COLTO study on whale depredation
2017-2018

TECHNICAL REPORT
Year 1

CHILE

Industry partners: AOBAC (GLOBAL PESCA SpA., PESCA CHILE, PESCA CISNE)

Dr Paul TIXIER & Prof. John ARNOULD

School of Life and Environmental Sciences, Centre for Integrative Ecology
Deakin University – Queenscliff Marine Centre, Queenscliff, VIC, Australia
p.tixier@deakin.edu.au
Phone: +61 (0)484 122 796

Contents

1. Introduction

Using COLTO as an opportunity for international collaboration between science, industry, government and NGO groups, a 1-year (two 6-month periods over 2 years) study was initiated in 2017 to investigate whale depredation in Chile, Falkland Islands, South Georgia/South Sandwich Islands (UK) and Marion/Prince Edward Islands (South Africa). This study was designed to develop multi-disciplinary research aiming at identifying the best combination of measures, both technological and behavioural, to reduce depredation both locally and globally, i.e. across the different Patagonian toothfish longline fisheries operating in the Southern Ocean.

This report is an interim report of Year 1 of the program for the Chilean industry partners, AOBAC, who have supported the study. Using existing fishing and observation datasets, this report presents the first results from analyses examining the behavioural ways of avoiding depredation, and addressing the following aims:

- To assess the levels of occurrence of depredation by killer and sperm whales:
- To investigate the spatio-temporal patterns of depredation;
- To identify the operational and environmental variables influencing depredation;
- To provide first insights on the number of depredating whales;
- To preliminarily estimate the amount of depredated fish biomass.

2. Occurrence of depredation

2.1. Summary of data

Two datasets were received to conduct the analyses, both from IFOP. The first dataset was sent on December 12th 2016 and included data spanning from 2006 to 2013. The second was sent on August 3rd 2017 and included data from 2014 to 2016. Both datasets included details on fishing operations (date/time, GPS coordinates, depth of longline sets at setting and hauling), data on the number of depredating whales during hauling, which was later converted to presence/absence data, as well as data on the fishing effort and catch of Patagonian toothfish.

Data from a total of 12,748 longline sets hauled in southern Chile could be used for the analyses (Figure 1). These sets included 894 sets using autoline and 11,854 using trotline equipped with a cachalotera system. While records of whale depredation during hauling of sets included three states (Presence, Absence, missing data) from 2006 to 2013, whale depredation was available as two states (Presence, Absence) from 2014 to 2016 (Figure 12).

