentified species); and in 2015, Bryde's whale (n=2), Humpback whale (n=2) and a Sperm whale (n=1) stranded in Lambayeque, as well as an unidentified species (n=1) on the coast of Piura (Fig. 5).

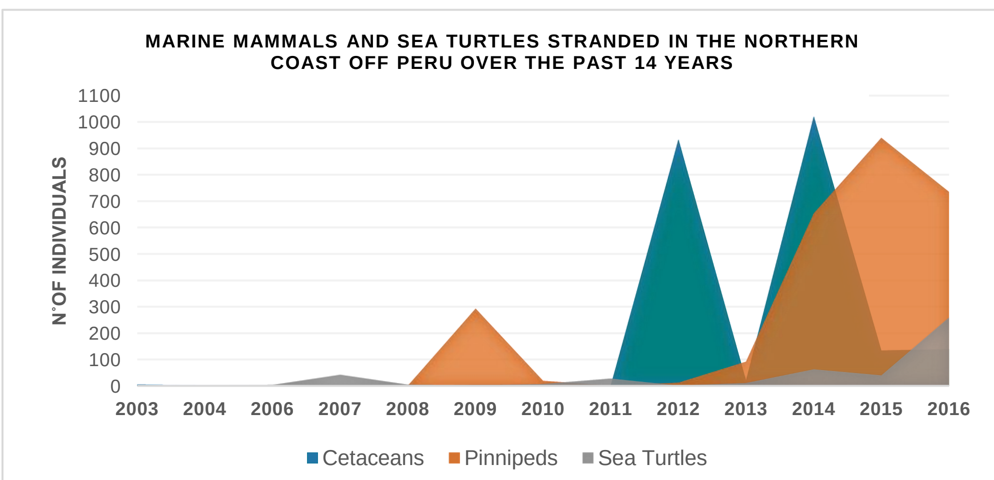

Figure 4. Sea turtles and marine mammals stranding peaks in the northern coast of Peru from 2003 to 2016. Note the peaks of stranding occurrence of sea turtles on 2016, sea lions on 2009, 2014 to 2016 and cetaceans in 2012 and 2014.

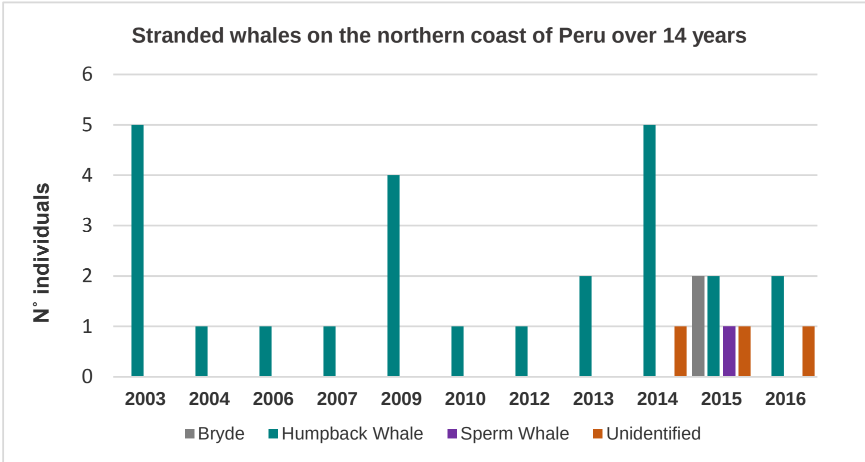

Figure 5. Stranded whales on the northern coast of Peru from 2003 to 2016. Humpback whales was the most frequent species stranded with peaks on 2003, 2009 and 2014. Several species of whales were registered in 2015 and 2016.

Table 10. Marine mammal strandings per animal group occurring during peak years in the coast of Northern Peru, considering the period 2003-2016

Species	2009		2012		2013		2014		2015		2016		p-value
Sea Turtles +	1	1%	1	0%	10	8%	62	4%	39	4%	259	23%	< 0.01
Sea lions ++	293	98%	12	1%	92	75%	654	38%	940	84%	735	65%	
Cetaceans +++	4	1%	934	99%	21	17%	1021	59%	134	12%	139	12%	

p-value (X^2-Test)

+ *Chelonia mydas agassizii, Lepidochelys olivacea, Dermochelys coriacea*

++ *Otaria flavecsens*

+++ *Delphinus capensis, Tursiops truncatus, Phocoena spinipinnis, Physeter macrocephalus, Delphinidae, Megaptera novaeangliae, Balaenoptera edeni, Balaenopterid*

4.4 Sex Composition and age class affected

Sex composition of the stranded sea turtles and marine mammals are described in Appendix 3. These analyses were based on 2,295 animals (out of 5,464) in which their sex could be determined, representing 42% of recorded stranded animals. In a reduced number of sea turtles that its sex could be determined (n=13), 62% were females and 38% males, with no significant statistical difference between sexes per region (X^2 test, p-value 0.15) (Table 9). Stranded sea lions were mainly composed by male individuals (79%), with a significant difference between sexes composition per region found (X^2 test, p-value <0.01). Stranded long-beaked common dolphins, Burmeister's porpoise and bottlenose dolphins were mainly composed by males (Appendix 3); with a non-significant difference between sexes per region (X^2 test, p-value 0.04) (Table 9).

Concerning to age groups affected, based on the mean CCL of stranded green and leatherback turtles, juvenile individuals were the most frequent (Table 11, Fig.6a); whereas in olive Ridley turtles were mostly adult individuals (Table 11). Statistical difference between sea turtles age class per region was identified (X^2 test, p-value <0.01) (Table 9), with predominant juveniles in three evaluated regions. Nevertheless, Tumbes was the region with higher number of adults.

Significant statistical difference between stranded sea lions age class per region was found (X^2 test, p-value <0.01) (Table 9). Sea lions were largely composed by adult in the northernmost regions (Tumbes and Piura), whereas in Lambayeque were compose by sub-adult males (SAM), based on the carcasses mean TL (Table 12, Table 13, Fig. 6b, Appendix 3). Likewise, significant statistical difference between cetacean age class per region (X^2 test, p-value <0.01) was found (Table 9). Stranded cetaceans were mainly adult individuals in Piura and Lambayeque, whereas in Tumbes were composed by juveniles (Table 9, 12, 13, Fig.6c, Appendix 3).

Table 11. Curve Carapace Length of stranded sea turtles on the northern coast of Peru in the period 2003-2016

Species	Mean CCL ± SD (cm)	Range (cm)	n
Olive Ridley turtle	64.63 ± 6.92	46-89	45
Green turtle	63.74 ± 9.78	31-94	286
Leatherback	103.00± 21.33	80-182	5

Table 12. Total Length of stranded marine mammals on the northern coast of Peru in the period 2003-2016

Species	Mean TL ± SD (m)	Range (m)	n
Sea lion	2.17 ± 0.32	0.95-3.25	990
Long-beaked common dolphin	2.10 ± 0.38	0.5-2.89	812
Bottlenose dolphin	2.16 ± 0.69	0.89-3.23	25
Burmeister´s porpoise	1.54 ± 0.34	0.69-2.75	77
Humpback whale	10.00 ± 3.61	3.3-15.2	22
Sperm whale	10.3 ± 0.00	___	1
Bryde’s whale	10.1 ± 0.00	___	2

Table 13. Total Length of stranded marine mammals classified by sex, in northern Peru in the period 2003-2016

Species	Male TL mean TL ± SD (m)	Range (m)	n	Female TL mean TL ± SD (m)	Range (m)	n
South American sea lion	2.24 ± 0.27	1.03-3.25	777	1.88 ± 0.31	1.22-2.72	92
Long-beaked common dolphin	2.13 ± 0.36	0.77-2.85	336	2.10 ± 0.33	0.84-2.83	269
Burmeister's porpoise	1.50 ± 0.31	0.86-1.97	25	1.53 ± 0.20	0.92-1.80	24
Bottlenose dolphin	2.56 ± 0.76	0.89-3.23	10	1.79 ± 0.36	1.52-2.41	5
Sperm whale	10.3	--	1	--	--	--
Humpback whale	8.30 ± 4.16	3.30-13.40	6	10.79 ± 3.18	6.70-15.00	7

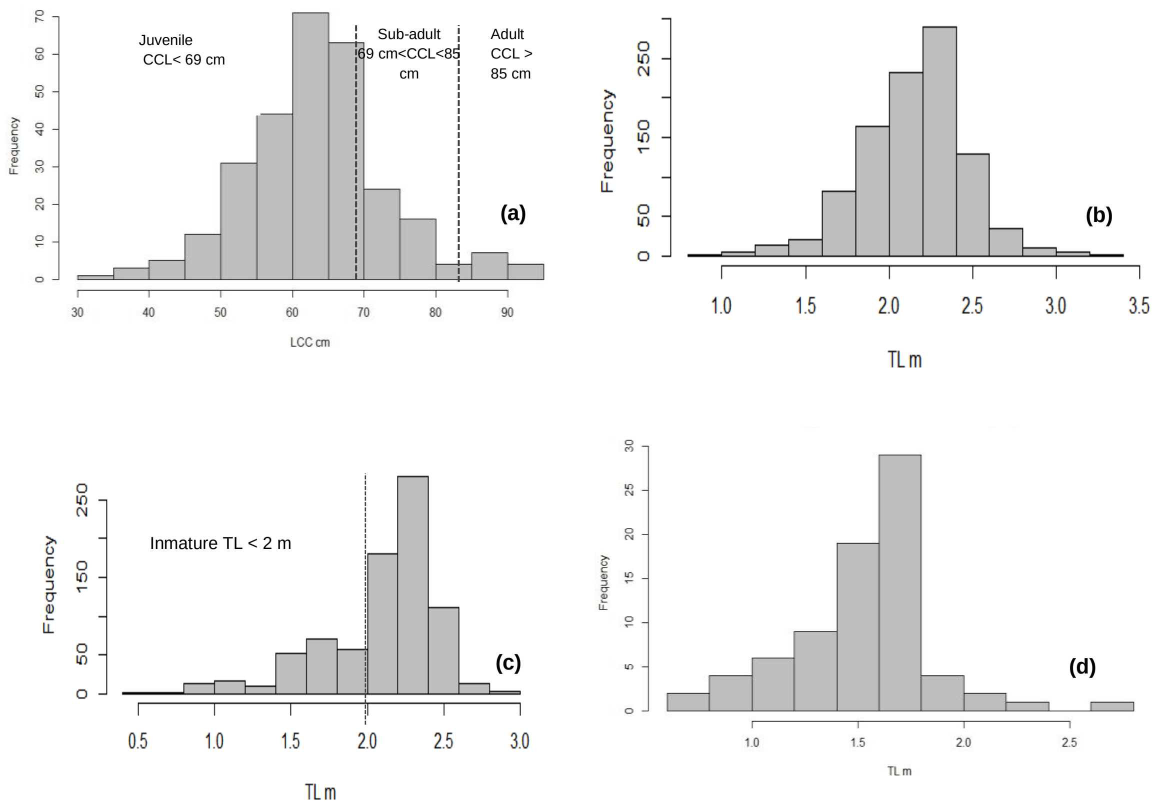

Figure 6. Size composition of stranded East Pacific green turtles, South American sea lions, long-beaked common dolphins and Burmeister's porpoises in northern Peru, **a.** Curve Carapace Length of stranded green turtles along the northern coast of Peru during 2003 and 2016. Notice that the stranded population is mainly compose by juvenile individuals. **b.** Total length of stranded sea lions. Notice that sub-adults and adult specimens constitute the stranded population. **c.** Total length of stranded long-beaked common dolphins. The histogram shows primary adults individuals stranded. **d.** Total length of stranded Burmeister's porpoises.

4.5 State of carcasses and causes of death

Most of the carcasses assessed were in advance stage of decomposition (61.9%), some were in moderate decomposition (11.7%) or mummified (20.6%). Only the 122 (1.1%) of the stranded carcasses were in fresh condition (Fig. 7). For this reason, cause of death of 4,863 animals could not be determined. However, from 613 individuals in which their carcass condition allowed more appropriate examination causes of death were determined and are specified on Table 14, of which an 11% of which were mainly related to human interaction. Stranded sea turtles revealed that 52% died butchered for human consumption (Fig.8a), 28% due to vessel collision (Fig.8b) and 16% due to fisheries gear interaction. Stranded sea lions revealed that 65% died due to intentional poisoning with agricultural pesticides (carbamates), 29% perished due to blunt trauma, 3% due to entanglement, 2% ingested fishing gear debris and died do to an intestinal obstruction (Fig.9, 10a, 10b). Identified causes of cetaceans revealed that 64% died entangled, 22% butchered for meat use, 12% due to disease (Appendix 7). It is important to highlight that ten humpback whales died as consequence of gillnet (n=9) and longline gear (n=1) entanglement; in addition, one whale of non-identified species died due to vessel collision (Fig. 11a, 11b).

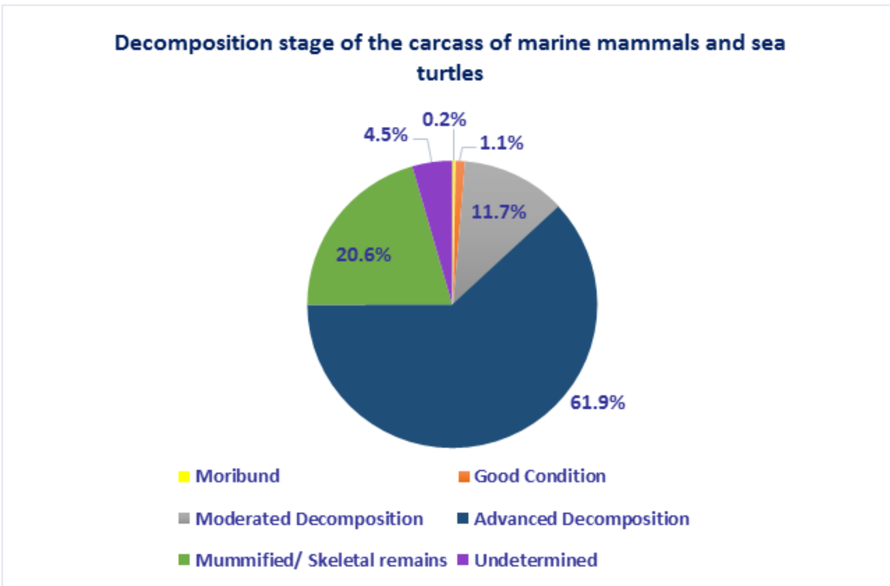

Figure 7. Stage of decomposition of stranded marine mammals and sea turtles along the northern coast of Peru during 2003 and 2016. The great majority of animals were found in advance and moderate state of decomposition as well as mummified.

