UN environment programme

Convention on the Conservation of Migratory Species of Wild Animals

CMS

2nd CMS Workshop on Conservation Implications of Animal Culture and Social Complexity – Part II

Parma, Italy & online, 3-4 April 2023

UNEP/CMS/Culture-2-2/Doc.9.1

Reports of the Concerted Action Sub-Groups: Eastern Tropical Pacific Sperm Whales[1]

I. Introduction

The population of eastern tropical Pacific (etP) sperm whales (*Physeter macrocephalus*) is structured into cultural clans with distinct vocal and social behaviors, distributions, movement patterns, and foraging strategies (Rendell & Whitehead 2003b, Whitehead & Rendell 2004, Marcoux et al. 2007a b, Cantor & Whitehead 2015, Eguiguren et al. 2019). A clan comprises thousands of individuals (females and juveniles) that share a distinct, socially-transmitted vocal repertoire. Individuals from a clan can spread over thousands of kilometers within an ocean basin (Rendell & Whitehead 2003b, Cantor et al. 2015, Hersh et al. 2022). EtP sperm whales are nomads, traveling an average of 1,000 km a year, which can result in shifting clan distributions across decades (Whitehead 2003, Cantor et al. 2016).

Recognizing the role of culture in shaping sperm whale population structure, along with the vastness of sperm whale home ranges and wide distribution in this region, the Conference of the Parties (COP) agreed on a Concerted Action Plan for the sperm whales of the etP under the concerted action for sperm whales in 2017. The action plan aimed to create **collaboration across Range States for data gathering within their jurisdictional waters.** This collaboration would enable photo-identification, elucidating distribution, identifying environmental-ecological niches, acoustic monitoring, assessment of anthropogenic threats and, where possible, the collection of behavioral data and fecal samples to further elucidate social structure and differences in foraging success among clans. Ultimately, these data would produce more detailed information about the social structure, foraging behavior, distribution, environmental-ecological niches, and acoustic segregation of sperm whales in the etP **to determine whether and how these clans should be conserved separately according to their differing responses to environmental and anthropogenic pressures.**

Here, we report on the progress (to February 2022) toward the objectives set forth by the Concerted Action Plan. We identify critical gaps in our current knowledge regarding the etP clans that must be addressed to fulfill the original mandate. Finally, we recommend future steps to conserve sperm whales while incorporating their cultural structure.

[1] Eguiguren A, Avila IC, Rosero P, Toro F, Hersh T, Rojas C, Alava JJ

II. Progress made

a. Creation of a collaboration network across Range States

Between November 21–23, 2022, we held the "Cachalotes del Pacifico" virtual workshop. The goals of the workshop were to share knowledge and tools (fieldwork methods and software/modelling approaches) for sperm whale research with colleagues across the etP and establish a collaborative network dedicated to the study of sperm whales within the region. Thirty-five people participated in the workshop, which featured talks from leading sperm whale researchers—some of whom are members of the expert group on sperm whales for the Convention on Migratory Species (CMS)—on topics including photo-identification protocols and software, social network analysis, acoustic monitoring, clan identification, sample collection and processing, and stranding management and data collection.

We conducted a roundtable on the workshop's final day with interested participants to formally establish a research network (Figure 1). There were 17 participants from across Range States (México, Costa Rica, Colombia, Venezuela, Ecuador, Perú, and Chile) and backgrounds (graduate and undergraduate students, biologists, marine mammal ecotoxicologists, tourism operators, an electrical engineer, and a veterinary doctor). At the roundtable, we agreed to create the **Cachalotes del Pacífico Network** to promote and consolidate research and conservation efforts of sperm whales throughout the etP and the southeastern Pacific (Food and Agriculture Organization (FAO) Major Fishing Areas 77 & 87).

Figure 1. Screenshot of some of the participants of the "Cachalotes del Pacífico" roundtable. (Photo Credit: Esteban Duque).

The specific objectives agreed upon by members of the network are to:

- Collaborate in the standardized collection and analysis of data on the biology and behavior of sperm whales in the region
- Identify anthropogenic threats to the survival of sperm whales in the region

- Cooperate towards acquiring funds for sperm whale research and conservation in the region
- Develop communication tools to promote the conservation of sperm whales and other highly migratory marine species
- Advise policymakers and government officials for the management and conservation of sperm whales and other highly migratory species
- Promote long-term research and conservation efforts
- Promote collaboration with sperm whale research collectives across the world

Each of these objectives will be carried out under an inclusive, transversal cultural lens. Based on this first meeting, we identified opportunities for collaboration, including consolidating existing sperm whale photo-identification catalogs on Flukebook (Levenson et al. 2015). This open-source, cloud-based platform uses artificial intelligence to detect matches among individuals and already contains photographs of tens of thousands of individuals from across the globe. Additionally, we established collaborations with colleagues that had recorded sperm whale vocalizations in different regions to assist in the acoustic identification of sperm whale clans outside the most frequently studied regions. This will be a crucial step in elucidating the movements of individuals and distribution of clans across the etP. Finally, members of this newly created network wrote this report, and some will act as experts for the etP sperm whale working group in upcoming CMS meetings.

a. Updates on the status of sperm whale clans of the etP

Since the drafting of the Concerted Action Plan in 2017, recent analyses have revealed important aspects of the status of sperm whale clans in the etP. Analysis by Hersh et al. (2022) of sperm whale recordings collected from 23 regions across the Pacific Ocean between 1978 – 2014 revealed the presence of seven clans in the etP. This analysis confirmed the presence of the previously well-documented *Regular, Plus-One, Short*, and *Four-Plus* clans mentioned in the 2017 Action Plan (Rendell & Whitehead 2003a, Cantor et al. 2016), and discovered three additional clans (*Palindrome*, *Rapid Increasing*, and *Slow Increasing*) that have used etP waters (Hersh et al. 2022) (Figure 2).