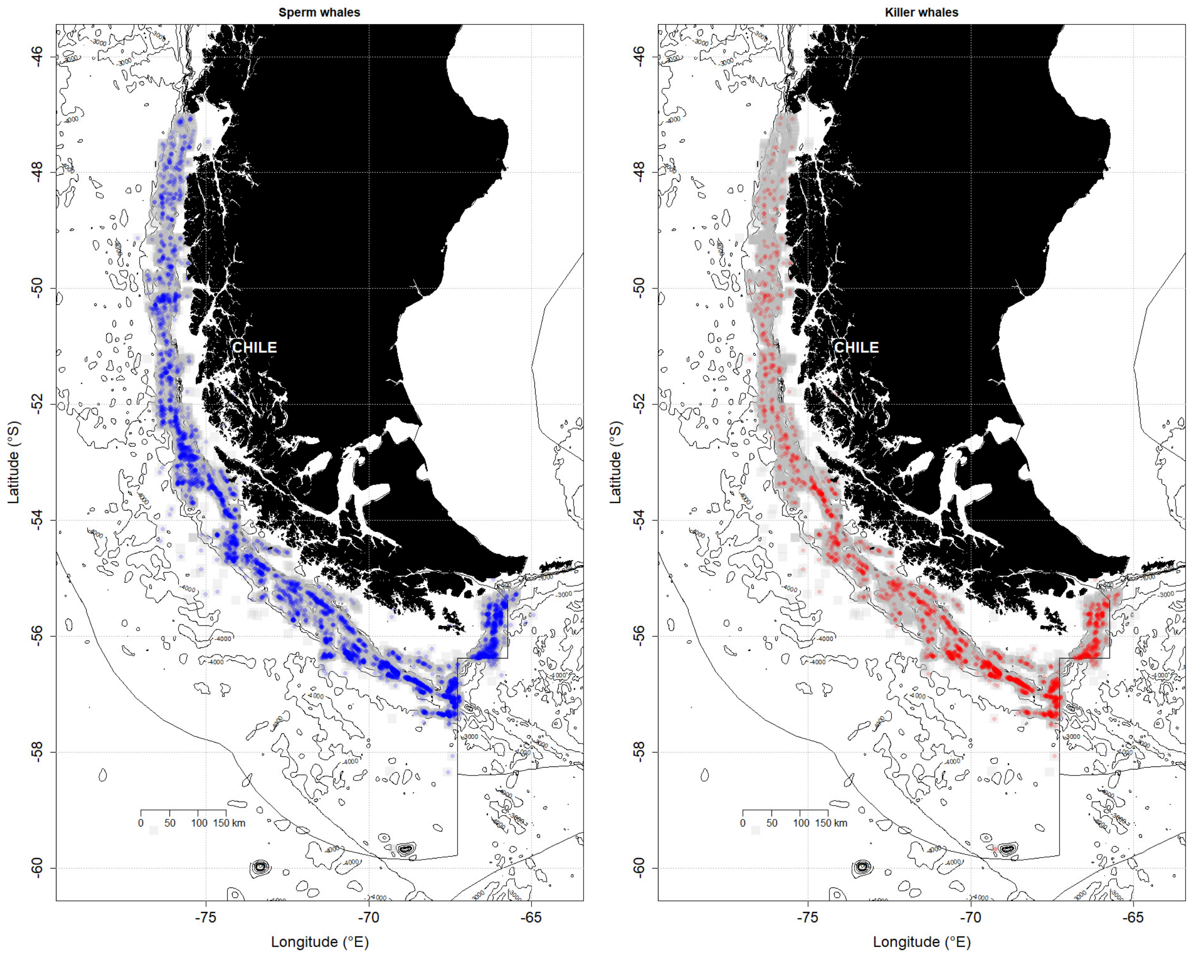

Figure 1. Distribution of all longline sets hauled in southern Chile from 2006 to 2016 (grey squares) and sets hauled in presence of depredating sperm whales (blue – left) and killer whales (red- right) by the commercial Patagonian toothfish longline fishery.

As such the overall number of sets considered as depredated was 5,428 (42.6 % of all sets) for sperm whales, and 2,525 sets (19.8%) for killer whales. Data from 12 different vessels were available, but the majority were collected from 7 vessels (Figure 3).

Data were available for all months of the year, but fishing effort was substantially less from June to August (Figure 4).

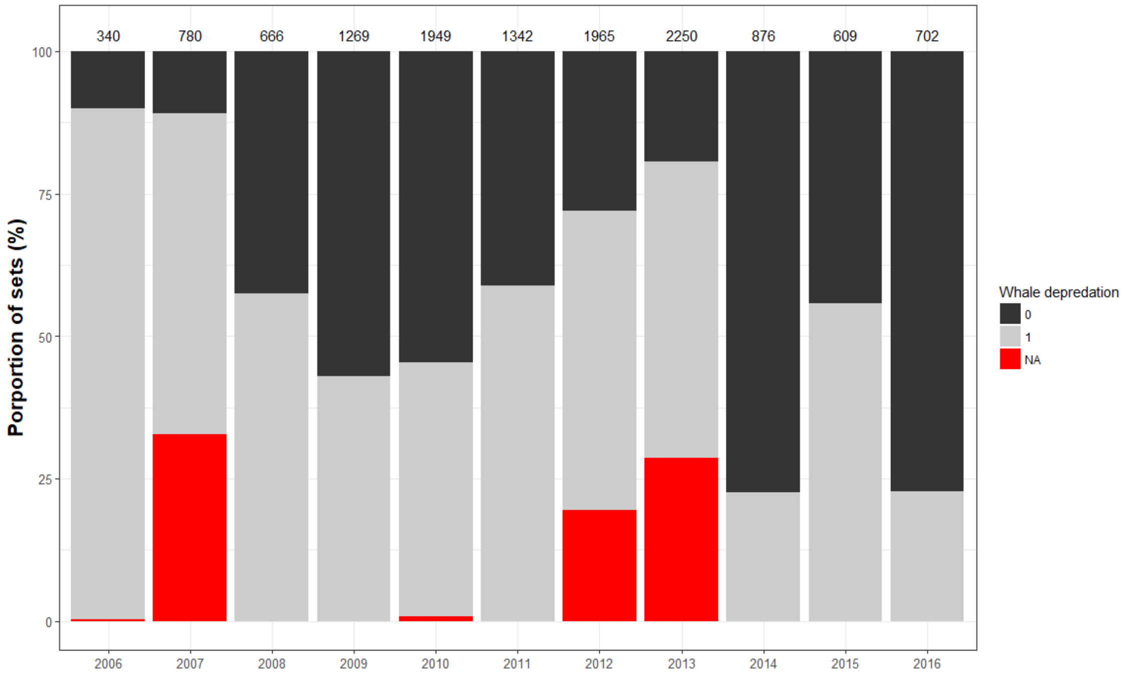

Figure 2. Available data on whale depredation in the Patagonian toothfish fishery in southern Chile from 2006 to 2016. 0 = sets for which none of the two whale species (killer whales and sperm whales) were observed as depredating during hauling; 1 = at least one of the two whale species confirmed depredating during hauling; NA = absence or presence of whales during hauling not known because the information was unavailable. Numbers at the top indicate the number of sets monitored per year.