Table 14. Identified death causes of stranded sea turtles and marine mammals on the northern coast of Peru recorded between 2003 and 2016

Animal Class	Entanglement		Butcherered for consumption or meat use		Blunt Trauma		Vessel Collision		Pesicide Intoxication		Intestinal Obstruction		Starvation		Disease		Total animals
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
Sea Turtles	8	16%	26	52%	1	2%	14	28%	0	0%	0	0%	0	0%	1	2%	50
Pinnipeds	13	3%	0	0%	138	29%	0	0%	312	65%	11	2%	7	1%	1	0%	482
Cetaceans	52	64%	18	22%	0	0%	1	1%	0	0%	0	0%	0	0%	10	12%	81
Cause of death	73	12%	44	7%	139	23%	15	2%	312	51%	11	2%	7	1%	12	2%	**613**

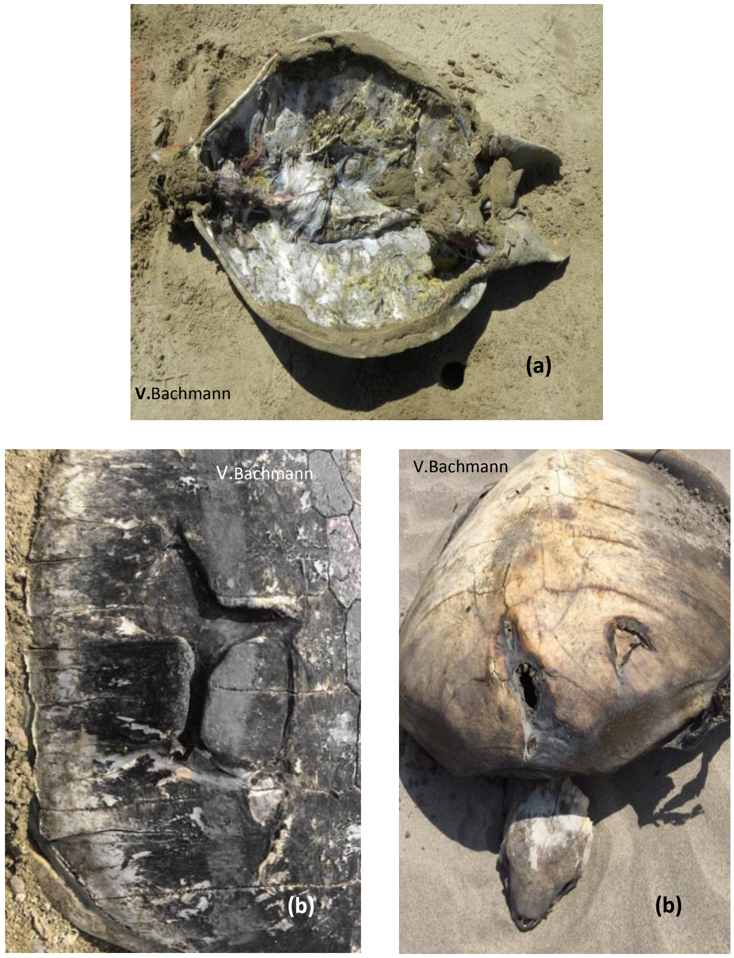

Figure 8. Carcasses of sea turtles stranded on the northern Peru. **a.** Green turtle butchered for consumption on San Pablo's beach, Piura. **b** and **c.** wounds on sea turtle carapace caused by vessel collision in sea turtle over Lambayeque and Constante seashore, Piura.

Figure 9. Monofilament net protruding from the intestines of a sea lion stranded on the coast of Lambayeque, northern Peru, 2016.

Figure 10. Mandibles and head blunt trauma lesion on sea lions over northern Peru. **a, b.** Sea lion head trauma cause by an apparent blunt object on Lambayeque littoral. **c, d.** Maxillary and mandibular fractures founded in sea lions of Piura littoral. **e.** Chipped bones due to maxillary and mandibular fractures.

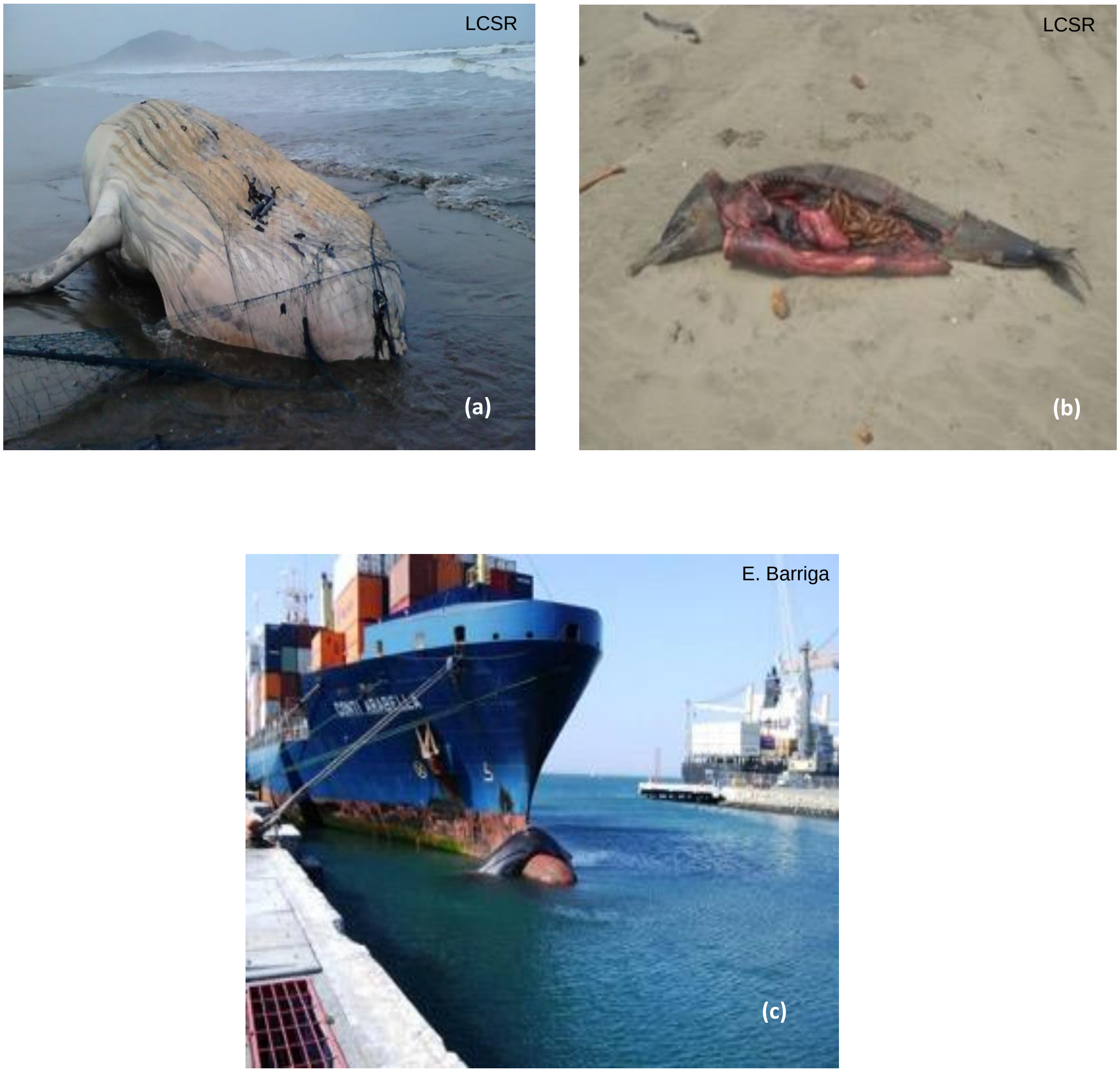

Figure 11. Human footprint behind the death of cetaceans. **a.** Humpback whale dead due to gillnet entanglement in the coast of Lambayeque. **b.** Common dolphin butchered. **c.** Whale dead due to commercial vessel collision.

4.6 Oceanographic abnormal conditions

In Table 15, the SST, SST anomalies and SSS during the period when sea turtles and marine mammals stranded on the northern coast are detailed. In appendices 8 to 13 is exposed the timeline SST, SST anomaly and SSS of Paita (Piura) and San José (Lambayeque) stations over the period of study. Additionally, Appendices 14 to 16 presented the mortality peaks of sea lions and long-beaked common dolphins versus SST anomaly.

Table 15. Mean sea surface temperature and Mean surface temperature anomalies measured during the stranding peaks of marine mammals and sea turtles over the northern coast of Peru between 2003 and 2016

Period	Station nearby stranded location	Species affected	Mean SST (°C)	MeanSST Anomaly (°C)	Mean SSS (PSU)
October 2003	San Jose, Lambayeque	Humpback whales	18.78	-0.13	35.097
November 2009	Paita, Piura	Sea Lions	18.30	0.40	35.052
February 2012	San Jose, Lambayeque	Long beaked common dolphin	21.84	-0.42	34.683
March 2012	San Jose, Lambayeque	Long beaked common dolphin	21.12	-1.44	ND
April 2012	San Jose, Lambayeque	Long beaked common dolphin	21.33	0.40	ND
January 2014	San Jose, Lambayeque	Long beaked common dolphin, Burmeister's porpoise, green turtles	22.11	1.62	34.918
February 2014	San Jose, Lambayeque	Long beaked common dolphin, Burmeister's porpoise	19.90	-2.79	34.996
November 2014	Paita, Piura	Sea lions	18.11	0.18	34.849
January 2015	San Jose, Lambayeque	Green turtles	21.06	0.25	34.913
October 2015	Paita, Piura	Sea lions	20.63	2.74	35.069
October 2015	San Jose, Lambayeque	Sea lions	21.39	2.48	35.151
November 2015	San Jose, Lambayeque	Sea lions	21.84	2.56	34.084
March 2016	San Jose, Lambayeque	Sea lions, green turtles	23.42	0.86	34.863
August 2016	San Jose, Lambayeque	Sea lions	19.49	0.79	35.097
October 2016	Paita, Piura	Sea lions	16.32	-0.84	35.069

Ten variables regarding to animal group strandings (sea turtle, pinnipedia, odontoceti, mysticeti), oceanographic conditions (ICEN categories, SST anomalies, SSS, ICEN index value, LABCOS index values), and death causes were evaluated using principal component analysis (PCA). PCA of animal strandings and oceanographic conditions produce two components (41.49% and 19.43%) that describe 60.91% of the variance in each case (Fig. 12ab, Appendix 17). The abundance of animal strandings were grouped in two ICEN categories, neutral (NE) conditions dominated by pinnipeds and odontoceti (green), and LN dominated by sea turtles and mysticeti (blue) (Fig. 12b). Moreover, pinnipeds strandings were associated with odontocetes and with SSS, as well as high correspondence with intentional poisoning and NE conditions; while gastrointestinal obstruction with nets and starvation were associated to EN (Fig. 12bcd, Appendix 17). Baleen whales and sea turtles strandings were associated to LN (Fig.12b, Appendix 17), as well as low correspondence with trauma and vessel collisions (Fig.12d, Appendix 17).

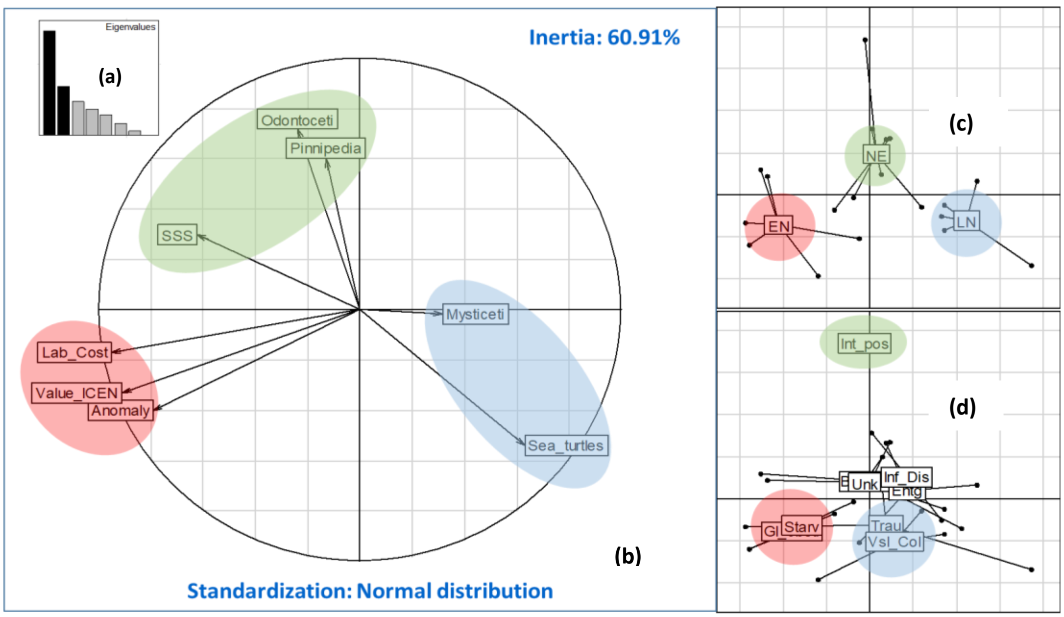

Figure 12. Principal Component Analysis (PCA) and Correspondence Analysis (CA). a. Eingenvalues that explained the variance or inertia in each component (7 of 10). b. Three main groups, odontoceti and pinnipedia stranding abundance and SSS in neutral conditions (green), sea turtles and mysticeti stranding abundance during LN, and ENSO Index (ICEN, LABCOS based con SST anomalies) associated with EN (red). c. AC analysis with three ICEN categories related with stranding occurrence of sea turtles and mysticetes LN (blue), odontocetes and pinnipeds NE (green), and EN (red). d. AC analysis with an association between death causes and ICEN categories.

PCA was done using oceanographic variables as supplementary variables; two components (41.55% and 24.19%) describe 65.74% of the variance (Appendix 18). High correlation between pinnipeds, odontocetes stranding abundance and oceanographic variables were observed (Fig.13, Appendix 18). Stranding abundance of these animal groups were highly correlated with LABCOS as well as SSS, and in less proportion with

ICEN index (Fig.13, Appendix 18); which are indicators of oceanic waters intromission that occurred during EN events.

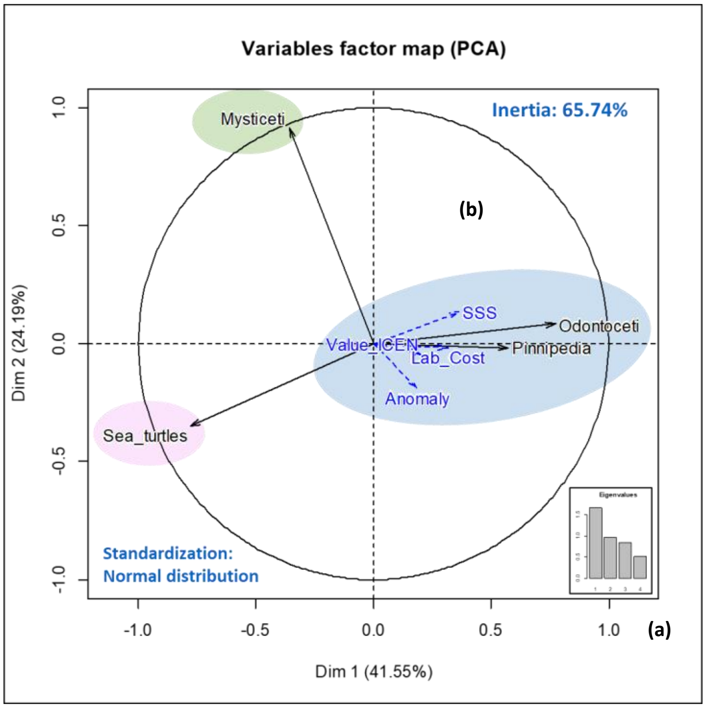

Figure 13. PCA with supplementary variables (oceanographic and stranding abundance of four animal groups). a. Eigenvalues that explained the inertia and describe the 65.74% of variance. b. An important cluster (in blue) that associates odontocetes and pinnipeds stranding abundance with SSS, LABCOS index, ICEN index and ICEN Index value.