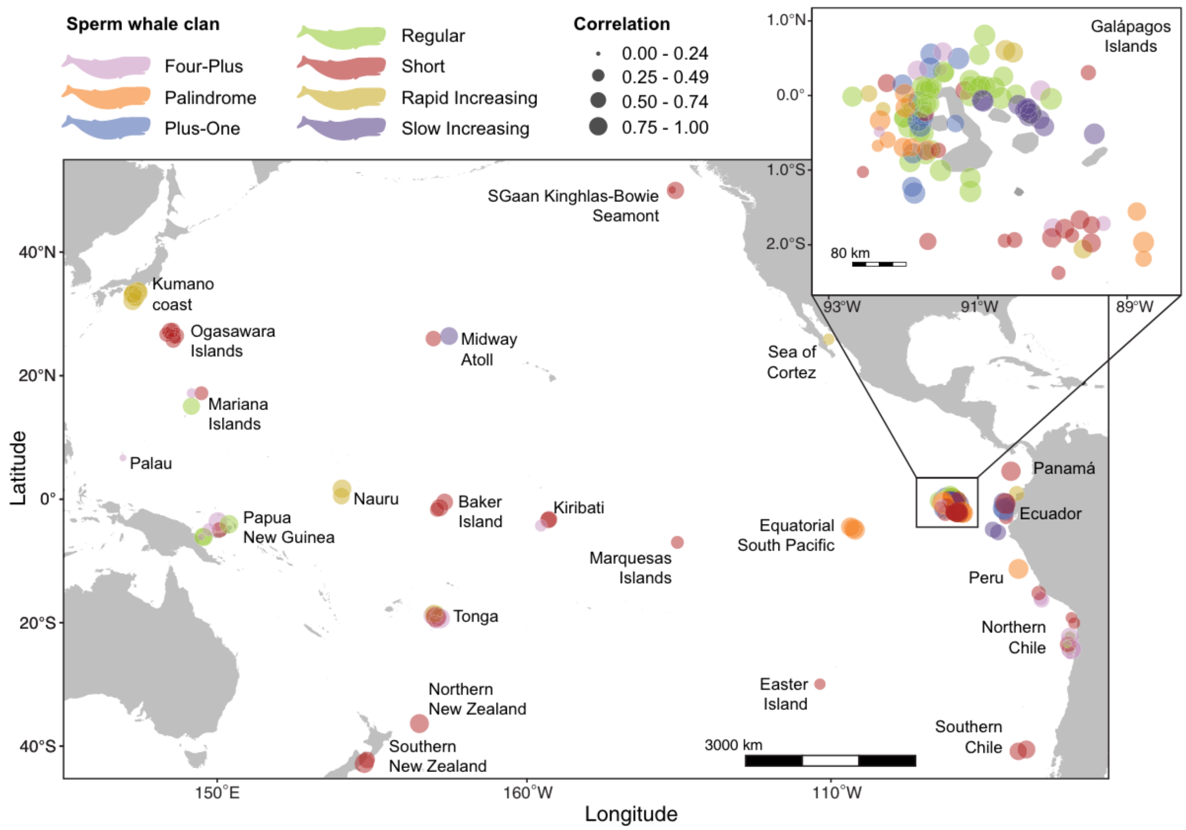

Figure 2. Location of sperm whale clans identified across the Pacific Ocean using the identity call method (Hersh et al. 2021). Each point represents a single repertoire of codas, colored by clan. Point size indicates statistical confidence in the repertoire-to-clan designation. The scale bar is approximate and most accurate along the Equator. (Figure adapted from Hersh et al., 2022).

All seven clans found throughout the Pacific Ocean were also found in the etP, making it the most culturally diverse sperm whale region currently known in the Pacific Ocean. While the ETP is also the best sampled Pacific Ocean region at present, culturally diverse sperm whales are clearly using the area. Additionally, while the *Four-Plus*, *Regular, Short*, *Rapid Increasing*, and *Rapid Decreasing* clans have been found in other locations throughout the Pacific basin as well, the *Palindrome* and *Plus-One* clans have only ever been detected in etP. Of these, the *Plus-One* has only been detected in Ecuadorian waters (i.e., waters off Ecuador's mainland coast and around the Galápagos Islands). This is in marked contrast to other clan distributions; for example, the *Short* clan has been detected in almost all of the sampled locations (Figure 2). When looking at clan presence in the etP by year, the region typically hosts at least three different clans per year (Table 1).

Table 1. Clan presence per year in the ETP based on the Hersh et al. (2022) dataset. Location abbreviations are C = Northern Chile, E = Ecuador, G = Galápagos Islands, and P = Peru.

Clan/year	1978	1985	1987	1989	1991	1993	1995	1999	2000	2013	2014
Four-Plus		E		G	G	C, P			C	G	G
Palindrome						P				G	G
Plus-One	G	G	G	G		E					
Regular		G	G	G	G		G		C		
Rapid Increasing		G	G		E		G			G	
Short		G	G		E	E, P			G	C, G	G
Slow Increasing			G		E	P		G			

The newly identified clans stem from the addition of recordings outside the regions used to describe the four original clans (Galápagos, continental Ecuador, and Chile) as well as from using a new method—the identity call method (ID-Call)—for assigning clan identity based on vocal repertoires developed by Hersh et al. (2021). Briefly, ID-Call improves upon previous methods of clan identification (Rendell & Whitehead 2003a) by 1) using a new method for classifying codas into types (contaminated mixture models), and 2) by using "identity calls" to classify call repertoires into distinct clades (Hersh et al. 2021). For sperm whales, the call repertoires are made up of all the codas recorded in one region on one day, and the clades are vocal clans. Identity calls are defined as those call types that are over-represented in one set of repertoires while being rare or absent in all others (Hersh et al. 2021). Contaminated mixture modelling has several strengths as a classification algorithm, including that it requires little *a priori* parameterization and efficiently deals with outliers (Punzo & McNicholas 2016). In sperm whales, there is quantitative evidence that identity codas may function as cultural symbolic markers, allowing individuals to ascertain clan identity much like local dialect variations do in humans (Boyd & Richerson 1987, Hersh et al. 2021, 2022).

A preliminary analysis of recordings collected off the Galápagos Islands in 2022 found that sperm whales in the region most likely belong to the *Short* clan (Figure 3). This clan was frequently encountered off the Galápagos in 2013 and 2014 (Cantor et al. 2016). However, in the 2022 data we have not found any of the other frequently encountered clans in the region in the past decade off the Galápagos Islands. The clan identity of sperm whales encountered in other areas of the etP has not been studied.

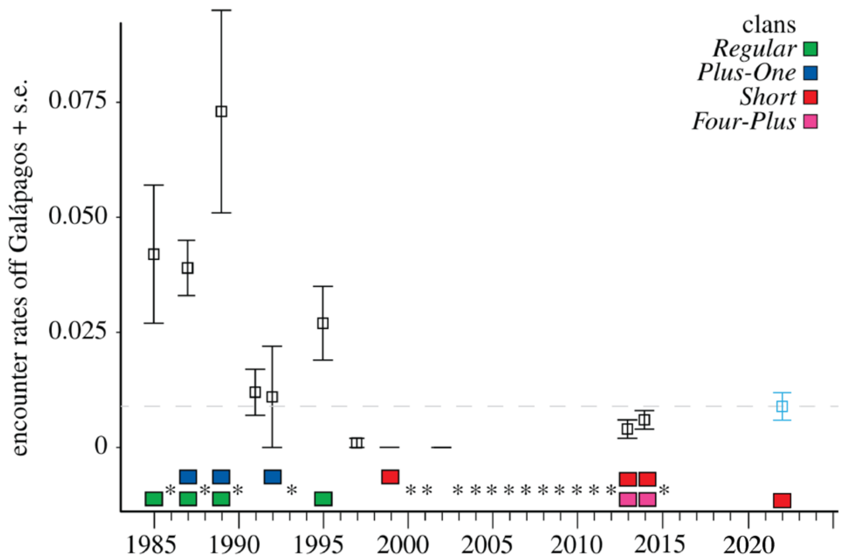

Figure 3. Encounter rates for female/juvenile sperm whales (number of encounters/hours searching) in surveys off the Galápagos Islands, with rates obtained from the 2022 field season highlighted in light blue. Clans present each year are indicated by colored boxes. Stars (*) indicate years during which no data was collected. Figure adapted from Cantor et al. (2016).