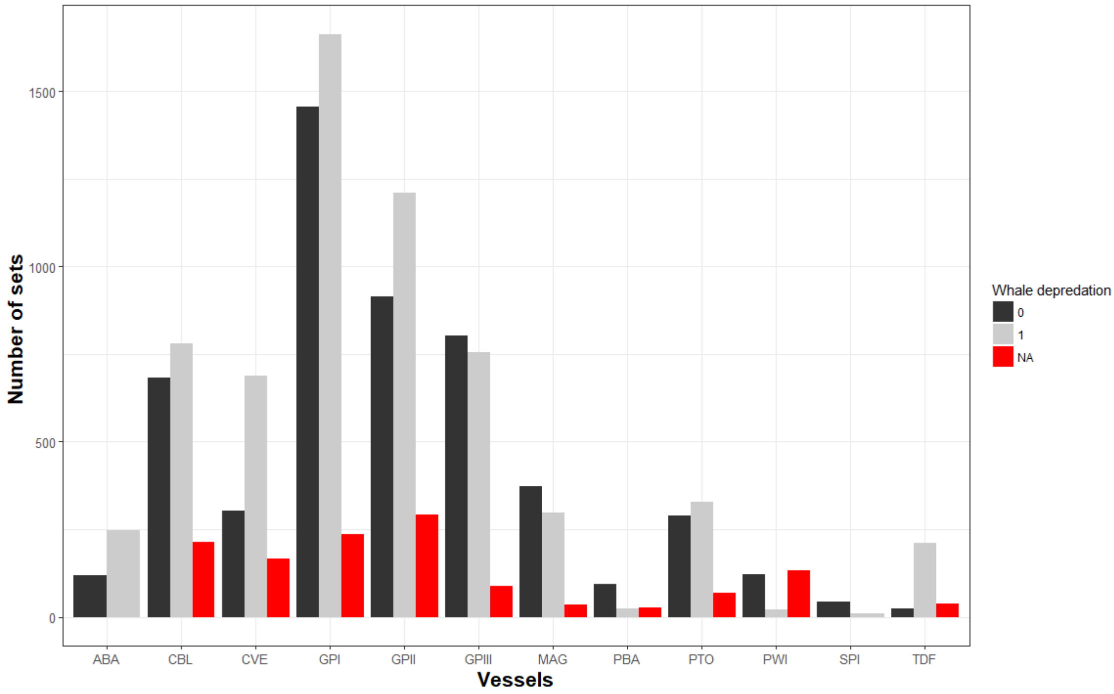

Figure 3. Number of longline sets available in the dataset per fishing vessel, whether these sets were depredated or not during hauling. 0 = sets for which none of the two whale species (killer whales and sperm whales) were observed as depredating during hauling; 1 = at least one of the two whale species confirmed depredating during hauling; NA = absence or presence of whales during hauling not known because the information was unavailable.

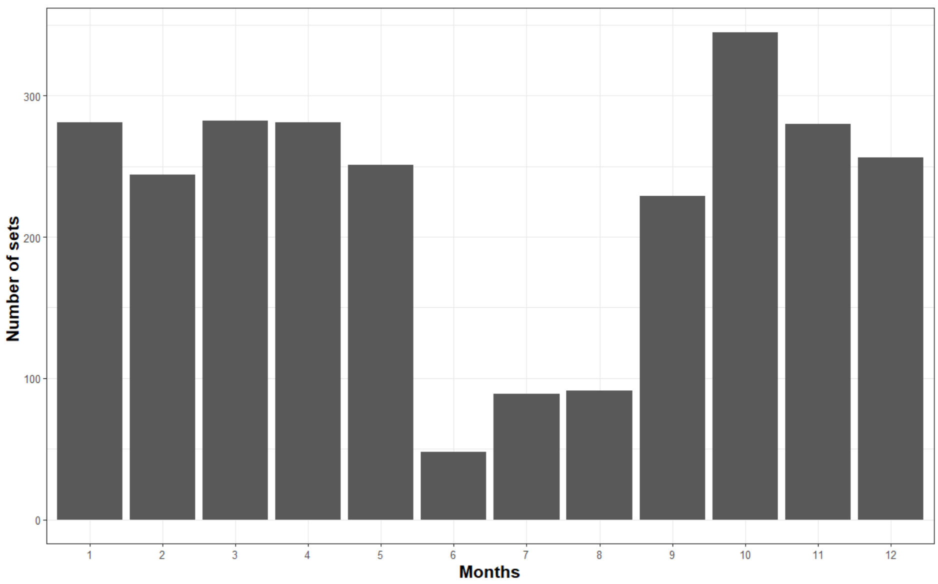

Figure 4. Number of longline sets available in the dataset per month.