When the evaluation is done by species, stranded green turtles revealed a significant weak positive association with SST anomalies (ρ(rho) = 0.11, p-value 0.02); and olive Ridley revealed a significant weak negative correlation with SST (ρ(rho) = -0.14, p-value <0.01), as well as a significant negative correlation with SSS (ρ(rho) = -0.12, p-value 0.01). Sea lion strandings shown a significant weak negative correlation with SST (ρ(rho) = -0.08, p-value <0.01), SST anomalies (ρ(rho) = -0.06, p-value 0.01) and SSS (ρ(rho) = -0.07, p-value <0.01). In regard to odontocetes, a significant weak positive association of stranded long beak common dolphins and SSS (ρ(rho) = 0.02, p-value 0.02); whereas, a significant negative weak correlation had been determined between stranded Burmeinster's porpoise and SST (ρ(rho) = -0.02, p-value 0.04), and a significant positive weak association with SST anomalies (ρ(rho) = -0.09, p-value 0.03) (Table 16). Figure14 shows the stranded animal class during ENSO years with coincidences between warm (EN) and cold phases (LN).

Table 16. Spearman correlation between sea turtles, sea lions, cetaceans and oceanographic variables Sea Surface Temperature, Sea Surface Temperature anomalies and Sea Surface Salinity in northern Peru 2003-2016

Species	SST		SST anolmalies		SSS	
	correlation	p-value	correlation	p-value	correlation	p-value
C. mydas	-0.02	0.59	0.11	0.02	0.07	0.13
L. olivacea	0.04	0.34	-0.14	<0.01	-0.12	0.01
D. coriacea	0.03	0.59	-0.01	0.83	-0.01	0.79
O.flavescens	-0.08	<0.01	-0.06	0.01	-0.07	<0.01
D. capensis	0.03	0.52	-0.06	0.07	0.02	0.02
T. truncatus	-0.05	0.11	0.01	0.59	-0.01	0.62
P. spinipinnis	-0.02	0.04	0.09	0.03	0.01	0.76
B. edeni	-0.02	0.49	-0.03	0.31	-0.05	0.08
M. novaeangliae	0.00	0.73	0.01	0.48	0.01	0.79
P. macrocephalus	0.04	0.15	0.05	0.08	-0.04	0.16
Delphinidae	-0.02	0.36	-0.05	0.17	-0.02	0.52
Balaenopteridae	0.03	0.56	-0.01	0.96	-0.08	<0.01

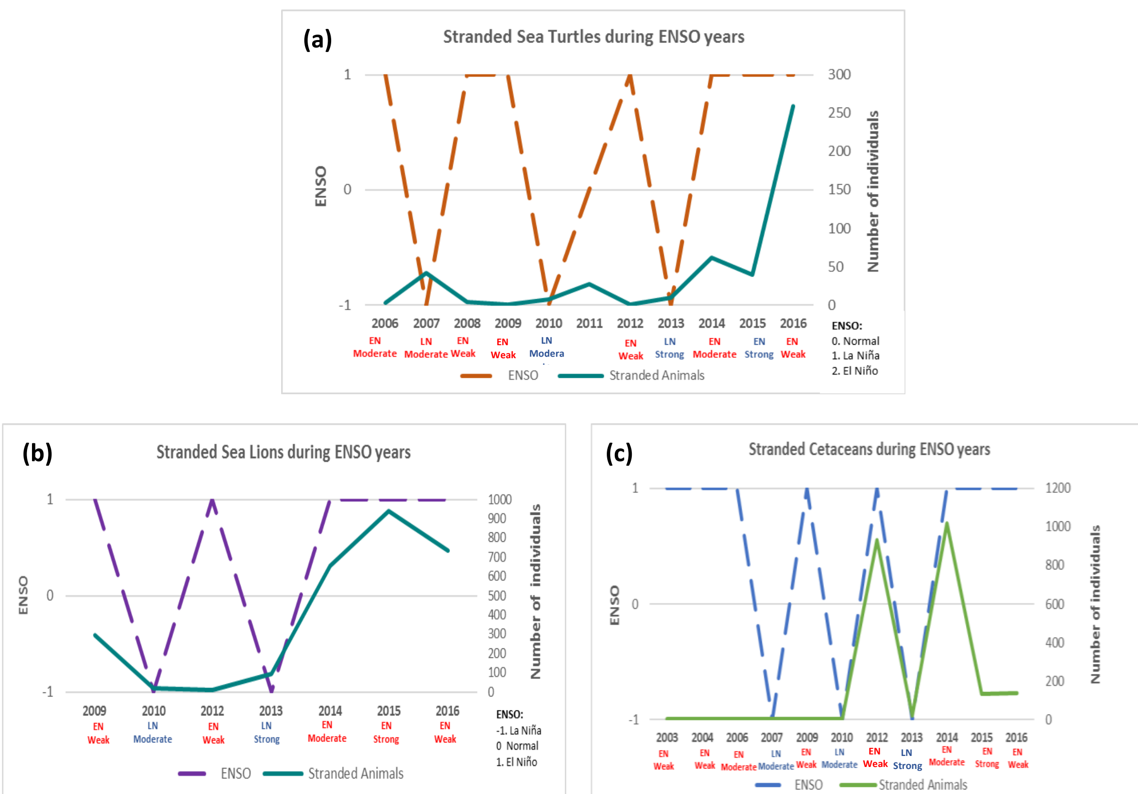

Figure 14. Major marine fauna stranded during EL Niño Southern Oscillation (ENSO) years. **a.** Sea turtles showing stranding peaks in ENSO years (moderate LN of 2007, moderate EN 2014 and strong EN 2015-16. **b.** Sea lions stranding peaks in ENSO years (weak EN 2009, moderate EN 2014 and strong EN 2015-16. **c.** Cetaceans stranding peaks in the year of weak EN 2012 and moderate EN of 2014.

5. DISCUSSION

This is the first study to explore the patterns and several causes behind sea turtles, pinnipeds and cetaceans stranded in Peru. Based on 5,464 stranded animals we detected an increased in marine mortalities with years and an association with ENSO. Despite the great number of cases in which the cause of death was undetermined, our results suggest an important interaction between marine megafauna and fisheries activities intensified during oceanographic abnormal conditions, which should be considered as one of the main factors behind strandings.

5.1 Affected species and cause of death

5.1.1 Sea turtles

Although our study determines Tumbes as an important stranding hotspot for marine turtles, Paredes-Coral (2017) registered 841 sea turtles stranded in Virrila Estuary, Piura during a period of seven years (2011-2017), with the east pacific green turtles (99%) as the main species affected and in a lesser extent hawksbill turtle *Eretmochelys imbricata* (1%). The number of stranded green sea turtles in Paredes-Coral (2017) study were more than triple of the stranded sea turtles amount obtained by the current study. This might be explained because Sechura Bay, where Virrila Estuary is located, is a key foraging area in the Peruvian northern coast and sustained an important aggregation of the east pacific green turtles. Likewise, the team of Paredes-Coral (2017) had made a greater sampling effort in that zone and because the estuary is not an open system as the seashore that can washed away the carcasses during a high tide. The current results, as well as the ones obtained by Paredes-Coral (2017) indicated that the southeastern Pacific green turtles have a coastal foraging behavior, and are abundant in the Peruvian northern coast. However, its foraging distribution encompass the coast of Peru and Chile as was reported by Alfaro-Shigueto et al*.* (2018) as the most common incidental catch species in those countries.

Leatherback turtles were reported bycaught by Alfaro-Shigueto et al*.* (2018) in low numbers in Ecuador, Peru and Chile, indicating that its distribution is oceanic; therefore, the possibility to encounter this species stranded is minor. While, olive ridley was commonly incidental caught mainly in Ecuador and Peru (Alfaro-Shigueto et al. 2018), thus the strandings findings herein are similar to bycatch areas described previously for these species.

Paredes-Coral (2017) and Quiñones et al. (2017), in Piura and Pisco, documented related causes of death for sea turtles as the ones found in our assessment respectively. The first study stated that 9.3% of 841 chelonians perished due to anthropogenic interactions, with direct captures (n=33) for human consumption and boat strikes (n=25) as the main threats for these species. Whereas, the second assessment, quantified 953 sea turtles' carapaces in Pisco dumpsites over a period of seven years (2009-2015), the evidence gathered indicated illegal captures for the black market trade; the species affected were mainly composed by green turtles (92.2%) and to a lesser extent by olive ridley turtles (4.3%), leatherback turtles (1.4%), and hawksbill turtle (0.1%). For all species, most of turtles reported were juveniles and came largely from illegal captures (89%) and not from stranding reports (1.4%) (Quiñones et al. 2017).

These results indicated that despite the current legislation known by fishermen (Alfaro-Shigueto 2018), meat consumption of sea turtle meat and derivate products still a common practice in the Peruvian coast as previously described by De Paz et al. (2002). This behavior is associated to the socio-economic characteristics of fishing communities, such impoverishment, remote locations, highly dependent on fisheries as source of food, absence of law reinforcement (Alfaro-Shigueto 2018). It is well known that fishermen retain bycatched turtles for local consumption over the northern coast of Peru, while in the southern coast (Pisco) a sea turtle target fishery for delicatessen cuisine still exists. Some local populations of sea turtles have been driven to extinction due to fisheries bycatch (Reeves et al. 2003). Moreover, fishermen vessels and recreational aquatic sports (yacht, sailboats or jets ski) represent an important threat to sea turtles, mainly in foraging aggregation areas.

Gillnets are used for their extraction, and have been known to cause considerable impact on sea turtles and marine mammals populations (Northridge 2002, Mangel et al. 2009, Wallace 2010, Alfaro-Shigueto et al. 2011, Castro et al. 2012). Gillnet fisheries included the use of surface nets (mainly driftnets), bottom set nets, trammel nets and encircling nets (Nédelec and Prado 1990). In Peru, gillnets represented the principal fishing gear employed in small-scale fisheries (Estrella and Swartzman 2010) due to their simplicity, and relatively low cost (Northridge 1991). This is also the case of Ecuador. As a result, the number of gillnet vessels in both countries double the Chilean gillnet fleet (Alfaro-Shigueto et al. 2018).

De Paz & Goya (2017) quantified the artisanal fleet bycatch of sea turtles in the main ports of Tumbes during spring of 2016, in 50 trips 84 sea turtles were captured in bottom and surface gillnets; with a registered mortality of 76.5% in bottom gillnets. Additionally, 136 sea turtles stranded in Tumbes during the period of study. The results obtained by De Paz & Goya (2017), highlight the entanglement mortality of sea turtle as an important reason of death, in which cases are underestimated. Pingo et al. (2017) had registered an important gillnet bycatch of green turtles (n=100), hawksbill turtles (n=3) and an olive ridley turtle (n=1) on Sechura Bay, Piura during July of 2013 to June 2014. This Bay is an important aggregation area for sea turtles (Santillán 2008); hence, these species have been exposed to an important fisheries pressure over Piura shore. Alfaro-Shigueto et al. (2011) documented seasonal peaks in incidental capture of leatherback turtles occurred in summer (Hays-Brown and Brown 1982). On the other hand, olive Ridley turtles have been suggested to occur on fisheries in summer months in northern Peru, and green turtles all year round along the coast (2011). The aforementioned patterns explain the numerous individuals of olive Ridley turtles stranded on summer, a pattern not observed for green turtles.

The eastern Pacific Ocean and its vast productivity sustains one of the greatest artisanal fleet of the word, which constituted an important threat for sea turtles. Alfaro-Shigueto et al. (2018) have estimated the bycatch mortality of sea turtles in Ecuador, Peru and Chile through 2010-2011. Their results shown that Ecuadorian artisanal fleet had a vast impact over marine turtle populations (13,302 animals per year); whilst, Peru and Chile annual mortality is lower than Ecuador, 2,927 and 6, respectively. The information presented gives an alert about the magnitude of the problem in the region, where sea turtle bycatch on gillnets is one of the largest of the world. Our results also highlight the stranding sea turtle hotspot in Tumbes neighboring Ecuador.

5.1.2 Pinnipeds

Sea lion mortalities due to human interaction intensified during ENSO years as presented in the current study, are common in other latitudes. In this context, Gulland (2006) reported hundreds of stranded Californian Sea lions (*Zalophus californianus*) over the Pacific coast of U.S.A. Moreover, during the ENSO event of 1982-1983, 50 sea lions perished due to gunshot, apparently caused by fishermen (Gulland 2006). Pinnipeds get shot by fishermen when they invade pens of cultured Salmon as they are considered as a threat for aquaculture activities (Geraci & Lounsbpury 1993).

A great pressure of the coastal zone by fishing activities resulted in human and marine mammal interaction (Bjørge et al*.* 2002, Camphuysen et al*.* 2008). Among all marine mammal species, pinnipeds had generated interactions in almost all fishing zones or near sea lion feeding or reproductive areas (Wickens, 1995). Hence, pinnipeds strandings can be used as a proxy to evaluate the impacts of anthropogenic activities (Warlick et al. 2018). Sea lions are generalist predators (Beverton 1985), thus, a permanent competition for prey exists between the South American sea lions and small-scale fisheries, which have become an important conflict not only in Peru (Imarpe 2013), but also in Chile (Sepulveda et al*.* 2006, Gonzales et al*.* 2015) due to the damage of commercial fish caught and their fishing gear (Sepulveda et al*.* 2006). Sepulveda et al*.* (2007) gave an overview of the conflict between South American sea lions and artisanal fisheries. The survey conducted to 384 fishermen along Chilean coast revealed that 56% of them have observed dead sea lion individuals during fishing operations due to entanglement; 8 to 10% admitted intentional slaughter of sea lions, and 93% believed that the solution of this conflict was legal hunt of sea lions. Due to the similar reality perceived by the artisanal Peruvian fleet, it is believed that an unauthorized killing of hundreds of sea lions occurred between 2014 to 2016 in the northern coast of Peru, years when commercial fish were not easily available due to ENSO events.

Evidence of human interaction was noticed in 11% of 14,729 stranded pinnipeds over a period of 1991 to 2016 in the northwest coast of USA; gunshot wounds and fisheries entanglements were important causes of Californian sea lion strandings, whilst boat collision injuries were registered in small number. Gunshots wounds were more common in adult and sub-adult pinnipeds, whereas entanglements were more frequent in juveniles (Warlick et al. 2018). Adult and sub-adult pinnipeds injuries reflect similar findings reported in our study, were these age classes with blunt or sharp object trauma, as well as poison individuals were higher than any other age class registered. The number of reported strandings and human interaction increased in areas where a great pressure exists due a combine factors, as a growing human and animal population, range of expansion, an enhanced stranding response capacity (Warlick et al. 2018).

Conflicts also arise when the population of pinnipeds and fishermen increase (Stewart 1997, Warlick et al. 2018). Despite that the national South American Sea lion census reveled a minimal population estimation of 105,464 individuals during the reproductive season of 2016, their numbers had diminished in relation to 2014 and 2015, were it was estimated to 141,225 and 147,291, respectively (Rivadeneyra et al*.* 2016). On the other hand, increased numbers of sea lions in fishing gears are not always related to an enlargement on their populations; but to other environmental factors, as the reduced availability of prey due to variation of oceanographic conditions that enables a superposition of foraging and fishing areas; as well as, the constant intrusion of fishermen near sea lion colonies (Szteren & Páez, 2002).