There are no clan-level estimates of the sperm whale population size in the etP. However, an estimate for the total population (Wade & Gerrodette 1993) with correction for availability bias by Whitehead and Shin (2022) using the etP in 1986-1990 is 37,777 (c.v. 0.37). The overall population in the etP was estimated to have decreased by 4% (s.e. = 4.3) annually between 1986 (soon after the end of commercial whaling in the region) and 2000 (Whitehead & Shin, 2002, using data from Gerrodette & Forcada, 2002). This trend likely arises from the nearly complete removal of mature males from the etP in the 1980's, which impaired the fecundity of the remaining females, as well as the social disruption of surviving individuals who may have lost crucial information for their survival (Whitehead et al. 1997, Whitehead & Shin 2022). These lingering effects of whaling on population growth likely reduce with time (perhaps 15 years; Whitehead & Shin 2022), so the population may now be stable or recovering slowly.

This regional trend is mirrored by local patterns in sighting rates and population estimates in the two areas where long-term dedicated research has taken place. Off the Galápagos Islands, sighting rates have more than halved over the last few decades (Whitehead et al. 1997, Cantor et al. 2017, Whitehead & Shin 2022) (Figure 3). However, this pattern most likely results from migrating clans that have moved from the Galápagos region towards other areas of the etP, explaining why the *Regular* and *Plus-One* clans have been entirely replaced by the *Four-Plus* and *Short* clans in Galápagos waters (Cantor et al. 2016). Preliminary analysis of the most recent fieldwork off the islands in 2022 shows similar sighting rates for *Short* clan whales as those from 2013 and 2014 (Figure 3).

In the Great Islands of the Gulf of California, data collected on dedicated surveys between 2010 – 2018 has a drastic decrease in sightings starting in 2012 which resulted in no sightings at all since 2015 (Ahuatzin-Gallardo 2020). This pattern is also reflected in the number of individuals sighted per year, which decreased from over 200 in 2010, to zero since 2015 (Ahuatzin-Gallardo 2020). However, we do not know the clan identity of sperm whales in the region.

While colleagues have reported opportunistic sightings and recordings of sperm whales in other areas, these are not suitable for population estimates (Table 2)

Table 2. Summary of data collected on sperm whales across the etP. Detections may refer to visual or acoustic encounters. Data marked in green has been analyzed and/or published, while data in orange has not.

						Type of Data Collected			
Region	**Time period**	**Type of research**	**Funding sources**	**Predominant age/sex classes**	**Clans Identified**	**Detections**	**Photo-Identification***	**Coda Recordings***	**Other**
Galapagos Islands	1985 – 2022	Dedicated surveys	Public research funds Foreign NGO's	Females/ Juveniles Mature males	X	X	X	X	X Defecation rate Fecal samples Skin samples Surface behaviour
Mainland Ecuador	1985 – 1996	Dedicated surveys	Public research funds (Canada) Foreign NGO's	Females/ Juveniles Mature males	X	X	X	X	X Skin samples Defecation rates
Chile (Northern)	2000	Dedicated surveys	Public research funds (Canada) Foreign NGO's	Females/ Juveniles Mature males	X	X	X	X	X Defecation Rate
Chile (Central)	2006 – 2022	Opportunistic (Whale-watching platforms)	Whale-watching operations Self-funded	Unknown		X	X		
Perú (North & South)	1995 - 2002	Opportunistic	Public funds (IMARPE)	Unknown		X			
Costa Rica (Pacific)	2009-2022	Opportunistic (Whale-watching platforms)	Whale-watching operations	Unknown		X			

						Type of Data Collected			
Region	**Time period**	**Type of research**	**Funding sources**	**Predominant age/sex classes**	**Clans Identified**	**Detections**	**Photo-Identification***	**Coda Recordings***	**Other**
Mexico (Gulf of California)	1998 - 1999	Dedicated Surveys	Unknown	Females/ Juveniles Mature males		X	X		
Mexico (Great Islands in the Gulf of California)	2010 - 2018	Dedicated Surveys	Unknown	Unknown					

*Datasets that can be used to determine clan identity.

c. Progress towards an environmental niche model for the sperm whale

The development of an environmental niche model for the sperm whale, based on the species distribution model (SDM), in the Eastern Tropical Pacific is of paramount to understanding the potential distribution of a species. Such model was built based on the quantified ecological niche to predict changes in distribution in agreement with environmental, temporal (Reygondeau & Beaugrand 2011, Reygondeau, 2019), as shown in Figure 4, The SDM quantifies the relationship between occurrence and environmental condition in which the species has been observed to delineate its ecological niche in a set of environmental dimensions (Reygondeau & Beaugrand 2011). The methodology rests on the concept of ecological niche as defined by Hutchinson (1957). The ecological niche theory states that a species can occur in a multidimensional environmental interval that has been defined by evolution shaping their physiological and competition characteristics to compete for resources and survive in their endemic environment.

Figure 4 portrays the predicted distribution of the sperm whale worldwide and, in the ETP projects the most likely preferred area where the species can be found, an ecological niche. The ecological niche is unique and refers to the species' specific role in its ecosystem, including how it interacts with other species and its environment. Doing so, this modeling tool predicts the environmental conditions under which sperm whales are likely to occur and then extrapolate on this data to map the species' potential distribution across the global ocean. Having a global pattern will support improved management in different scenarios better, especially in the context of global and/or regional climate change, where the species are moving or dispersing due to changing oceans. Thus, this global or regional modelling approach can account for scenarios where species move into new areas. For example, a similar modelling application using this approach has been performed for the recent and ongoing dispersion and extralimital movements of southern elephant seals (*Mirounga leonina*), the largest pinniped species, along the etP in the face of warming oceans (Alava et al., 2022a)