One of the main colonies was located on the northern coast of Peru, Lobos de Afuera Island, where 8% of the estimated population inhabits (Rivadeneyra et al*.* 2016). Artisanal fleet operates surrounding this island, which is located in proximity to one of the main stranding areas registered in this study, Lambayeque and southern Piura. Additionally, during mid-July through October of each year anchovy extraction is banned for industrial fisheries. During these months, the extraction of anchovy relies on artisanal fleet that is supposed to use this resource for human direct consumption. It is known that several local fishermen illegally sell their fish to industrial fisheries. Moreover, the anchovy first season closure promotes a migration of fishermen from large-scale vessels to smaller artisanal ships that might intensify interactions (J. Salcedo, personal communication 2017).

It is important to mention, that weak sea lion individuals can starve to death based on the results presented in our study. Additionally, deaths due to diseases outbreaks cannot be rule out if we take in consideration immunosuppression related to prolonged periods of malnourishment. Unfortunately, the decomposition of carcasses over the study site was very frequent, hence is no easy to identify these cases.

5.1.3. Cetaceans

Our results indicate that the most abundant species washed ashore differs with the evidence gathered by Van Waerebeek et al. (2018), whom describe Burmeister's porpoise (66.3%; n=942 small cetaceans), followed by Dusky dolphin (14.9%) and common dolphins (8.5%) as the main affected species in a study over different sites of northern, central and southern Peru during 2000 to 2017. This difference of species could be related to a major study effort undertook by Van Waerebeek et al. (2018) in central and southern coast, where species composition differs. Nevertheless, similar stranded species composition of three cetaceans (Burmeister's porpoise, common dolphins and bottlenose dolphins) species described by Van Waerebeek et al. (2018) were found in our assessment. Furthermore, this author also identified signs of fisheries interaction and/or meat utilization, mainly in Chilca, Lima (58.5%; 24/41 carcasses). Herein, humpback whales were the most common baleen whale species stranded in the study area, similar to the information presented by García-Godos et al. (2013) over the Peruvian coast.

The evidence gathered in our assessment, reveled whale, dolphin and porpoise interaction with fisheries as cause of mortality; mainly due to entanglement. Severe fluke is an important sign of entanglement found in small cetaceans, as stated by Reyes (unpublished data); since fishermen cut the animal tail in order to release it from their gear. Similarly, the impacts of fisheries on marine wildlife have been described in Peru (García-Godos et al*.* 2013, Van Waerebeek et al*.* 2007, Pizarro 2008, 2010, Rosales et al*.* 2010), as well as in other latitudes (Kemper et al*.* 2005, Galleti 2007, Reeves et al*.* 2003, Wallace et al*.* 2010). Geraci & Lounsbury (2005) highlight that entanglements associated with coastal fisheries particularly gillnets, as the main threat for porpoise species; as well as pelagic fisheries impacts diverse species of dolphins. Likewise, small-scale drift and set gillnets, industrial purse seines, longlines and beach seining had an important impact in small cetaceans in Peru (Van Waerebeek et al*.* 2002).

Van Waerebeek et al*.* (2002) estimated 471 small cetaceans' captures between 1999 to 2000 in surroundings areas of 15 ports/coves of northern and central coast of Peru (from Piura to Ica). In that study, the species largely affected over the northern coast were Burmeister's porpoise and long-beaked common dolphin, and in less proportion dusky and bottlenose dolphin (Van Waerebeek et al*.* 2002)*.* These authors also stated that in those years, intentional captures occurred for human consumption and bait use for elasmobranchs. For that matter, Mintzer et al*.* (2018) affirmed that Latin America and Asia widely used this practice for shark bait and that small cetaceans are the aquatic mammals most vulnerable to this threat. Likewise, countries of the region like Colombia, Chile, Ecuador and Argentina recorded small cetaceans bycatch, which is also used as bait (Avila et al*.* 2008, Lescrauwaet & Gibbons 1994, Felix & Samaniego 1994, Goodall et al*.* 1994).

An additional assessment over the northern coast of Peru (Salaverry port in Trujillo, La Libertad) registered 253 dolphins and porpoise captured between 2005 and 2007 in artisanal fishing fleet during 66 fishing monitoring trips; of which 46 were artisanal drift gillnet vessels and 20 longline vessels (Mangel et al*.* 2010). All gillnet ships monitored targeted sharks and rays; whereas, eighty percent of longline ships target Dorado and

20% sharks. Mangel et al. (2010) findings revealed that gillnets had more impact on small cetaceans than longlines, and the species affected were the ones with neritic habits on the continental shelf as Burmeister's porpoise (Clay et al. 2018), common and dusky dolphins (Reyes 2009, Llapapasca 2017); as well as the ones distributed on the continental slope as bottlenose dolphins (Llapapasca 2017) and Risso's dolphins (Reyes 2009). Furthermore, gillnet fisheries mainly discharged bycatch death cetaceans (n=92), but 68 animals were used as bait, nine eaten at home, three consumed at the boat, 14 dolphins were used for meat commercialization, five individuals harpooned, and only three animals were released alive. Conversely, longline fleet only registered one dusky dolphin entangled by the flukes, but 16 animals were harpooned alive (Mangel et al. 2010). This finding is in agreement with other bycatch study in artisanal fisheries of Salaverry port which between 2009 and 2011 determined fives species of small cetaceans (n=125) to be bycaught, including dusky, common and bottlenose dolphins, as well as Burmeinster's porpoise and pilot whales (Mangel et al. 2013). Forty-five percent of all cetacean bycatch was common dolphins. Their findings shown that dusky and common dolphins were used as bait, whereas Burmeister's porpoise was use for food; other species, as bottlenose dolphins and pilot whales were discarded (Mangel et al. 2013). These reports indicated that in the 2000s cetacean consumption and bait used was a common practice in Peru, and to some extent still occurring nowadays in the outer sea.

It is important to emphasis that fishermen for bait or food purposes retain death or alive bycatch animals in an opportunistic manner (Mangel et al. 2010, Mangel et al. 2013, Alfaro-Shigueto et al. 2018). Thus, determine if the animal drown while was entangled, or was kept and then slaughtered is difficult when the carcasses appear on the coastline. Therefore, animals could be slaughtered when there are entangle alive. Nonetheless, is important to collect data of carcasses with anthropic interaction signs in order to prove consumption of cetaceans by fishermen.

The number of humpback whales stranded due to gillnet entanglement shown in this study highlight the importance of this threat to the eastern South Pacific stock over

Peruvian waters during whale annual migrations from Antarctica to the Equatorial region for reproduction and calf breeding (Felix & Hasse 1997, Llapapasca 2014, Acevedo et al. 2007). The season when this species is vulnerable for entanglement is from July to November each year during these migrations (García-Godos et al. 2013). During this period, the individuals tend to occupy neritic zones that surround island and coastal areas with quiet and shallow waters (Smultea 1991, Llapapasca 2014). García-Godos et al. (2013) reported 15 entangled whales along the Peruvian waters between 1995 and 2012, with 19 cases since 1979. The main affected species was humpback whales (10 individuals, 66.7%), followed by sperm whales (3 individuals, 20%), one Antarctic Minke whale (6.7%), and another unidentified Balaenopterid. The specimens registered by García-Godos et al. (2013) were not part of the data analysis of the current assessment. Furthermore, the concentration of entangled humpbacks occurred mainly in Tumbes, the northernmost province of Peru (García-Godos et al. 2013). Tumbes and the north tip of Piura are the southern boundary of the Southeast Pacific breeding ground that encompasses Peru, Ecuador and Colombia (Pacheco et al. 2009). Whilst, sperm whales stranded on northern Peru and registered by García-Godos (2007) could be part of the Ecuador-northern Peru stock. In other latitudes, as the eastern North American Continental shelf, entanglement on fishing gears is the main cause of death among 323 individuals of eight large whale species (18%) and in a lesser extent ship strikes (10%) (Van der Hoop 2013).

Large whales chronically suffered when they are entangled in fishing gear. In entanglement mortality, the cause of death is irreversible and the effect is ultimately lethal trauma through a cumulative increase of body drag, loss of body condition and constriction of body parts, with or without secondary infection and the level of pain and stress is presumably extreme (Moore & Van der Hoop 2012, Cassoff et al. 2011). Drowning of entangled small cetaceans and pinnipeds cause a quick death (Hooker & Baird 2001) compared to large whales; as they entangle in debris and fishing gear that can have longer time courses (Moore & Van der Hoop 2012). If an animal is entangled in abundant gear that it cannot release or swim to the surface, it will drown. In these cases, lesions include one or several impressions of the rope over the skin (Hooker & Baird

2001). Rope texture imprints, might not be evident if the rope has been sawing back and forth as the animal struggles, causing deep skin, blubber and muscle lacerations even affecting the underlying bone (Winn et al. 2008).

Entanglement involving head regions has been reported in 67% of all lethally whale entanglements in the Atlantic waters of USA and Canada during 1995 to 2009 (Crassoff et al. 2011). Numerous wraps around the rostrum are common and could restrict the mouth opening. This can result in the decline of feeding efficiency. Rope may get stuck in baleen filter, disrupt the movement patterns, and limit the movement of tongue and lips with a severe impact on feeding capability (Lambertsen et al. 2005). Whales swim at a low drag coefficient (Miller et al. 2004) and an additional drag of accessory gear could deplete energy reserves of an entangled whale over time (Fowler 1987, Moore 2018). Such leakage of energy contributes to emaciation commonly seen with chronic entanglement (Lambertsen et al. 2005). Likewise, the animal lost energy needed to swim and fight infections (Moore 2018). In addition, laceration and subsequent infection can cause death in chronically affected animals, with secondary bronchopneumonia (Cassoff et al. 2011). Cases reported in North Atlantic right whales where line is fixed to more than one body part, such baleen and flippers, shown that the continual swimming motion of the animals generates chronic laceration on the limbs bones (Cassoff et al. 2011). In the case whales not drowning, they could die over periods of about 6 months (Cassoff et al. 2011), with cases where entanglement can persist for years (Consortium 2012).

Fatal ship strikes first occurred late in the 1800s as ships began to reach 13-15 km/h, and remained infrequent until about 1950 and then increase during 1950-1970s, as the speed of vessels increased (review in Laist et al. 2001). Injuries and death resulting from ship strikes with whales remain a significant threat to endangered species, as the case of North Atlantic right whales that face this cause as one of the primary reason in its slow recovery of a highly depleted population (Jensen & Silber 2004). Numerous vessel collision episodes go undetected or unreported as they may occur in remote areas, struck animals may drift out to sea or captains of large ships may not be aware of that a collision with whales had occurred and thus not report the incident. Moreover, captains do not have any legal obligation to do so (Jensen & Silber 2004). Hence, the information present in the current study represent a small fraction of the real problem faced by large cetaceans in Peruvian waters.

A review done by Jensen & Silber (2004) indicated that ship strikes with whales are a worldwide phenomenon that encompasses waters off Antarctica, Australia, Brazil, Canada, Canary Islands, United States, France, Japan, Mexico, New Zealand, Panama, Peru, Puerto Rico and South Africa, Caribbean, Mediterranean and Yellow seas, as well as Indian and South pacific Oceans. The database of Jensen & Silber review (2004) reported 292 confirmed or possible ship strikes to large whales; the species primarily affected were fin whales (75 records), humpback (44), North Atlantic right (38), gray (24), minke (19), southern right (15) and sperm whales (17). Fewer reports exist of blue (8), Bryde's (3), sei (3) and killer whale (1). Furthermore, several collision incidents were identified as Balaenopterids (3), and a large proportion of animals were not identified to species (42). Ship strikes are more commonly reported in North America, but the information could be biases due to the source of stranding data and enforcement reports (review in Laist et al*.* 2001, review in Jensen & Silber 2004). Both studies identify mortal injuries in whales and vessel damage are caused by operating speed equal or greater to 10 knots. A vessel collision with a non-identified species of whale was reported by Jensen & Silber (2004) 19 km west from Callao port in April of 1992; the ship was a research vessel of 89 m with a speed of 14 knots.

Mortalities due to entanglement, as well as vessel collision, are underestimated due to the negative buoyancy of blue and fin whales that sink most of the time after death, only refloating by the accumulated decomposition gases. In addition, other species normally buoyant on death can also sink if they are lipid depleted. In this case, offshore entanglements are not frequently sighted or reported (Moore 2018). Palliative measures included disentanglement response by trained teams and prevention (IWC 2011). However, due to the difficulty of disentanglement operations the only viable solution is prevention (Moore 2014). Meyers et al*.* (2007) highlights the importance of fundamental shift of fishery management in order to mitigate whale entanglements focusing on spacetemporal separation of gears and whales, as well as effective gear modifications. For ship strikes, Dynamic management areas (DMAs) are suggested, where speed vessels of 19.8 meters long are restricted to 10 knots or less, and transit in areas where dispositive of separation traffic scheme are considered (NOAA 2018).

5.1.4 Infectious Diseases

Regardless of the reduced numbers of necropsies (n=20) performed in stranded marine mammals during the study period (mainly cetaceans), natural causes were involved in their death (10%). Inflammatory processes incompatible with life as pneumonias were the main pathology registered in odontocetes in the current study. Pneumonia is an important cause of morbidity and mortality in marine mammals and may have diverse causes. Parasites have caused important health problems in these species (Dailey 2001); marine mammals are exposed to parasites infections through their prey that possess infective larvae (Howard et al. 1983) that can migrate to the lungs. Pneumonias registered in our study were not compatible with CMV infection, as massive mortal events reported elsewhere (Van Bressen et al*.* 2014). On the other hand, Higgins (2000) stated that bacterial pneumonias are the most common diseases in aquatic marine mammals and are strongly associated with their death. Gonzales-Viera et al. (2011) found nonspecific inflammatory processes in lung tissues of ten South American sea lions, two bottlenose dolphins, one dusky dolphin and one Burmeister´s porpoise stranded in Lima, Peru; the majority of these lesions had bronchopneumonic pattern, which is usually related to infectious diseases (Schumacher et al 1990). Other pulmonary findings of our study were similar to Vieira's (2009), Ruoppolo (2003), Knieriem and García-Hartmann (1996), which affirmed that congestion, pulmonary emphysema and edema had been associated to death by asphyxia associated with bycatch.

Furthermore, hepatic lipidosis is compatible with toxin action, acute anoxia and hypoxia; as well as, a diet rich in lipid content and low protein or mobilization of fat to the hepatocytes in emaciation and toxin insults (Sanchez 1993, Gulland et al*.* 2001, Howard 1983). Condition that could been developed due to algal bloom, prey shift or starvation, during warm phase of ENSO. The information gathered in this study suggest that stress periods due to environmental changes and prey variation and scarcity could lead to the vulnerability to infections of immunodepressed individuals (8 cases of immune depletion in marine mammals determined by histopathology) that can affected their survival.

5.1.5 Biotoxins

Biotoxins could be involved in mass stranding events of marine mammals (Fire & Van Dolah 2012, Geraci & Lousboury 2005). Based on the degenerative lesions reported in eight stranded long beaked common dolphins during the summer of 2014 we found biotoxins could be involved in cetacean strandings in northern Peru. In the Austral fjords of Chile, Häusserman et al*.* (2017) suggest biotoxins as the main cause involved of the greatest Baleen mass mortality ever recorded globally, involving 343 whales, primarily Sei whales (*Balaenoptera borealis*) stranded in 2015-2016 in southern Chile. Fire et al*.* (2017) registered Domoic Acid (DA) (15/57), Okadaic Acid (OA) (6/26) and Saxitoxins (STX) (3/48) in live pinnipeds over Punta San Juan, southern coast of Peru. Furthermore, Sanchez et al*.* (2016) had registered 16 species of potential harmful algal over the coast of Paracas, Sechura and Samanco (*Pzeudonizchia spp, Alexandrium ostenfeldii, Dinophysis caudata, D. acuminate, Gonyaulax spninifera, Azadinium spp., Karlodinium spp., Kerenia sp., Protoceratium reticulatum and Prorocetrum minumun*). These authors stated that OA was the most frequent toxin recorded in Samanco, Chimbote (central coast of Peru) and Sechura Bay (Piura); as well as STX over Paracas coast. Warm phase of ENSO can exacerbate harmful algal blooms in upwelling system coasts due to the rise of SST, continental nutrient discharge over rainfall and fast reproduction of harm algal blooms (HAB) in those waters (Moore et al*.* 2010).

Biotoxins were known to bioacumulate in planktivorous fishes, as anchovies, which are the main prey of marine mammals causing subsequently mass mortality events over California current system (Van Dolah 2012), an important productive upwelling system, caused by repeated seasonal HAB toxins exposure (Gulland & Hall 2007, Bejarano et al*.* 2008). Biotoxin detection techniques using bioassays (as the available methodology in Peru) are not the preferable method for sea turtles and marine mammals because this assay cannot detect small toxins concentrations. Thus, liquid chromatography-tandem mass spectrometry (LC-MS/MS) technique is recommended for biotoxin detection due to its high sensibility and selectivity analysis capability (Marrouchi et al*.* 2010).

5.2 Area of Occurrence

Lambayeque coastline, area of greatest odontocetes stranding occurrence, is known to have a wide continental platform of more than 100 km in length and about 65 m of depth over a 20 nm strip that gets narrow in its limit with Piura (Moron 2000, Appendix 7). Low depth, intense wave’s incidence on the seashore, broad beaches, and extensive coastal platform suggest an important transport of sediments between the wave breaker zone and the shore facilitating the deposit of material carried by the waves (Imarpe 2012). Drift models over Lambayeque and southern Piura coast had proved that the potential animal deaths occurred <50 km of the coast over the continental shelf, hence there is a major probability to found fresh carcasses on the coastline (IMARPE 2012).

The Peruvian current system, composed by the Peruvian coastal current, the oceanic current and Chilean-Peruvian current flow from south to north direction (Novoa 2007). Trade winds are the predominant winds in the coast of Peru governed by the South Pacific anticyclone, which projects towards northwest. These winds are strengthened during winter, and weaken in austral summer. Currents and wind direction could define the direction and timing of strandings (Braulik & Fernandez 2007). The northern Humboldt Current System (HCS) off Peru, located in the Southeastern Pacific, is one of the world most productive upwelling ecosystems, characterized by a great abundance of pelagic resources (Chavez et al. 1999, Bouchon 2016), allowing to sustain important artisanal and industrial fisheries. Precisely, is in this region where ENSO is most notable, where sea surface temperature (SST) anomalies greater than 10 °C had been registered (Barber and Chavez 1983). However, due to the unpredictability of the Peruvian upwelling system pinnipeds and other marine megafauna have to face inter-annual fluctuations of food supply (Trillmich & Ono, 1991). Studies of pinnipeds suggest that severe fluctuations in prey may cause high mortality and reproductive failure, directly affecting population dynamics (Soto et al*.* 2004). Furthermore, longitudinal stranding data may reveal spatial and temporal trends and, thus, provide insight into predisposing factors for morbidity and mortality (Greig et al. 2005).

5.3 Sex composition and aged class affected

Sex was determined in 58% of the individuals registered. The remaining could not be sexed mainly due to the decomposition state, the stranding position of whales, and those cases of juvenile sea lions that might not evidence external sexual organs or secondary characteristics (e.g. male mane).

5.3.1 Sea Turtles

Sex classed was not possible to determine in the great majority of stranded sea turtles due to that fact that it only can be determined in adult individuals, and that the main age classed registered in the northern coast of Peru were juveniles and sub-adults. Therefore, the reduced number of sexed sea turtles can explain the no significant statistical difference found between regions.

Our findings in the three evaluated regions coincided with the main age class (juveniles) of stranded and live captured green turtle registered by Paredes-Coral (2017) in Piura (~5°S), and juvenile green turtles and leatherback turtles in illegal dumping sites of Pisco (~14°S) (Quiñones et al*.* 2017). Juvenile green turtle aggregation could be explained by the natural dispersal behavior of the species that had several habitat changes during the life cycle, with a juvenile neritic phase where they grow until reaching sexual maturity (Luschi et al*.* 2003). In the northern tip of the Peruvian coast, neritic areas could be shared with adults who forage between reproductive seasons (Musick & Limpus 1997), and also mixed group composed by juveniles, sub-adults and adults are common in this habitats (Velez-Suazo et al*.* 2014), due to the predominate convergence of northward upwelling waters with the warm waters from the Equator and warm tropical waters towards Equator in the transition area (~6°- 3°S) (Swartzman et al*.* 2008). Furthermore, Velez Zuazo et al. (2014), predicted proportionally more adult individuals would occur in this transition area (El Ñuro, Piura ~4°S), whereas in the site dominated by an upwelling, juvenile individuals would predominate (Paracas ~14°S). Stranded green sea turtle predominant age class registered in Tumbes was similar to the natural aggregation patterns described earlier (Velez-Suazo et al. 2014, Musick & Limpus 1997).

Moreover, stranded olive Ridley turtles registered on the current study were composed by an important number of adult specimens, similar to the findings of Quiñones et al. (2017) in Pisco. Sminoff et al. (2008) indicated that temperature restricts sea turtle distribution and during ENSO conditions the thermal water mass that normally act as a barrier disappears and triggers their distribution expansion. It could be possible that mature individuals used transitional areas for foraging before reaching reproduction grounds. Musick & Limpus (1997) suggest that adults may use coastal and oceanic foraging habitats, whereas juveniles may use both depending on food availability. In continental Australia, immature and adult olive Ridley turtle specimens are captured all year round over the continental shelf (Musick & Limpus 1997). Despite that fact that leatherbacks are pelagic, they recruit seasonally to temperate and boreal coastal habitats depending on the jellyfish concentration, main prey of this species (Musick & Limpus 1997). Over the Atlantic, the first coastal individuals appeared with a CCL of 110 to 120, based on stranded data (Musick & Limpus 1997).

5.3.2. Pinnipeds

Similar stranded age class as the ones described in our study, has been recorded in Monterey Bay, where sub-adult and adult male Californian sea lions (*Zalophus californianus*) strandings were reported (Bargu et al. 2012) during spring of 2007, in an ecosystem with similar characteristics to the northern HCS, the California Current System (CCS). Likewise, Warlick et al. (2018) through a spatio-temporal characterization of pinnipeds strandings in the Pacific Northwest from 1991 to 2016 determined that Californian sea lion was one of the main species of pinnipeds stranded with a predomination of adult and sub-adult males. This was previously reported in the same locality (Bargu et al. 2010), and was attributed to the fact that the breeding season for the species is May each year, thus is likely that the number of males of these age class increase their numbers near coast previous southward migration to their breeding sites (Melin et al. 2000). Moreover, during anomalous oceanographic conditions males of

Californian sea lions forage up to 450 km offshore spending more time at the ocean (Weise et al. 2006). Similar to northern Peru, strandings were registered prior to the breeding season of South American Sea lions, and the predominant age class affected was sub-adult and adult males. As in CSS, ENSO events might increase the time spent by male sea lions at the sea searching for prey, thus major probability to interact with fisheries and get injured by fishermen due to its opportunistic behavior. Sepulveda et al. (2007) described that sub-adults and adult South American sea lion individuals in Chile tend to interact with artisanal fleet.

5.3.3 Cetaceans

An important number of adult cetaceans were registered stranded in Ceará, Brazil during 1992 to 2005 (n = 252, 64%) (Meirelles et al. 2009) as was presented in our study. Our assessment shows several small cetacean species with a maximum TL larger than previously described (Folkens et al. 2002, Reyes 2009), as the case of long-beaked common dolphins with 0.31 to 0.63 m over the maximum length, and Burmeister's porpoises with 0.07 to 0.15 m more (Table 11). These findings are also recorded previously by Van Waerebeek et al. (2017), whom registered a total length maximum 1.92 cm for Burmeinster's porpoise and might be explained by a post mortem relaxation due to decomposition of epaxial and hypaxial muscles and enlargement of the vertebral column.

The distribution of dolphin species seems to be correlated to certain waters masses (Llapapasca 2017), but it could change at different temporal scales as a response to predominant environmental regime seasonally (Neumann 2001) or inter-annually during ENSO evens (Henderson et al. 2014). Adult animals were the age class predominant but juveniles were also registered, showing the gregarious behavior of common and bottlenose dolphins with several mix neritic herds. Llapapasca (2017) describe potential habitat of long-beaked and bottlenose common dolphin during warm (EN) and cold conditions (which take into account LN and normal conditions) over the coast of Peru. The author found a patchy habitat for long-beaked common dolphin species along the Peruvian coast in cold conditions, which is distributed in three potential zones 7-10°S, 12-

14°S and 17-18°S near to the continental shelf brake; whereas during warm conditions its potential habitat was continuous particularly between 7-14°S, with to small patches in the north (5-6°S) and the south (17-18°S) and restricted to the continental shelf. In addition, during warm ENSO years, the author predict that dolphins will constrain their distribution near the coast due to a decrease in upwelling intensity (Llapapasca 2017). The author findings could explain the mass stranding events of long-beaked common dolphins in EN years (2012 and 2014) described by the current assessment, years when the animals occupied the continental shelf between in latitudes where Lambayeque and southern Piura are located (5-6°S); even the herd of dolphins of 7-8°S could stranded in Lambayeque due to the northward direction of currents.

The distribution of long-beaked dolphins found by Llapapasca (2017) showed a high degree of overlap with Peruvian anchovy and other CCW species of prey in cold conditions; therefore, the change of distribution of prey also modificate the small cetacean distribution during warm conditions, as they approach to coast were these prey species are restricted. The presence of this species occurred in habitat with SST ranged between 22.5 to 23.2°C and a SSS of 34.9 to 35.1 PSU; but during warm conditions preference of this species change to SSW and MESC 18 to 19.6°C /24.8 to 28 and SSS of 34.8 to 35.1 (Llapapasca 2017). The SSS and SST measure in the months of strandings events during 2012 herein differ with the information describe by (Llapapasca 2017) during normal conditions; whilst were similar in warm conditions (ENSO year 2014). This could be due to the coastal distance were the SSS and SST were obtained. Llapapasca (2017) take these parameters offshore in research vessels, whereas the information presented herein was measure in oceanographic stations near shore.

Additionally, predicted potential habitat of bottlenose dolphin was proposed as an extended area over the continental shelf off the central (7-13°S) and southern Peruvian coast (17-18°S) during EN and LN with an association with SSW and MESC waters. This species had SST preferences of 21.7 to 26.5°C and SSS 35.08 to 35.16 PSU; during EN variables changes into SSW with 23.8 to 24.7°C SST and SSS of 35.21 to 35.33 PSU (Llapapasca 2017).

5.4 State of the carcasses

High temperatures that prevail in northern Peru all year round combined with the fact that the rate of decomposition is proportional to body temperature (with larger and rounded shape carcasses retaining heat longer than smaller), as well as the accelerated decomposition due to scavengers (Geraci & Lounsbury 2005) led to higher numbers of mummified, moderated and advanced decomposition categories found herein. On the other hand, a great number of carcasses in these categories prevent the determination of death causes. Furthermore, other factors such as odontocetes, with the exception of sperm whales, sinking after death and subsequently floating for days or weeks by the action of decomposition gases makes more difficult the codification of carcasses, due to a fresh appearance but internal decomposition (Geraci & Lounsbury 2005). In summer, and particularly after an infection process, the decomposition rates accelerate (Geraci & Lounsbury 2005). The rate of decomposition might be increased by the animal's terminal condition, like a sepsis with high fever or rapid bacterial colonization. Whereas this process slows down when the animal bleed to death and in carcasses that had been cut open and exposed to cold waters (Geraci & Lounsbury 2005). Additionally, the rugged geographic characteristics of the study area difficults the access to the beaches, limiting the periodicity of surveys that results in more decomposed carcasses, and less number of necropsies and correct sampling constraints with a negative outcome for the stranding investigation.

5.5 Peaks of occurrence and oceanographic abnormal conditions

The stranded increase trend over the years might be related to a major death rate of marine fauna, but also could be influenced, although to a lesser extent, to a greater sample effort. Since the creation of IMARPE in 1964 until 2013, IMARPE just act as the only governmental organization that responds to massive mortality events of sea turtles, seabirds, cetaceans and sea lions, gathering information due to its lack of a specific line of research on these matters. Since 2014 due to the mass stranding of dolphins in 2012, IMARPE reinforced its response and starting 2014 a consistent stranding monitoring program in the northern coast of Peru began and the efforts to register and determine cause of death of mass mortality events improved. Nowadays, other governmental and civilian institutions join the efforts but IMARPE is still leading the marine vertebrates stranding response. Therefore, the information gathered in this study reflects the most important massive events occurred in northern Peru.

Nevertheless, due to the lack of periodical evaluations, seasonality of massive strandings could not be determined. In any case, is important to highlight the significant number of stranded sea lions in spring during the last three assessed years, an important number of death sea turtles in during ENSO event of 2015-2016, as well as cetacean mass stranding events in summer of 2012 and 2014. Cetacean strandings are recorded depending on the human presence at the seashore, abundance of species during certain periods, and oceanographic conditions such as winds and currents (Norman et al*.* 2004). The increased presence of fishermen in inhabit coastal areas (where the majority of events occurred) may serve as an important alert for these species and other marine stranded species. Die-off episodes reveal the necessity of a regular long-term evaluation at least in the main stranding hotspots.

The warm phase of ENSO is a macroscale phenomenon responsible of short, middle and long-term global changes (Moron 2000), that generates substantial alterations in oceanographic and meteorological conditions in the Pacific Ocean, with manifestation affecting the Peruvian coast (Zuta et al*.* 1976). In Peru ENSO is characterized by and intense warming of the ocean between Paita and Chimbote (5°-10°S) due to the penetration of warm equatorial surface waters (Ñiquen et al*.* 1999). The impact of ENSO events on Peruvian marine ecosystems depends on its intensity and spatial structure (Espinoza-Morriberón et al*.* 2017). During moderate ENSO, SST can reach 3 to 4 °C over the monthly media and could last three to four months; it is characterized by the southern projection of the ESW up to 11°S (Moron 200). Whilst, strong ENSO had an effect along the entire Peruvian littoral, with a duration of 10 to 18 months, and causing SST anomalies up to 8 to 10 °C above the mean, as well as SSS anomalies of +0.3 to +0.4 PSU. For instance, during ENSO events of 2014, 2015-2016 important SSS anomalies were registered with the intrusion of SSW, and the reduction coastal habitat dominated by CCW (Bouchon et al*.* 2015, Bouchon et al. 2016). Moreover, the ENSO event of 2015-2016 was characterized for being one of the three strongest events in the historical record (Huang et al*.* 2016).

On the contrary, the cold phase La Niña is manifested with an intensification of the coastal and equatorial upwelling due to strong southeastern trade winds blowing along the Equatorial and Peruvian coast (Moron 2000). For instance, LN had negative SST anomalies of -1.5 to -3.0 °C and had been registered in Peruvian since 1904, and is associated with SSW, ESW oceanic, and northwards retreat, respectively. The upwelling waters are projected towards north and northwest, reaching distances greater than 100 to 150 nm off the coast, consequently pelagic resources as anchovies find a wide distribution area, scattering their schools (Moron 2000). In this scenario, marine mammals invest more time and energy foraging, whilst fishermen spend longer periods at the sea, thus the probability of marine wildlife-fisheries interactions increase.