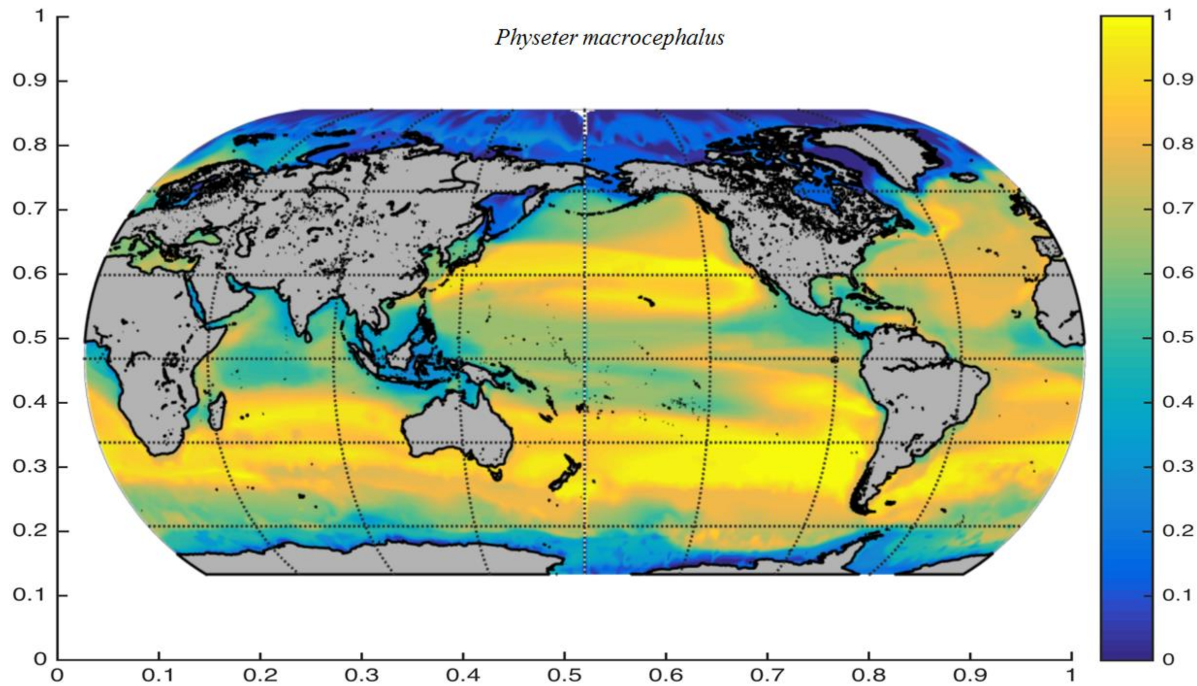

Figure 4. Preliminary global map of the environmental-ecological niche using the species distribution model (SDM) of the sperm whale. The SDM statistical approach was applied based on Reygondeau (2019). Map development courtesy of Dr. Gabriel Reygondeau in collaboration with Dr. Juan Jose Alava (Institute for the Ocean and Fisheries, University of British Columbia, BC, Canada).

d. Anthropogenic and environmental threats to sperm whales in the etP

Sperm whales are globally classified as Vulnerable due to the decline in their population of over 30% in the last 200 years resulting from intensive between the 18th – 21st centuries (Whitehead & Shin 2022). Throughout this period, whalers directly targeted waters in the etP. Off the Galápagos Islands, open boat whalers removed about 5,000 individuals between 1830 – 1850, after which population decline resulted in decreasing catch rates (Shuster 1983, Whitehead et al. 1997, Palacios & Salazar 2002). Between 1976 – 1981, whaling operations based off Perú and Chile disproportionately targeted large mature male sperm whales, virtually eliminating them from the etP (Ramirez 1989). The effect of removing these males from the etP had long-lasting results in the sperm whales' reproductive capacity decades after commercial whaling was globally banned by the International Whaling Commission (IWC) in 1986, so that abnormally low fecundity levels were detected at least 20 years after the operations almost entirely ceased (Whitehead et al. 1997, Whitehead & Shin 2022).

But, while sperm whales are no longer hunted, they continue to face environmental and anthropogenic threats which, coupled with their intrinsically slow reproductive rates, hamper their ability to recover to pre-whaling numbers. Sperm whales potentially face several of these threats within the etP (Figure 5) (Avila et al. 2018). Specifically, this region is impacted by entanglements with fishing gear, vessel collisions, marine pollution, oceanographic changes, and direct catches (Figure 6) (Alava et al., 2019; Avila et al. 2018).

Figure 5. Map of the distribution of documented threats potentially faced by sperm whales resulting from the intersection between threats documented between 1991 – 2016 and the global range of the species. The blue region shows waters potentially inhabited by sperm whales where no threats have been documented. Red cells show areas of high risk where at least 2 threats were detected per cell. Adapted from Avila et al. 2018.

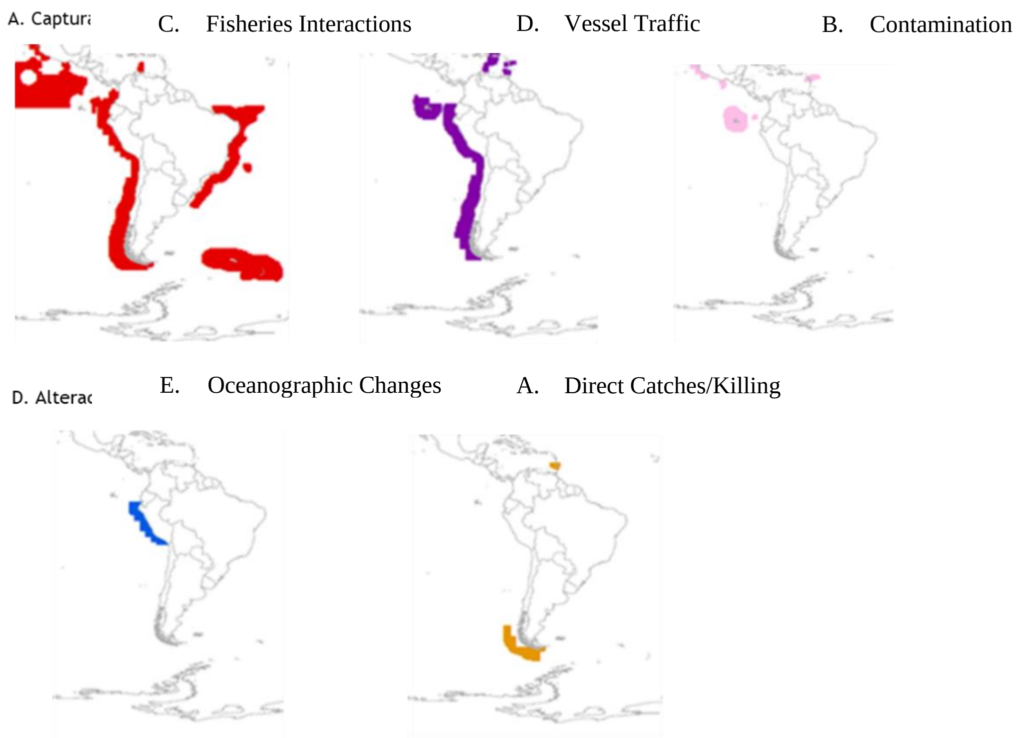

Figure 6. Map of anthropogenic threats within the sperm whale range documented between 1991 – 2016 within the etP. Adapted from Avila et al. 2018.