The central Pacific is divided in four “El Niño” regions, which correspond with labels assigned to ship tracks that crossed these regions. Data from these tracks allowed the historic records of El Niño since 1949 (Rasmusson and Carpenter, 1982). The Niño 1+2 region (0-10S, 90W-80W) is the smallest and eastern-most of the Niño SST regions, and corresponds with the region of coastal South America where the local populations first recognized ENSO. El Niño 3 region (5N-5S, 150W-90W) was the primary focus for monitoring and predicting ENSO, but later the key region for coupled ocean-atmosphere interactions for ENSO was registered further west (Trenberth, 1997). El Niño 3.4 region (5N-5S, 170W-120W) had anomalies that may be thought of as representing the average equatorial SSTs across the Pacific from about the dateline to the South American coast. El Niño 4 (5N-5S, 160E-150W) captures SST anomalies in the central equatorial Pacific; this region tends to have less variance than the other Niño regions (Trenberth & National Center for Atmospheric Research Staff 2016, Appendix 6).

The years 2012, 2014 and period 2015-2016 were characterized by warm sea temperature conditions associated with ENSO events, with the constant arrival of Kelvin waves and intrusion of Subtropical Surface Waters (SSW) up to 40 nautical miles (nm) of coast (Salcedo et al. 2016). Moreover, during the anchovy (*Engraulis ringens*) fish opening season of the year in 2012, 2014 and 2015 the variations of SST and SSS impacted the distribution and depth of this resource (Ulloa et al. 2016). By the end of 2013 to the second half of 2014, the arrival and propagation of Kelvin waves was evident (IMARPE 2014a) due to a moderate ENSO Event (ENFEN 2014). The accumulative effect of these waves affected the ecosystem, with a reduction of the Peruvian ocean productivity, phytoplankton decline and subsequently anchovy decrease (IMARPE 2014b). The spatial distribution of anchovy biomass shown notorious changes in its distribution, for instance in summer of 2014 it showed a coastal and disperse distribution within the 20 nm of the coast. This situation was intensified on winter, when the biomass of this resource was reduced and scattered within 10 nm. The retreat of the anchovy and its high concentration near shore made it vulnerable to the action of fisheries fleets. Moreover, the school of anchovies distributed between Punta La Negra (6°00’ S) and San Nicolás (15°00’S) registered 43 m mean depth and a maximum of 110 m (Bouchon et al. 2015).

Since April 2015 to March 2016, the strongest ENSO event that have ever been recorded hit the Oceans of the southern hemisphere (Bouchon 2016). During this event, the intrusion of western warm waters (Superficial Subtropical Waters-SSW), a reduction coastal habitat dominated by Surface Cold Coastal Waters (CCW), and a decline of the fertility and productivity of the Peruvian sea were documented (Bouchon 2016). Additionally, the intrusion of SSW changed the plankton and zooplankton composition (Espinoza-Morriberon et al. 2017).

The years when mass stranded sea turtles and marine mammals peaked, coincided with ENSO years (LN and EN) (Fig. 14). However, PCA show an important association between odontocetes, pinnipeds with SSS during NE conditions (Fig. 12) changes that indicate the intrusion of SSW and upcoming changes as EN events. Fact that was confirmed with a supplementary PCA with oceanographic variables, that revealed an association between SST anomalies (LABCOS, ICEN index) and SSS variations with dolphin, porpoise and pinnipeds strandings (Fig. 13). Thus, oceanographic abnormal conditions could be linked to mass mortalities of marine vertebrate species as many authors have confirmed (Geraci & Lounsbury 1993, Trillmich and Ono 1991, Greig et al. 2005), although the main reasons varies in relation to the local sea dynamics and the fishing pressure over marine resources. Sea turtles and baleen whales are highly migratory species that shown a seasonal occurrence in the Peruvian ocean, therefore its specific association with EN or LN events could change over time and with the specific characteristic of each event.

Spearman correlation for the strangings by species revealed that, even if green sea turtle mortalities were not statistically significant related with SST and SSS, a weak statistical correlation with SST confirm the association of abnormal conditions; fact that mainly happened during the strong EN event of 2016. Similarly, Seminoff et al. (2008) explained that sea turtles are restricted by SST ≤24-25°C, and during ENSO events a thermal front breakage between CCW of the Humboldt current and SSW occurs, situation that foster sea turtle migration to foraging areas of South America attracting more turtles and expanding its distribution. Therefore, they are susceptible to die due to an increase probability of interaction with the artisanal fisheries fleet. This trend was reflected in the substantial increase in the local harvest rate of green turtles during EN events in Pisco, central Peru (Quiñones et al. 2010). Likewise, during the EN of 1997-1998 an increase sea turtle bycatch was reported in Lambayeque, which was associated with the increment in SST (Castro et al. 2012). Whereas, salinity had more influence than sea surface temperature for olive Ridleys; the intrusion of subtropical waters from the west Pacific during EN events increase SSS and could restrict its distribution over the CCW small coastal strip increasing the probability to get caught incidentally by fishermen.

It is important to highlight that Piura-Lambayeque (5-6°S), and Ica (14-15°S) constitute important upwelling zones that might change their prey composition due to SST, SSS and SST anomalies variations (Moron 2000). In this context, temperature and salinity in the oceans are important parameters that determine the distribution of marine organisms. These parameters are disrupted before, during and after ENSO events (Moron 2000). Furthermore, ENSO could trigger algal and seagrass predominance offering more food source for sea turtles (Poloczanka et al. 2009). Also regarding foraging behavior, leatherbacks off the U.S. West Coast avoid entering their typical nearshore habitats when waters are overly warm (Benson et al. 2007), a habitat use pattern that has been linked to positive phases of ENSO and the Northern Oscillation Index (Schwing et al. 2002). In contrast, green turtles aggregate in greater density along the Peruvian coast during the warm ENSO periods, presumably because of the warming of local waters that are usually too cold for this species.

Although negative correlation between SST, SST anomalies and sea lion strandings was found by Sperman correlation, ENSO long term effects could explain mass mortalities of this species, which could be linked directly or indirectly, whether by starvation or major probability of interaction with fishermen in their desperate eager of food intake. Pinniped strandings might also be driven by SST anomalies, variations in SSS (as was shown by PCA) and change of distribution of their preys over time. Additionally, the intrusion of warm and high salinity waters changes the plankton and zooplankton composition, and subsequently the availability of anchovy and other cold water pelagic prey species for South American sea lions change (Trillmich & Ono 1991, Arias- Schreiber 2003, Soto et al. 2006). Furthermore, the opportunistic behavior of this species conjoined to the initial abundance of cold pelagic species, as anchovies, during the early EN period where the reduce area of CCW concentrate a great number of fish it could sustain the population of sea lions and fishermen, but as the event progresses and the prey became scarce, difficulties finding the prey and fishermen conflict arise.

Zuta et al. (1976) and Valdivia (1976) indicate that the occurrence of ENSO generates strong changes in oceanographic conditions of the Peruvian Ocean, with an important impact on pelagic resources, disturbing their biological processes and behavior, and causing a progressive decline in their populations. The anchovy is the most sensitive species to those changes with a biomass reduction (Tsukayama 1983). Warm conditions in the early stages of ENSO in the north-center Peruvian region determines the retreat of anchovy in the 20 nm coastal strip in high mass, making it highly vulnerable to the action of the fisheries fleets. Subsequently, the schools moved southwards and deepened below

10 m (Ñiquen & Bouchon 2004), affecting prey availability and enhancing the competition between fishermen and sea lions. California sea lion strandings associated with ENSO have been well documented for the 1982-1983 (Trillmich and Ono 1991), 1992-1993, and 1997-1998 ENSO years (Greig et al*.* 2005). Moreover, oceanographic anomalies causing drastic decline in prey species led to mass starvation of Galapagos fur seals and sea lions in the 1982-83 ENSO event (Trillmich 1985), and of Cape fur seals along southwestern Africa in 1993 and 1994 (Geraci et al*.* 1999).

The same scenario also affects cold water prey availability for long-beaked common dolphins (Llapapasca et al*.* 2017), as well as other small cetacean species, leading them to compete with fishermen that under this conditions displayed a greater fishing effort resulting in mass mortalities. The aforementioned situation could be explained by the retreat of rich CCW near shore (Bouchon 2016) and the overlap of artisanal fleet activity, marine mammals and sea turtles foraging areas. Furthermore, oceanography variations and ocean productivity changes modified the abundance and distribution of prey species, which affect the foraging ecology of their predators (Moron 2000, Guinet et al*.* 2001, Soto et al*.* 2006). In our study, a weak Spearman correlation had been found between SSS and mortality events of long-beaked common dolphins, it is possible that their distribution change due to the increase of SSS, which indicates intromission of SSW and therefore changes in prey availability. García-Godos et al*.* (2007) suggest that long-beaked common dolphin preys mainly on Peruvian anchovy during cold conditions. Llapapasca et al*.* (2017) showed similar potential habitats between long-beaked common dolphin and Peruvian anchovy distribution particularly during cold conditions. Conversely, the overlap with Peruvian anchovy does not occur in warm conditions. During ENSO events, this species is mainly distributed over the continental platform (Llapapasca et al*.* 2017), and is likely to move east and southward following anchovy schools and other potential prey species inhabiting cold waters (e.g. red squat lobster) (Mathisen 1989; Yi et al*.* 2013). It has also been suggested that habitat use of bottlenose dolphins, dusky dolphins, long-beaked and short-beaked dolphins varies their extent depending the environmental regime and the distribution of potential prey (Llapapasca et al*.* 2017). Geraci & Lounsbury (1993) found that frequency of stranding events is associated to ENSO events, when conditions induce changes in prey distribution and abundance consequently caused cetaceans approach to the coast searching for food. Stranded Burmeister's porpoise shown a weak association with SST anomalies, and might indicate that during ENSO events the prey availability is scarce for both fishermen and cetaceans, thus a higher probability of interaction with fisheries and this species would exist, considering the neritic distribution of this species that make it more vulnerable to bycatch compared to normal oceanographic conditions.

5.6 Fisheries implications

Historically, artisanal fisheries have been considered as an important socioeconomic activity as source of employment, sustenance for thousands of families, and as source of protein, that ensures coastal communities food safety. Artisanal fishery activities have a particular dynamic in each port and bay of the Peruvian coast (Mendo et al*.* 2016, Estrella & Schwartzman 2010), producing between 200,000 and 400,000 tons of fish per year (Estrella & Swartzman 2010), which is primarily consumed directly through local markets. The number of fishermen has increased 34% to almost 38,000 over a period of 10 years, whereas the number of vessels has increased 54% to almost 10,000 gillnets used by 3,190 ships (Estrella 2006). Hence, fisheries add an extra pressure to marine mammals and turtles.

Despite that the Peruvian government restricted the industrial fishery activity outside 5 nm of the coastline (Executive order N° 017-92-PE), maintaining this area for the artisanal fishery, the law is not necessary followed, especially in warm water conditions, such as ENSO years when the anchovy stock is largely confined within 5 nm of seashore (Appendix 4, 5). This situation potentially creates a conflict between the artisanal and the industrial fisheries (Estrella & Schwartzman 2010). Thus, the competition between artisanal, industrial fisheries and marine megafauna in such conditions could result on a greater probability of human interaction between marine mammals, particularly sea lions (Wickens 1995, Gulland 2006, Sepulveda et al*.* 2006, Gonzales et al*.* 2015).

6. CONCLUSIONS

Over the last 14 years, the number of stranded marine mammals and sea turtles in the north coast of Peru have increased and caused a great concern among society and government agencies that pinpoint the importance of investigate and mitigate these mortality trends. Of a total of 5,464 marine vertebrates reported in this assessment, 8.3% represented sea turtle's die-off, 50.2% South American sea lions and 41.4% cetaceans. The results obtained in this research could probably underestimate the extent of marine wildlife stranding in Peru; however is an important guide toward the main factors involved in sea turtle and marine mammal mortality in Peruvian waters. The information presented in this research provides important insights regarding sea turtles, sea lions and cetacean species with neritic foraging behavior that might have been competing with small-scale fisheries, particularly during oceanographic warm years associates with ENSO. It also revealed the necessity of an urgent joint effort for a better understanding of those interactions and work on mechanisms to assure protection of marine biodiversity.

Limited resources assigned by governmental entities, as well as a rough geography, scavengers efficiency, high environmental temperatures particularly in summer, lack of algal biotoxins local capability detection on marine megafauna tissues, restricted diseases diagnostics and reduce veterinary efforts on the field had limited the determination of the cause of death of the majority of the events. Therefore, a monthly monitoring program with compulsory necropsies for fresh and moderately decomposed carcasses is needed in the northern coast of Peru in order to elucidate the magnitude of this problem, and quantify each factor involved in stradings (e.g. climatic conditions, human consumption, interaction with fisheries, infectious diseases, among others).

Regional Strandings Networks are strongly recommended until a National system is formed. These responses had to be led by a governmental institution, in collaboration with local universities and NGOs using standardized methodology for data collection. Anthropogenic interaction, emerging diseases, as well as biotoxins determination is needed in order to elucidate driven causes behind every mortality event (Geraci & Lousbury 2005) in a rapidly changing ecosystems affected by global warming.

Nonetheless, the long-term information IMARPE is collecting along the Peruvian coast will lay the foundations of historical stranded patterns associated with oceanographic anomalies and fishing pressure, and will serve as relevant evidence for governmental approach strategies and management for human threat reductions for sea turtles and marine mammals. However, much work remains to be done through in the establishment of a National Stranding Network and the implementation of specialized laboratories for biotoxins detection on marine megafauna, as well as a panel of pathogens that affect these species.

The information gathered in this assessment identified the importance of the northern coast of Peru as a key area for sea turtles and marine mammals, which presents a large number of strandings. It also provides insights of the rising conflict/interaction between human activities and these species, intensified during oceanographic anomalous years. In this respect, 11% of the death causes determined were related to human interaction. Moreover, ENSO appears to increase the interactions between marine megafauna and artisanal fisheries. Nevertheless, identifying other causes are important for the unresolved puzzle.

Coastal inhabiting species were the most frequent stranding findings and the age classes affected was related to the life stage that reaches the shore while foraging in the case of sea turtles (Velez-Suazo 2014), and the ones that tend to interact with fisheries for opportunistic source of food, as sea lions (IMARPE 2013, Rivadeneyra *et. al* 2016). For cetaceans the age class compromised varied related to the reproductive behavior (e.g. humpback whales) (Llapapasca 2014) or the neritic resident species (e.g. long-beaked common dolphins, Burmeister's porpoise) (Reyes 2009, Llapapasca 2017).

Nonetheless, stranding information may have gaps, biases and inconsistencies; they are invaluable source of information for management and conservation actions directed to the threats of marine species (Warlick et al. 2018). Likewise, identification of stranding hotspots and species at higher risk for human impact are essential for conservation attention (Warlick et al. 2018). Joint efforts are needed for unveiling the signs these species are giving us as warnings of the deterioration of the marine ecosystems.