Of these threats, interactions with fisheries have caused most documented sperm whale deaths in the region (García-Godos et al. 2013, Avila et al. 2018, Rosero 2018). Most stranded individuals have been found entangled with artisanal gillnets or longlines (Galleti-Vernazzany & Cabrera 2007, Félix et al. 2010, Rosero 2017b a, 2019). More recently, a sperm whale carcass was found to be used as a fish aggregating device off the coast of Ecuador, but whether this is a common practice remains unknown (Castro et al. 2020). The looming threat of industrial fisheries interactions around the Galapagos Islands (Galapagos Marine Reserve) waters and its economic exclusive zone (EEZ) may well be exacerbated in the long term for sperm whales as they overlap with the purse seine, tuna longline, and industrial jumbo squid fisheries, as well as ongoing presence of illicit, unreported and unregulated (IUU) fisheries by foreign fleets (Martínez-Ortiz et al. 2015, Alava et al. 2017, Alava & Paladines 2017, Boerder et al., 2017, Eguiguren et al. 2020, 2021). There are also accounts of direct kills in southern Chile, where sperm whale depredation for Patagonian toothfish has caused adverse reactions from fisheries (González & Olivarría 2002, Hucke-Gaete et al. 2004). However, since these deaths were documented in cold temperate waters, these instance most likely involve juvenile/mature males and not the females/juveniles that can be identified as being part of one of etP clans.

Regarding the risk of vessel collision, there are few reports of stranded individuals with blunt force wounds and propeller cuts indicating vessel collisions as the primary cause of death (Félix & Van Waerebeek 2005, Félix 2006; J.J. Alava, pers. com., 2022).

Oceanic contamination may also impact the individual health and survival of sperm whales within the etP (Alava & Ross, 2018; Alava et al., 2020; Alava et al. 2022b). Biomarker analyses of skin samples collected across the Pacific Ocean found that whales off the Galápagos Islands had the highest expression levels of enzymes associated with organic compound contamination (e.g., polycyclic aromatic hydrocarbons and organochlorines) (Godard-Codding et al. 2011). Likewise, microplastics have been detected in all water samples and organisms collected throughout the etP (Alfaro-Núñez et al. 2021). More concerningly, plastic pieces and particle were found in 93% of the analyzed guts of Humboldt's squid (*Dosidicus gigas*), a main prey of sperm whales of the etP (Clarke et al. 1988); more recently, Rosas-Luis (2016), observed plastic debris (i.e., polyethylene lines and polyvinyl chloride pieces) in 12% of 100 stomachs of Humboldt's squid caught by the artisanal fisheries fleet in waters off Ecuador's main coast from May to November 2014. In other regions of the world the death of stranded sperm whales has been linked to the consumption of several tons of plastics, often including discarded fishing gear (Jacobsen et al. 2010, Alexiadou et al. 2019).

Global climate change may also affect the individual and population-level health sperm whales throughout the world (Albouy et al. 2020). Within the etP, climate change would most likely impact sperm whales through its effect on their deep-dwelling cephalopod prey, whose biomass and distribution is highly sensitive to environmental variation (Taipe et al. 2001, Waluda et al. 2006). Population collapses for the main prey of sperm whales in the region (*D. gigas*) have been documented during strong El Niño events associated with anomalously warm waters (Taipe et al. 2001, Waluda et al. 2006). El Niño Events have also been associated with significant declines in the feeding success of sperm whales studied off the Galápagos Islands, likely due to their on the biomass of deep-dwelling squid in the area (Whitehead et al. 1989). Additionally, the range of *D. gigas* has expanded from tropical and sub-tropical waters where they typically are found towards higher latitudes, reaching as far north as British Columbia (Canada) (Hoving et al. 2013, Stewart et al. 2014). This shift is most likely associated with the northward intrusion of warm water plumes resulting from ocean warming (Hoving et al. 2013, Stewart et al. 2014). Current climate models predict that the intensity and frequency of anomalously warm oceanic events will increase throughout time, posing an unmeasured risk to sperm whales globally.

In recent years, the industrial Humboldt squid fishing fleet that follows the Humboldt current has increased exponentially. This international fishery is frequently located outside nations' jurisdiction in open seas. In past decades, it has grown from catching a reported 12,550 tonnes in 1990 to 816,914 in 2019 (SPRFMO 2020, Eguiguren et al. 2021). Whether current and projected catch levels represent a competition for resources with sperm whales remains unknown. Past work suggests human consumption of squid did not deplete the resources available to other teuthophageous marine mammals (Trites et al. 1997). However, the continuously growing squid fishing fleet and updated sperm whale population estimates grant careful consideration to this question.

Acoustic contamination can also impair sperm whale's ability to sense their environment through echolocation, displace them from their habitats, damage their auditory processing organs, and even result in death (Weilgart 2013, Notarbartolo-Di-Sciara 2014, Taylor et al. 2019). Among different sources of acoustic contamination, the most intense is seismic surveying for marine oil and gas, which can be heard up to 4,000 km from the emission site (Weilgart 2013). While marine mining and oil industries are uncommon throughout the etP, there are signs that member states are looking to expand their extractive frontiers towards the oceans. Recently, Ecuador has developed a request to the International Maritime Organization (IMO) to expand its territorial sea to include the underwater Carnegie Mountain Range, which connects continental Ecuador to the Galápagos Islands. This expansion would grant Ecuador autonomy over the ocean floor, but not the overlaying water column, which points towards an interest in mineral ore exploration.

As shown in Figures 5 & 6, threats to the wellbeing of individual sperm whales have been documented throughout the etP, with a greater number of them co-occurring in nearshore waters where human populations and activities are concentrated (Avila et al. 2018). A map of these threats shows that more of them co-occur off the coast of Perú (Figure 5). However, the absence of certain threats from some regions may indicate a lack of documentation rather than a true absence of a threat. While there is rotund evidence for an impact of each of these threats on individual sperm whales, the degree to which they affect populations remains unknown. Moreover, **given the current lack of knowledge on the present distribution and foraging ecology of sperm whale clans, we do not know the degree to which each clan may be vulnerable to distinct anthropogenic threats**.

III. Outstanding questions

Despite the ongoing efforts of researchers to gather information on etP sperm whale biology over the past years, outstanding questions remain. Primarily, our gaps in knowledge stem from the logistical and financial constraints of studying a highly oceanic, deep-sea dwelling species at a spatial and temporal scale that is comparable to that of their life-histories and movements. Thus, besides the long-term projects off the Galápagos Islands and in the Sea of Cortez, no other monitoring projects exist in the region (Table 1). Colleagues have been able to opportunistically collect data on sperm whales through collaborations with whale-watching operations (Table 1). However, while whale watching tours provide a valuable financial and logistical support, surveys carried out in these platforms are limited in time and space by the needs of tour operators.

Questions that arise from our current knowledge pertaining to the mandates of the 2017 Action Plan include:

1. **What is the current population status and distribution of sperm whales from the *Regular*, *Plus-One, Four-Plus*, *Palindrome, Short, Rapid Increasing*, and *Slow Increasing* clans?** Although the *Short* clan has been sighted across the region and in recent years, we have no reports of any of the other clans. Particularly, the *Regular* and *Plus-One* clans, which were frequently sighted in the 1980s and 1990s, have not been documented since. Likewise, there is no information about the newly described *Palindrome*, *Short Increasing,* and *Slow Decreasing* clans.

2. **What is the foraging ecology (including diet, foraging strategies, and feeding success) of each of the sperm whale clans in the etP?**
   While we have recent data on the foraging success of *Short* clan sperm whales, there is no information on the foraging ecology of any of the other clans since the 1990s.

3. **What are the primary anthropogenic threats faced by each of the clans in the etP?**
   Specifically, the impact each of the previously identified threats has on individual sperm whales' health and at a population level is unknown. Particular attention needs to be given to the increased fishing of the main prey of sperm whales in the etP, *D. gigas.*

4. **How vulnerable/resilient are each of the ETP clans to anthropogenic threats and environmental change?**

IV. Recommended actions

Future research should be directed towards answering the questions above to adequately determine **whether and how these clans should be conserved separately according to their differing responses to environmental pressures.**

Formalizing the "Cachalotes del Pacífico" network represents a key step towards answering these questions by facilitating and formalizing cooperation across Range States. However, we identified a lack of financial support among most Range States to support the logistically demanding fieldwork that entails documenting and characterizing sperm whales at a clan level. In the cases in which long-term dedicated monitoring has taken place, funding has been provided by research funds and NGO's based in high-income countries (e.g., Canada, United Kingdom, United States). This highlights the need to strengthen collaboration not only among researchers across Range States, but to build and strengthen ties among us and institutions from high-income countries.

A tool that would propel key data acquisition on the distribution and behaviour of sperm whale clans to new levels in the region is autonomous recording. Autonomous hydrophone recorders can be moored at the bottom of the ocean floor, drift at the ocean's surface, or glide along the water column. By constantly recording the acoustic landscape in a site, they can be used to assess distribution, population size, behavior and, in the case of sperm whales, clan identity. An array of autonomous recorders along the etP waters can gather data in any condition (including overnight, in rough seas, and distant waters) throughout the year at a significantly lower cost than active surveys. In the etP, an array of autonomous recorders could vastly increase our knowledge of sperm whale clans. Such arrays have been instrumental in greatly increasing knowledge of cetacean distributions off north America and in informing place-based conservation policies.

V. Conclusion

Our current knowledge of the behavior and distribution of sperm whale clans in the etP provides strong support for sperm whale clans having distinct behaviors, ecologies, and distributions. It is highly likely that they then experience different levels of human-made impacts. However, the specific status of each of the clans with respect to multiple anthropogenic stressors and threats remains unknown. In the face of the threats identified in the region, we strongly recommend continued research and support toward answering these questions. We have taken essential first steps towards this by establishing a formal collaboration network and will continue this work in the future. We, therefore, recommend the extension of the Concerted Action Plan, emphasizing the need for collaboration mechanisms that funnel funds toward research in low-income Range States and highlighting the potential of autonomous recording technologies to propel data acquisition.

Acknowledgements

We would like to thank Dr. Hal Whitehead for reviewing the report and providing valuable insights, Luke Rendell for spearheading the Action Plan, the lecturers for the Cachalotes del Pacifico Workshop for sharing their knowledge and helping shape the report (Maurício Cantor, Philippa Brakes, Christine Konrad, Sarah Mesnick, Felícia Vachon), and the members of Red de Cachalotes del Pacífico for their invaluable contribution input in structuring the report (Franco Cruz, Esteban Duque, Héctor Pérez, José David Palacios)

References

Alava JJ, Riofrío-Lazo M, Reygondeau G, Rosero P, Avila IC, Lara D, Gil F, Yaipen-Llanos
CF, Elorriaga- Verplancken FR, Páez-Rosas D (2022a) Southern elephant seals (*Mirounga leonina*) in the Galapagos Islands and the Eastern Tropical Pacific amidst ocean environmental changes: towards a habitat suitability anomaly index. *Aquatic Mammals* 48(5): 418-431.

Alava JJ, McMullen K, Jones J, Barragán-Paladines MJ, Hobbs C, Tirapé A, Calle P, Alarcón D, Muñoz-Pérez JP, Muñoz-Abril L, Townsend KA, Denkinger J, Uyaguari M, Domínguez GA, Espinoza E, Reyes H, Piedrahita P, Fair P, Galloway T, Grove JS, Lewis C, Schofield J (2022b) Multiple anthropogenic stressors in the Galápagos Islands' complex social–ecological system: Interactions of marine pollution, fishing pressure, and climate change with management recommendations. Integrated Environmental Assessment and Management 1-26 https://doi.org/10.1002/ieam.4661

Alava JJ, Calle P, Tirapé A, Biedenbach G, Alvarado Cadena O, Maruya, K, Lao W, Aguirre W, Jiménez PJ, Dominguez GA, Bossart GD, Fair PA (2020) Persistent organic pollutants and mercury in genetically identified inner estuary bottlenose dolphin (*Tursiops truncatus*) residents of the Guayaquil Gulf, Ecuador: Ecotoxicological science in support of pollutant management and cetacean conservation. Frontiers in Marine Science (Marine Pollution) 7 (122):1-24 doi: 10.3389/fmars.2020.00122

Alava JJ, Tatar B, Barragán M J, Castro C, Rosero P, Denkinger J, Jiménez PJ, Carvajal R, Samaniego J (2019). Mitigating Cetacean Bycatch in Coastal Ecuador: Governance Challenges for Small-scale Fisheries. Marine Policy 110: 102769 DOI 10.1016/j.marpol.2017.05.025

Alava JJ, Ross PS (2018). Pollutants in tropical marine mammals of the Galapagos Islands, Ecuador: An Ecotoxicological Quest to the Last Eden (Chapter 8). pp. 213-234, In Marine Mammal Ecotoxicology: impacts of multiple stressors on population health. (C. Fossi, and C. Panti, eds.). Elsevier/Academic Press. London, UK. DOI: 10.1016/B978-0-12-812144-3.00008-5

Alava JJ, Barragán-Paladines MJ, Denkinger J, Muñoz-Abril L, Jiménez PJ, Paladines,, F, Valle,, CA,
Tirapé A, Gaibor N, Calle M, Calle P, Reyes H, Espinoza E, Grove JS (2017) Massive Chinese Fleet Jeopardizes Threatened Shark Species around the Galápagos Marine Reserve and Waters off Ecuador: Implications for National and International Fisheries Policy. International Journal of Fisheries Science and Research, 1 (1). 1001:1-3.

Alava JJ, Paladines F (2017) Illegal fishing on the Galapagos high seas. Science 357: 1362.

Ahuatzin-Gallardo D (2020) Estudio de la ecología poblacional de cachalote (*Physeter macrocephalus* mediante técnicas de foto-identificación en la Región Oriental de las Grandes Islas del Golfo de California, México. B.Sc., Universidad de Las Américas Puebla, Puebla, México

Albouy C, Delattre V, Donati G, Frölicher TL, Albouy-Boyer S, Rufino M, Pellissier L, Mouillot D, Leprieur F (2020) Global vulnerability of marine mammals to global warming. Scientific Reports 10:548.