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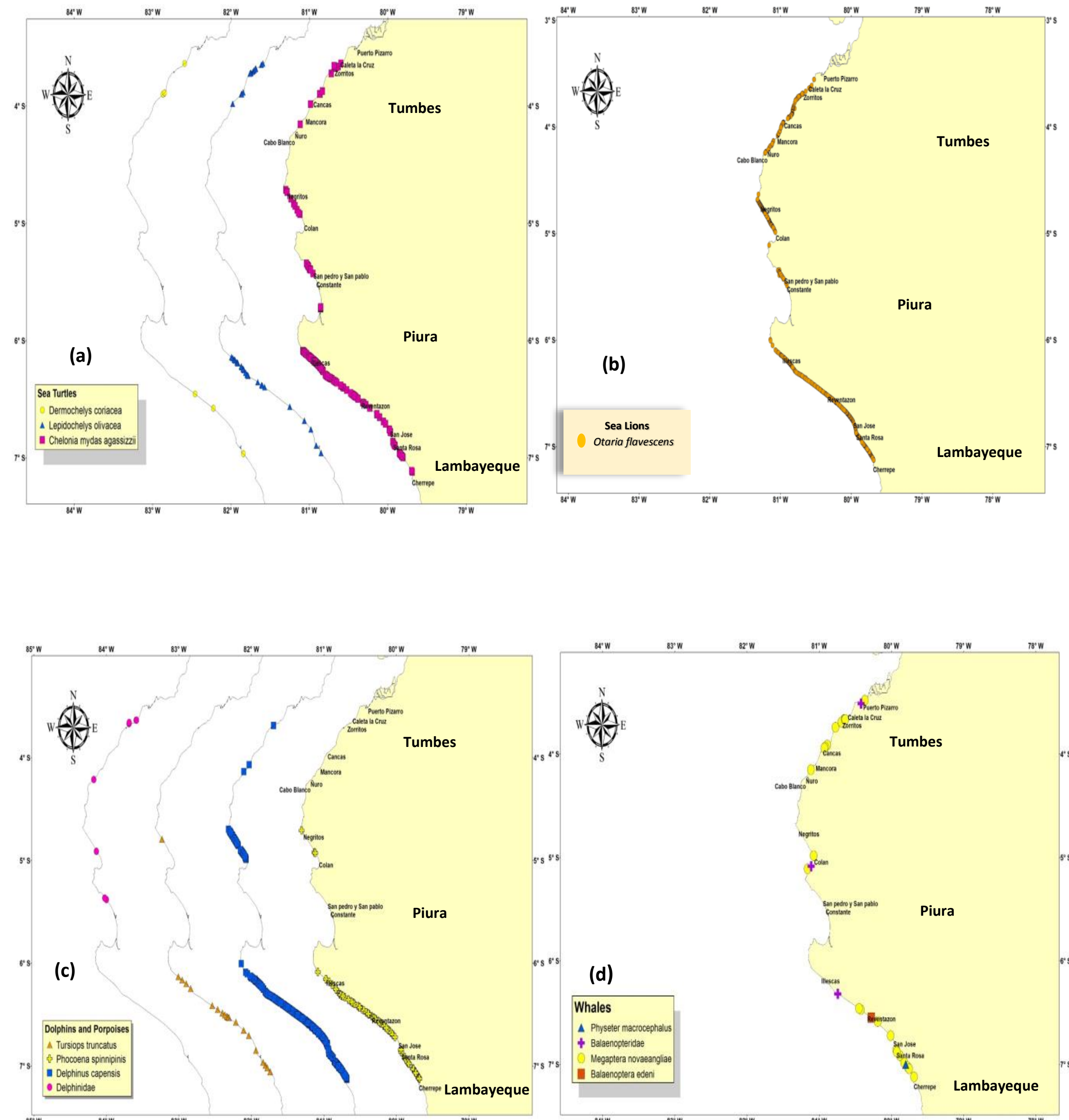
7. APPENDICES

Appendix 1. Marine mammals and sea turtle species of inhabiting the northern coast of Peru (Reyes 2009, Majluf and Trillmich 1981, Fraizer 1981)

GROUP	SPECIES	COMMON NAME	CONSERVATION STATUS (IUCN)
Cetacean (Odontoceti)	*Delphinus capensis*	Long beaked common dolphin	Data Deficient
	Phocoena spinipinnis	Burmeister's porpoise	Data Deficient
	Tursiops truncatus	Bottle nose dolphin	Least concern
	Globicephala macrorhynchus	Short-finned Pilot whale	Data Deficient
	Stenella longirostris	Spinner dolphin	Data Deficient
	Stenella attenuata	Pantropical spotted dolphin	Least concern
	Stenella coeruleoalba	striped dolphin	Least concern
	Mesoplodon peruvianus	Lesser beaked whale	Data Deficient
	Grampus griseus	Risso´s dolphin	Least concern
	Orcinus orca	Killer whale	Data Deficient
	Pseudorca crassidens	false killer whale	Data Deficient
	Physeter macrocephalus	sperm whale	Vulnerable
Cetacean (Mysticeti)	*Megaptera novaeangliae*	humpback whale	Least concern
	Balaenoptera musculus brevicaudata	blue whale	Endangered
	Balaenoptera physalus	fin whale	Endangered
	Balaenoptera edeni	Bryde's whale	Data Deficient
	Balaenoptera borealis	Sei whale	Endangered
Pinnipeds	*Otaria flavescens*	South American sea lion	Least concern
	Arctocephalus australis	South American fur seal	Least concern
Chelonia	*Chelonia mydas agassizii*	green turtle	Endangered
	Lepidochelys olivacea	olive Ridley	Vulnerable
	Eretmochelys imbricata	hawksbill	Critical endangered
	Dermochelys coriacea	leatherback	Vulnerable

Appendix 2. Area of sea turtles, sea lions, dolphins, porpoises and whales died-off occurrence. Notice differentiation of species with purple, red, blue and yellow symbols **a.** Location of stranded sea turtles over the northern coast of Peru**. b.** Sea lions stranded location. **c.** Location of stranded Odontocetes in northern Peru. **d.** Location of stranded whales.



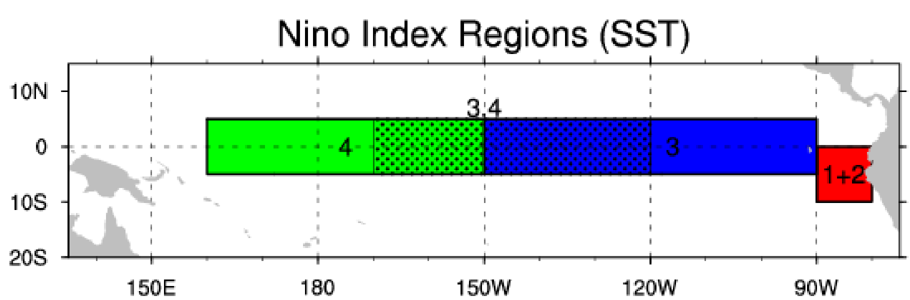
Appendix 3. Sex and age composition per stranded species on the northern coast of Peru

Species	Male	%	Female	%	n	Adult	%	Sub-adult	%	Juvenile	%	Pup/calf	%	Fetus	%	n
Olive Ridley	2	40%	3	60%	5	26	46%	5	9%	25	45%	0	--	0	--	56
Green turtle	3	38%	5	63%	8	14	4%	68	20%	253	76%	0	--	0	--	335
Leatherback	0	--	0	--	0	0	0%	3	38%	5	63%	0	--	0	--	8
South American sea lion	1204	79%	327	21%	1531	722	48%	663	44%	125	8%	2	0.1%	0	--	1512
Long-beaked common dolphin	372	56%	288	44%	660	765	80%	0	--	158	17%	30	3%	1	0.1%	954
Burmeister's porpoise	37	60%	25	40%	62	43	40%	0	--	59	55%	5	5%	0	--	107
Bottlenose dolphin	10	67%	5	33%	15	16	62%	0	--	10	38%	1	4%	0	--	26
Sperm whale	0	0%	1	100%	1	1	100%	0	--	0	0%	0	0.0%	0	--	1
Humpback whale	6	46%	7	54%	13	2	13%	0	--	11	73%	2	13%	0	--	15
Bryde whale	0	--	0	--	0	0	0%	0	--	2	100%	0	0%	0	--	2
TOTAL			2295								3016					

Appendix 4. Small scale artisanal vessels fishing near Los Organos coastline, Piura

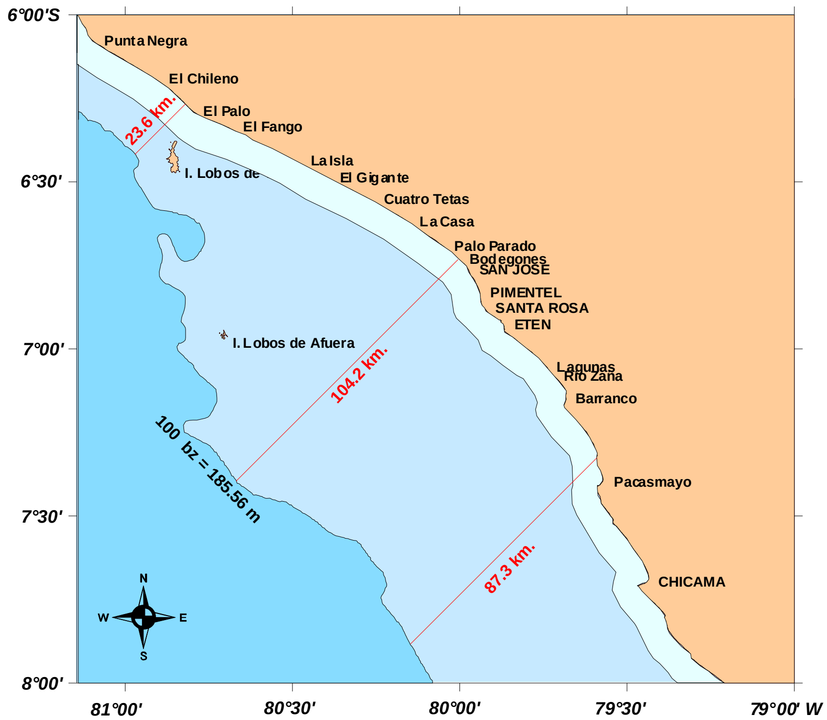
Appendix 5. Artisanal vessel operating close to a colony of sea lions, Punta Balcones, Piura

Appendix 6. Diagram of regions used for assorted El Niño indices

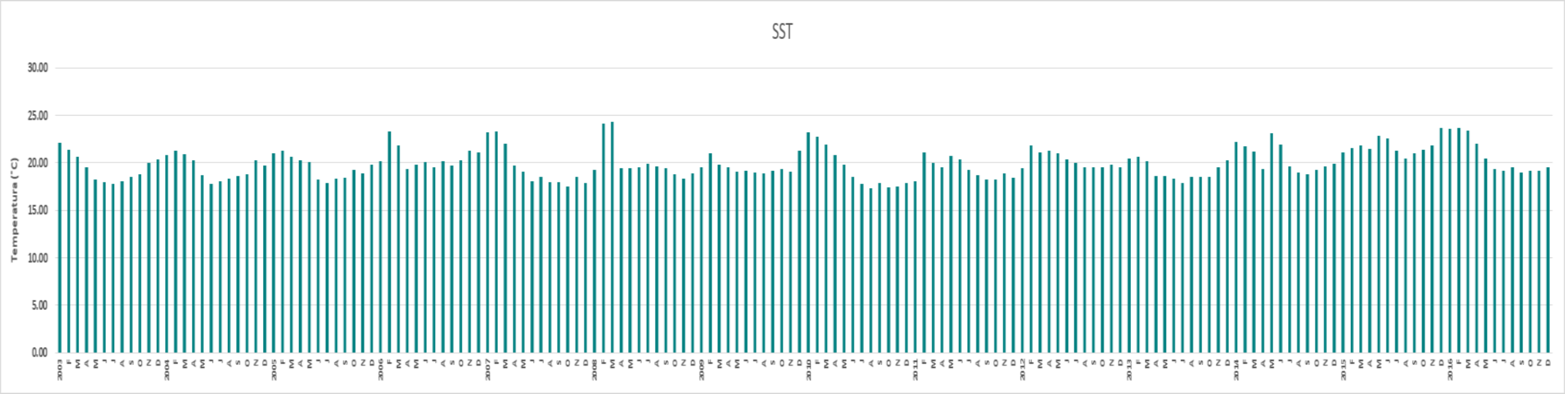


Source: Climate Data Guide

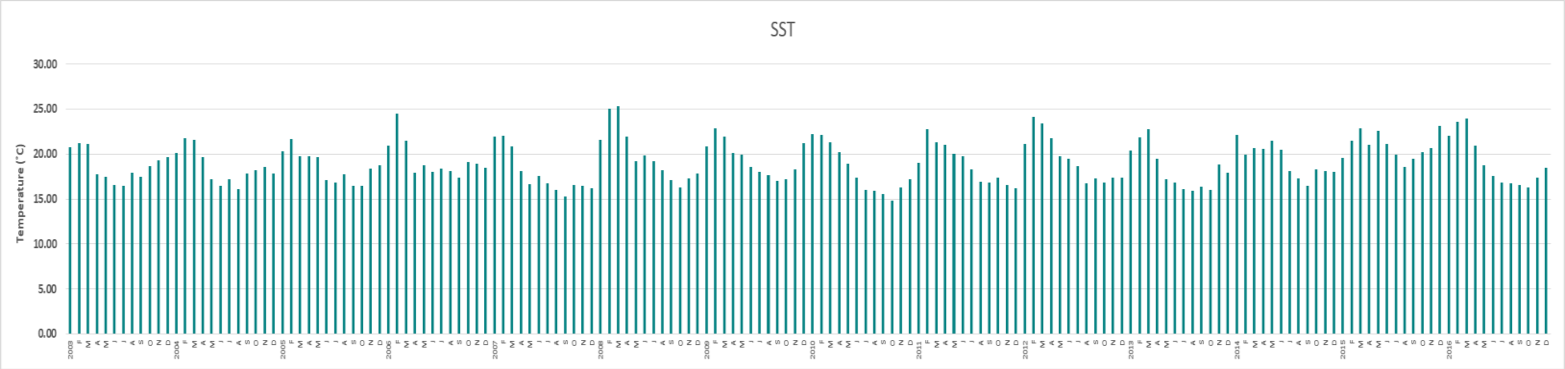
Appendix 7. Continental platform characteristics of the Coast of Lambayeque and southern Piura