Alexiadou P, Foskolos I, Frantzis A (2019) Ingestion of macroplastics by odontocetes of the Greek Seas, Eastern Mediterranean: Often deadly! Marine Pollution Bulletin 146:67–75.

Alfaro-Núñez A, Astorga D, Cáceres-Farías L, Bastidas L, Soto Villegas C, Macay K, Christensen JH (2021) Microplastic pollution in seawater and marine organisms across the Tropical Eastern Pacific and Galápagos. Scientific Reports 11:6424.

Avila IC, Kaschner K, Dormann CF (2018) Current global risks to marine mammals: taking stock of the threats. Biological Conservation 221:44–58.

Boerder K, Bryndum-Buchholz, A Worm B (2017). Interactions of tuna fisheries with the Galápagos marine reserve. Marine Ecology Progress Series 585: 1– 15. https://doi.org/10.3354/meps12399

Boyd R, Richerson PJ (1987) The Evolution of Ethnic Markers. Cultural Anthropology 2:65–79.

Cantor M, Eguiguren A, Merlen G, Whitehead H (2017) Galápagos sperm whales (*Physeter macrocephalus*): waxing and waning over three decades. Canadian Journal of Zoology 95:645–652.

Cantor M, Shoemaker LG, Cabral RB, Flores CO, Varga M, Whitehead H (2015) Multilevel animal societies can emerge from cultural transmission. Nature Communications 6.

Cantor M, Whitehead H (2015) How does social behavior differ among sperm whale clans? Marine Mammal Science 31:1275–1290.

Cantor M, Whitehead H, Gero S, Rendell L (2016) Cultural turnover among Galápagos sperm whales. Royal Society Open Science 3:160615.

Castro C, Van Waerebeek K, Cárdenas D, Alava J (2020) Marine mammals used as bait for improvised fish aggregating devices in marine waters of Ecuador, eastern tropical Pacific. Endangered Species Research 41:289–302.

Clarke R, Paliza O, Aguayo A (1988) Sperm whales of the southeast Pacific, Part IV: Fatness, food and feeding. In: *Investigations on Cetacea*, Volume XXI. Pilleri G (ed) Privately published by G. Pilleri, Berne, p 53–195

Eguiguren A, Pirotta E, Cantor M, Rendell L, Whitehead H (2019) Habitat use of culturally distinct Galápagos sperm whale *Physeter macrocephalus* clans. Marine Ecology Progress Series 609:257–270.

Eguiguren A, Pirotta E, Boerder K, Cantor M, Merlen G, Whitehead H (2020). Historical and contemporary habitat use of sperm whales off the Galápagos Archipelago: implications for conservation. *Marine and Freshwater Ecosystems*, 31:1466–1481.

Eguiguren A, Rosero P, Shin M, Whitehead H, Cáceres-Farías L, Alava JJ, Tirira D (2021) Cachalote (*Physeter macrocephalus*). In: Libro rojo de los mamíferos del Ecuador, 3rd ed. Tirira D (3ra edición, Versión 2022.1). Asociación Ecuatoriana de Mastozoología, Fundación Mamíferos y Conservación, Pontificia Universidad Católica del Ecuador y Ministerio del Ambiente, Agua y Transición Ecológica del Ecuador. https://bioweb.bio/faunaweb/mamiferoslibrorojo/FichaEspecie/

Félix F (2006) Evidencia de colisiones de embarcaciones con cetáceos en Ecuador. In: Memorias del Taller de Trabajo Sobre el Impacto de las Actividades Antropogénicas en Mamíferos Marinos del Pacífico Sudeste. Bogotá, Colombia, p 55–59

Félix F, Haase B, Denkinger J, Falconí J (2010) Varamientos de mamíferos marinos registrados en la costa continental de Ecuador entre 1996 y 2009. Acta Oceanográfica del Pacífico 16:61–73.

Félix F, Van Waerebeek K (2005) Whale mortality from ship strikes in Ecuador and West Africa. Latin American Journal of Aquatic Mammals 4:55–60.

Galleti-Vernazzany B, Cabrera E (2007) Varamiento de cetáceos en Chile 1970-2005 y su relación con impactos antropogénicos. In: Memorias del taller de trabajo sobre el impacto de las actividades antropogénicas en mamíferos marinos en el Pacífico Sudeste, Bogotá, Colombia, 28 al 29 de noviembre de 2006. CPSS/PNUMA, Guayaquil, Ecuador, p 32–37

García-Godos I, Waerebeek KV, Alfaro-Shigueto J, Mangel JC (2013) Entanglements of Large Cetaceans in Peru: Few Records but High Risk. Pacific Science 67:523–532.

Gerrodette T, Forcada J (2002) Estimates of abundance of western/southern spotted, whitebelly spinner, striped and common dolphins and pilot, sperm and Bryde's whales in the eastern tropical Pacific Ocean. SWFSC Administrative Report LJ-02-20.

Godard-Codding CAJ, Clark R, Fossi MC, Marsili L, Maltese S, West AG, Valenzuela L, Rowntree V, Polyak I, Cannon JC, Pinkerton K, Rubio-Cisneros N, Mesnick SL, Cox SB, Kerr I, Payne R, Stegeman JJ (2011) Pacific Ocean–Wide Profile of CYP1A1 Expression, Stable Carbon and Nitrogen Isotope Ratios, and Organic Contaminant Burden in Sperm Whale Skin Biopsies. Environmental Health Perspectives 119:337–343.

González E, Olivarría C (2002) Interactions between odontocetes and the artisan fisheries of Patagonian toothfish *Disossitchus eleginoides* off Chile, Eastern South Pacific. In: Toothed Whale/Longline Fisheries Interactions in the South Pacific Workshop SREP.

Hersh TA, Gero S, Rendell L, Cantor M, Weilgart L, Amano M, Dawson SM, Slooten E, Johnson CM, Kerr I, Payne R, Rogan A, Antunes R, Andrews O, Ferguson EL, Hom-Weaver CA, Norris TF, Barkley YM, Merkens KP, Oleson EM, Doniol-Valcroze T, Pilkington JF, Gordon J, Fernandes M, Guerra M, Hickmott L, Whitehead H (2022) Evidence from sperm whale clans of symbolic marking in non-human cultures. Proceedings of the National Academy of Sciences USA 119:e2201692119.

Hersh TA, Gero S, Rendell L, Whitehead H (2021) Using identity calls to detect structure in acoustic datasets. Methods in Ecology and Evolution: 2041–210X.13644.

Hoving H-JT, Gilly WF, Markaida U, Benoit-Bird KJ, -Brown ZW, Daniel P, Field JC, Parassenti L, Liu B, Campos B (2013) Extreme plasticity in life-history strategy allows a migratory predator (jumbo squid) to cope with a changing climate. Global Change Biolology19:2089–2103.

Hucke-Gaete R, Moreno CA, Arata J (2004) Operational interactions of sperm whales and killer whales with the patagonian toothfish industrial fishery of Southern Chile. 11:127–140.

Hutchinson GE (1957) Concluding remarks. Cold Spring Harbor Symposium Quantitative Biology 22 415-427

Jacobsen JK, Massey L, Gulland F (2010) Fatal ingestion of floating net debris by two sperm whales *Physeter macrocephalus*. Marine Pollution Bulletin 60:765–767.

Levenson J, Gero S, Van Oast J, Holmberg J (2015) Flukebook: a cloud-based photo-identification analysis tools for marine mammal research.

Marcoux M, Rendell L, Whitehead H (2007a) Indications of fitness differences among vocal clans of sperm whales. Behavioral Ecology and Sociobiology 61:1093–1098.

Marcoux M, Whitehead H, Rendell L (2007b) Sperm whale feeding variation by location, year, social group and clan: evidence from stable isotopes. Marine Ecology Progress Series 333:309–314.

Martínez-Ortiz, J., Aires-da-Silva, A. M., Lennert-Cody, C. E. y Maunder, M. N. 2015. The Ecuadorian

artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. *PLOS ONE* 10: e0135136.

Notarbartolo-Di-Sciara G (2014) Sperm whales, *Physeter macrocephalus*, in the Mediterranean Sea: a summary of status, threats, and conservation recommendations. Aquatic Conservation: Marine and Freshwater Ecosystems24:4–10.

Palacios DM, Salazar S (2002) Cetáceos. In: *Reserva Marina de Galápagos Línea Base de la Biodiversidad*. Danulat E, Edgar GJ (eds) Fundación Charles Darwin/Servicio Parque Nacional Galápagos, Santa Cruz, Galápagos, Ecuador, p 291–302

Punzo A, McNicholas PD (2016) Parsimonious mixtures of multivariate contaminated normal distributions. Biometrical Journal 58:1506–1537.

Ramirez P (1989) Captura de cachalote en Paita: 1976–1981. Boletín de Lima 63:81–88.

Rendell LE, Whitehead H (2003a) Comparing Repertoires of Sperm Whale Codas: a Multiple Methods Approach. Bioacoustics 14:61–81.

Rendell LE, Whitehead H (2003b) Vocal clans in sperm whales (*Physeter macrocephalus*). Proceedings of the Royal Society of London B 270:225–231.

Reygondeau G (2019) Current and future biogeography of exploited marine exploited groups under climate change. In AM Cisneros-Montemayor, WWL Cheung & YA Ota (Eds.), Predicting Future Oceans: Sustainability of Ocean and Human Systems amidst Global Environmental Change (pp. 87-101). Elsevier.

Reygondeau G, Beaugrand G (2011) Future climate-driven shifts in distribution of *Calanus finmarchicus*. Global Change Biology 17:756–766.

Rosas-Luis, R. (2016). Description of plastic remains found in the stomach contents of the jumbo squid dosidicus gigas landed in Ecuador during 2014. Marine Pollution Bulletin 113, 302–305. doi: 10.1016/j.marpolbul.2016.09.060

Rosero P (2017a) Experiencias en el trabajo colaborativo entre pescadores artesanales en temas de interacción de mamíferos marinos con pesquerías en Ecuador. In: *Informe del Taller sobre la Interacción de Mamíferos Marinos con Pesquerías y las Potenciales Implicaciones para el Comercio de Productos Pesqueros con Estados Unidos*. Instituto Nacional de Pesca/Comisión Permanente del Pacífico Sudeste, Guayaquil, Ecuador, p 17

Rosero P (2018) La problemática de la interacción con pesquerías en Ecuador y experiencias para mitigarla. National Oceanic and Atmospheric Administration/World Wildlife Fund/Comisión Permanente del Pacífico Sur, Guayaquil, Ecuador, p 49

Rosero P (2017b) Pesca incidental de cetáceos con redes de enmalle de superficie en Ecuador. Tesis de doctorado, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria

Rosero P (2019) Pesca incidental de cetáceos con redes de enmalle de superficie en Ecuador. Mammalia aequatorialis 2019:51–59.

Shuster GW (1983) The Galápagos Islands: a preliminary study of the effects of sperm whaling on a specific whaling ground. Reports of the International Whaling Commission 5:81–82.

SPRFMO (2020) SC8-SQ01_rev1_clean Squid information held by the secretariat. In: *8th Meeting of the Scientific Committee*. New Zealand.

Stewart JS, Hazen EL, Bograd SJ, Byrnes JEK, Foley DG, Gilly WF, Robison BH, Field JC (2014) Combined climate- and prey-mediated range expansion of Humboldt squid (*Dosidicus gigas*), a large marine predator in the California Current System. Global Change Biology 20:1832–1843.

Taipe A, Yamashiro C, Mariategui L, Rojas P, Roque C (2001) Distribution and concentrations of jumbo flying squid (*Dosidicus gigas*) off the Peruvian coast between 1991 and 1999. Fisheries Research 54:21–32.

Taylor BL, Baird R, Barlow J, Dawson S, Ford JKB, Mead JG, Notarbartolo-Di-Sciara S, Wade P, Pitman RL (2019) *Physeter macrocephalus*, Sperm Whale. The IUCN Red List of Threatened Species 2019 e.T41755A160983555.en.

Trites AW, Christensen V, Pauly D (1997) Competition Between Fisheries and Marine Mammals for Prey and Primary Production in the Pacific Ocean. Journal of Northwest Atlantic Fisheries Science 22:173–187.

Wade PR, Gerrodette T (1993) Estimates of Cetacean Abundance and Distribution in the Eastern Tropical Pacific. Reports of the International Whaling Commission 43:477–494.

Waluda CM, Yamashiro C, Rodhouse PG (2006) Influence of the ENSO cycle on the light-fishery for *Dosidicus gigas* in the Peru Current: an analysis of remotely sensed data. Fisheries Research 79:56–63.

Weilgart L (2013) A review of the impacts of seismic airgun surveys on marine life. CBD Expert Workshop on Underwater Noise and its Impacts on Marine and Coastal Biodiversity:25–27.

Whitehead H (2003) Sperm whales: social evolution in the ocean. The University of Chicago Press, Chicago, USA.

Whitehead H, Christal J, Dufault S (1997) Past and distant whaling and the rapid decline of sperm whales off the Galápagos Islands. Conservation Biology 11:1387–1396.

Whitehead H, Papastavrou V, Smith S (1989) Feeding success of sperm whales and sea-surface temperature off the Galapagos Islands. Marine Ecology Progress Series 53:201–203.

Whitehead H, Rendell L (2004) Movements, habitat use and feeding success of cultural clans of South Pacific sperm whales. Journal of Animal Ecology 73:190–196.

Whitehead H, Shin M (2022) Current global population size, post-whaling trend and historical trajectory of sperm whales. Scientific Reports 12:19468.