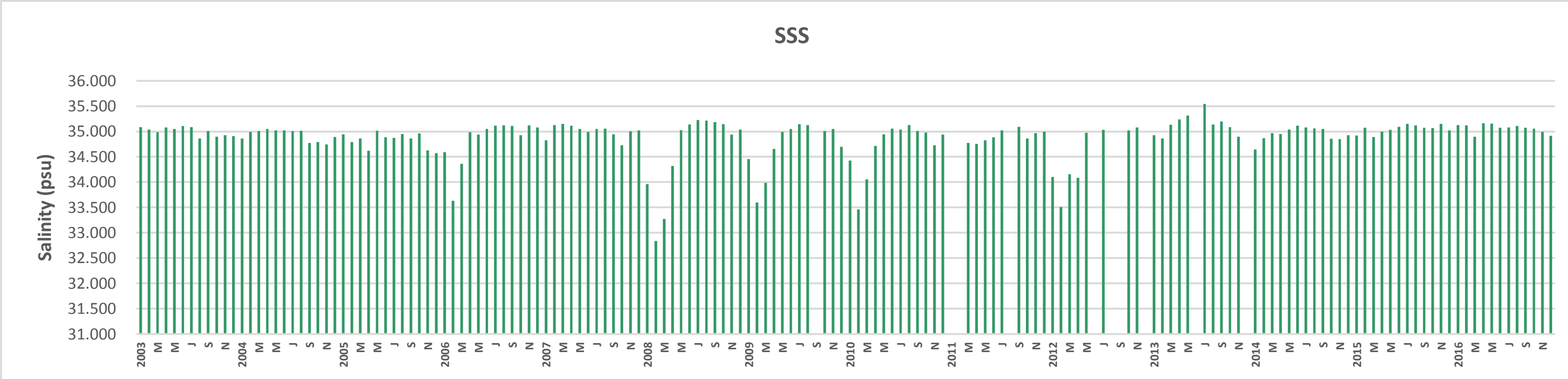
Source: Manuel Castro



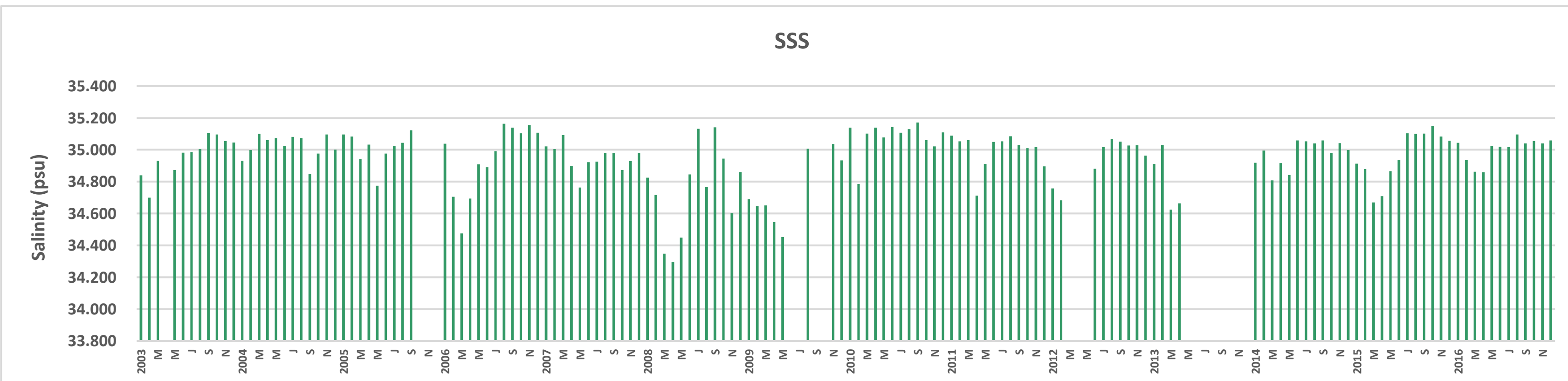
Appendix 8. Paita Station (Piura) monthly mean Sea Surface Temperature during 2003 to 2016



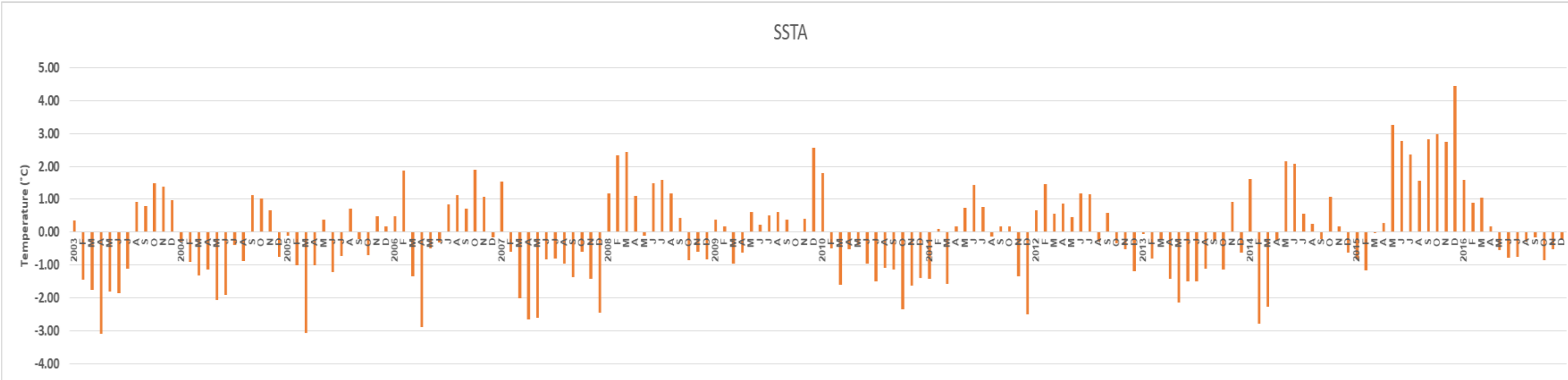
Appendix 9. San Jose Station (Lambayeque) monthly mean Sea Surface Temperature during 2003 and 2016



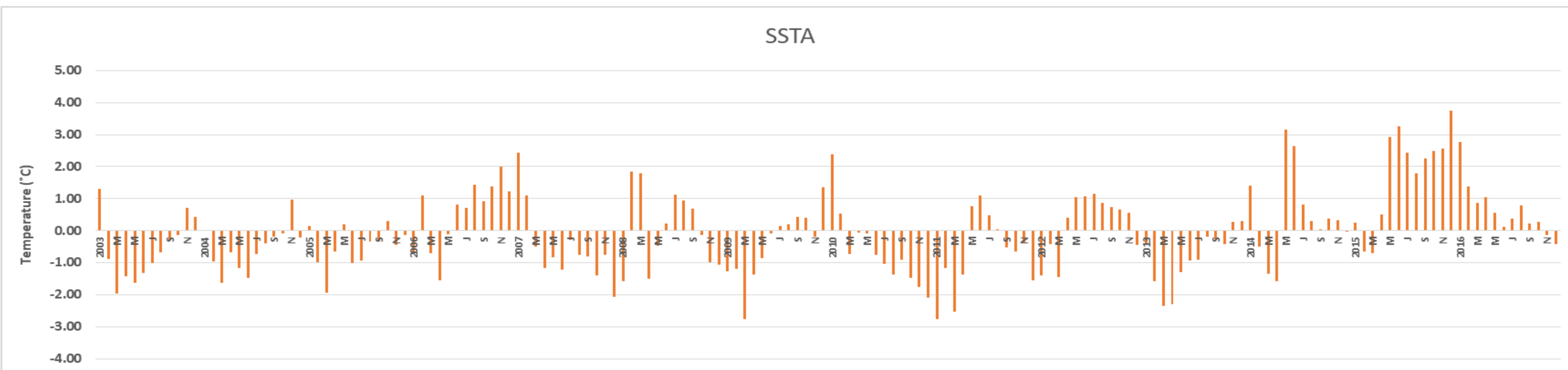
Appendix 10. Paita Station (Piura) monthly mean Sea Surface Salinity during 2003 and 2016



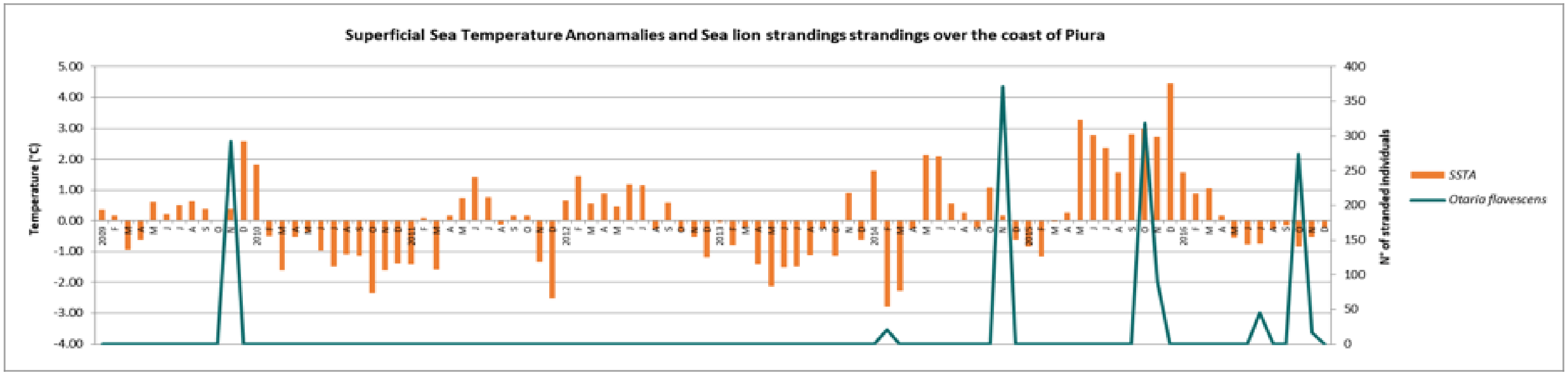
Appendix 11. San Jose Station (Lambayeque) monthly mean Sea Surface Salinity during 2003 and 2016



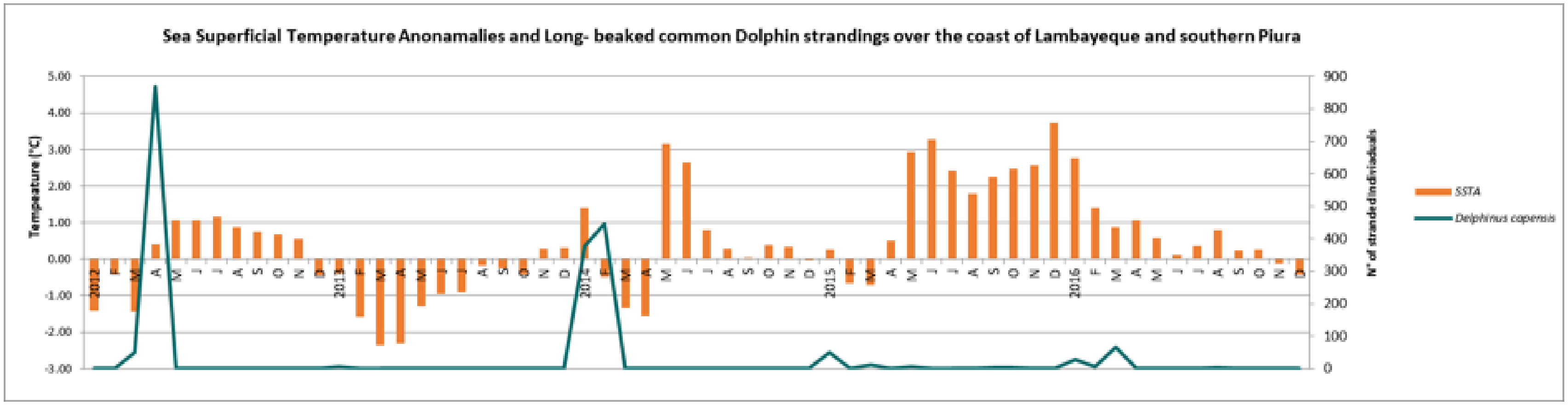
Appendix 12. Paita Station (Piura) Monthly mean Sea Surface Temperature Anomalies during 2003 and 2016



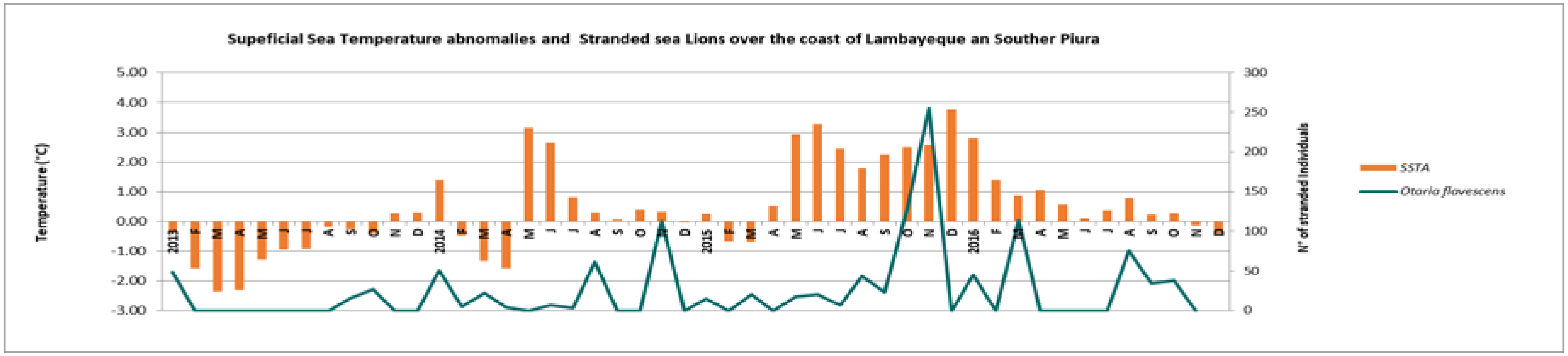
Appendix 13. San Jose Station (Lambayeque) monthly mean Sea Surface Temperature Anomalies during 2003 and 2016



Appendix 14. Paita Station monthly mean Surface Sea Temperature Anomalies and sea lions mortality peaks in Piura during 2009 and 2016



Appendix 15. Paita Station (Piura) monthly mean Surface Sea Temperature Anomalies and lon- beaked common dolphin mortality peaks during 2012 and 2016



Appendix 16. San Jose Station (Lambayeque) monthly mean Surface Sea Temperature Anomaly and sea lion mortality peaks during 2013 and 2016

Class: pca dudi

Call: dudi.pca(df = pca_bio, scannf = F, nf = 7)

Total inertia: 8

Eigenvalues:

Ax1	Ax2	Ax3	Ax4	Ax5
3.3188	**1.5541**	1.076	0.8471	0.6537

Projected inertia (%):

Ax1	Ax2	Ax3	Ax4	Ax5
41.486	**19.426**	13.45	10.589	8.171

Cumulative projected inertia (%):

Ax1	Ax1:2	Ax1:3	Ax1:4	Ax1:5
41.49	**60.91**	74.36	84.95	93.12

(Only 5 dimensions (out of 8) are shown)

> pca_biol$co

	Comp1	**Comp2**
Odontocetes	**-0.2380203**	**0.71771466**
Mysticetes	**0.3155912**	**-0.01749348**
Pinnipeds	**-0.1310233**	**0.60055102**
Sea turtles	**0.6298394**	**-0.53803436**
SST Anomaly	**-0.7908701**	**-0.40099247**
SSS	**-0.6229248**	**0.29905353**
ICEN	**-0.9113997**	**-0.33074606**
LABCOS	**-0.9510873**	**-0.16993805**

Appendix 17. Principal component analysis (PCA) statistics results between animal groups, oceanographic conditions and death causes

> pca.bio$eig

	Eigenvalue	**Percentage**	**Cumulative percentage**
comp 1	**1.6620045**	**41.55011**	41.55011
comp 2	**0.967616**	**24.1904**	**65.74051**
comp 3	0.8505673	21.26418	87.00469
comp 4	0.5198122	12.99531	100.0000

> pca.biovarcor

	Dim.1	Dim.2
Odontoceti	**0.7745564**	0.08526065
Mysticeti	-0.3581258	0.91502612
Pinnipedia	**0.5734811**	-0.01884699
Sea_turtles	**-0.7777739**	-0.35031212

> pca.bio$quanti.sup$cor

	Dim.1	Dim.2
SST Anomaly	**0.1873514**	**-0.18995112**
SSS	**0.3654707**	0.13687883
ICEN	**0.2011177**	-0.04419292
LABCOS	**0.3160417**	-0.0178838

Appendix 18. PCA statistics results using oceanographic variables and animal groups as supplementary variables