2.2. Observed spatio-temporal patterns of depredation

In this section, depredation was measured and depicted as an "interaction rate", which was calculated using three different indexes:

1) the proportion of sets depredated out of the total number of sets hauled;
2) the proportion of fishing days during which at least one set was depredated out of all fishing days;
3) the proportion of the fishing area (0.1 x 0.1° grids) in which at least one set was depredated out of all grids.

These observed interaction rates were calculated separately for sperm whales and killer whales.

2.1.1. Sperm whales

Over the 2006-2016 period, sperm whale depredation was recorded on average on 44.6 ± 5.9 % of the sets, 72.6 ± 5.7 % of the fishing days and 63.1 ± 5.3 % of the fishing area per year (Figure 5). The apparent declining trend is biased by high levels of sperm whale depredation in 2006, for which the available data were limited and collected over the September – December period only.

Observed sperm whale depredation varied between months, July being the month with the lowest levels: 26.2 % of sets, 47.9 % of fishing days, and 34.2 % of the fishing area (Figure 5). The months with the maximum depredation levels were November with 53.7 % of sets, and 73.6 % of the fishing area, and December with 91.2 % of the fishing days.

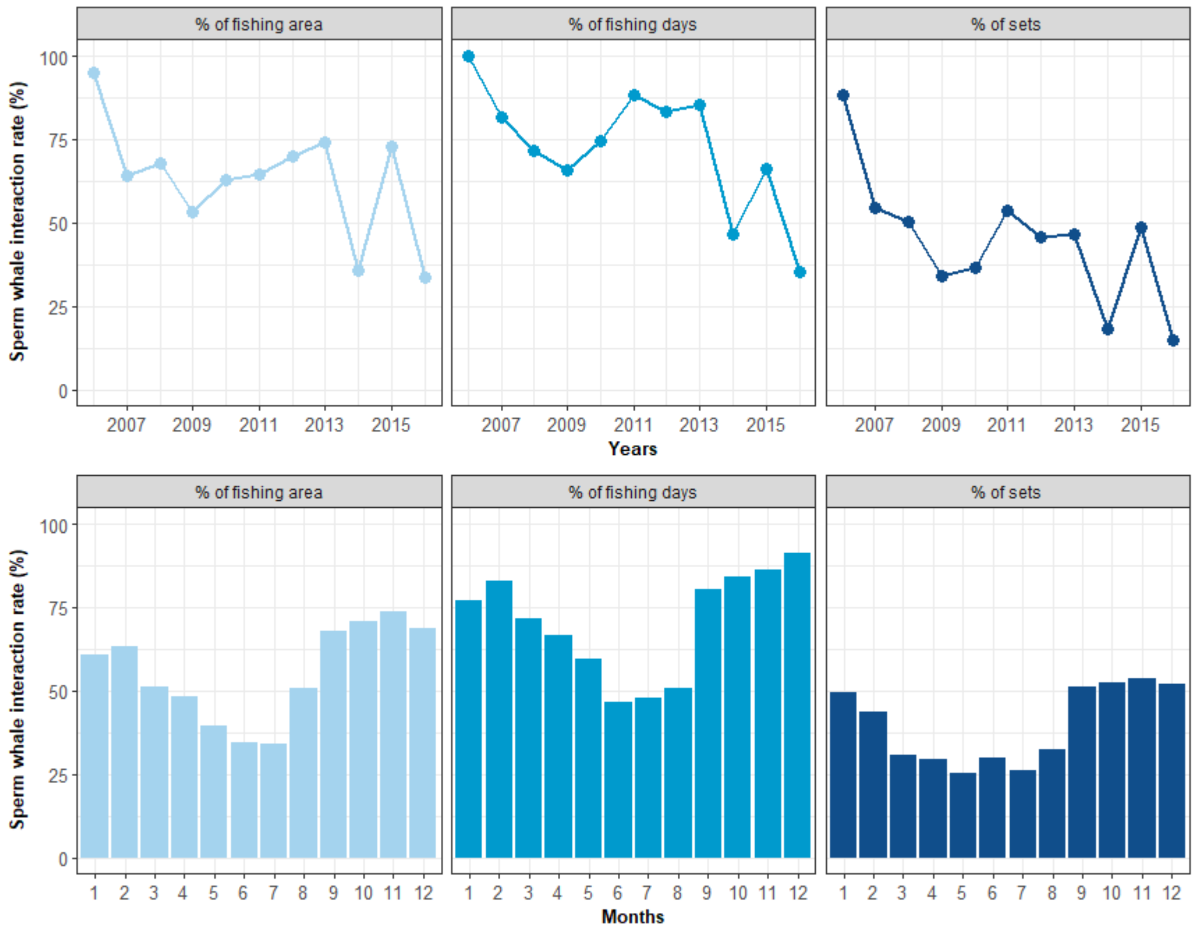

Figure 5. Observed levels of sperm whale depredation per year (top) and per month (mean across years - bottom) over the 2002-2016 period.

Sperm whale depredation events were spatially spread out across the fishing area of southern Chile although some variations were visually apparent on the maps (Figure 6 & 7). Fishing grounds located in the northern part (between latitudes 47° and 48.5° South) and in the southern part (between latitudes 56° and 58° South) of the fishery had higher depredation rates than other areas, and these variations were consistent across seasons within years (Figure 7). However, differences in the spatialized proportion of sets depredated between seasons were striking, especially between Spring, for which this proportion was high (> 50%) across a major part of the area, and Autumn, for which this proportion was primarily low and high depredation was restricted to the two "hotspots" previously described.

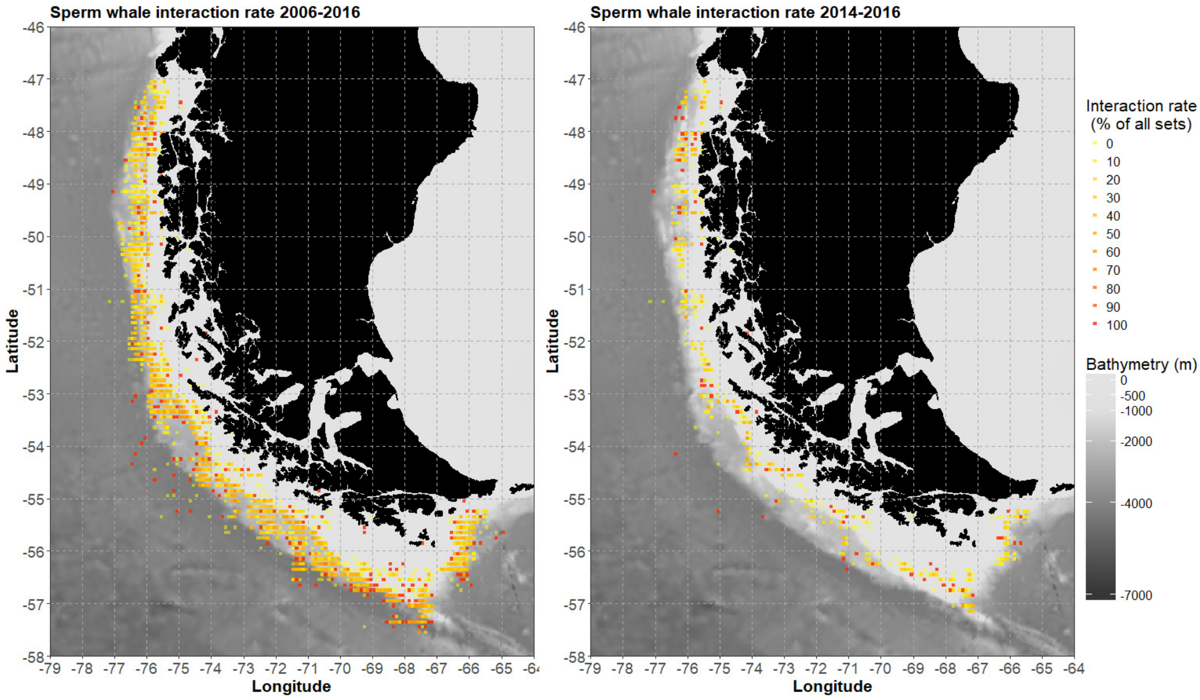

Figure 6. Distribution of sperm whale depredation in southern Chile. Depredation was calculated as the proportion of longline sets hauled in presence of depredating sperm whales out of all longline sets in 0.1 x 0.1 ° grids using all data (left) and data from 2014-2016 only (right).

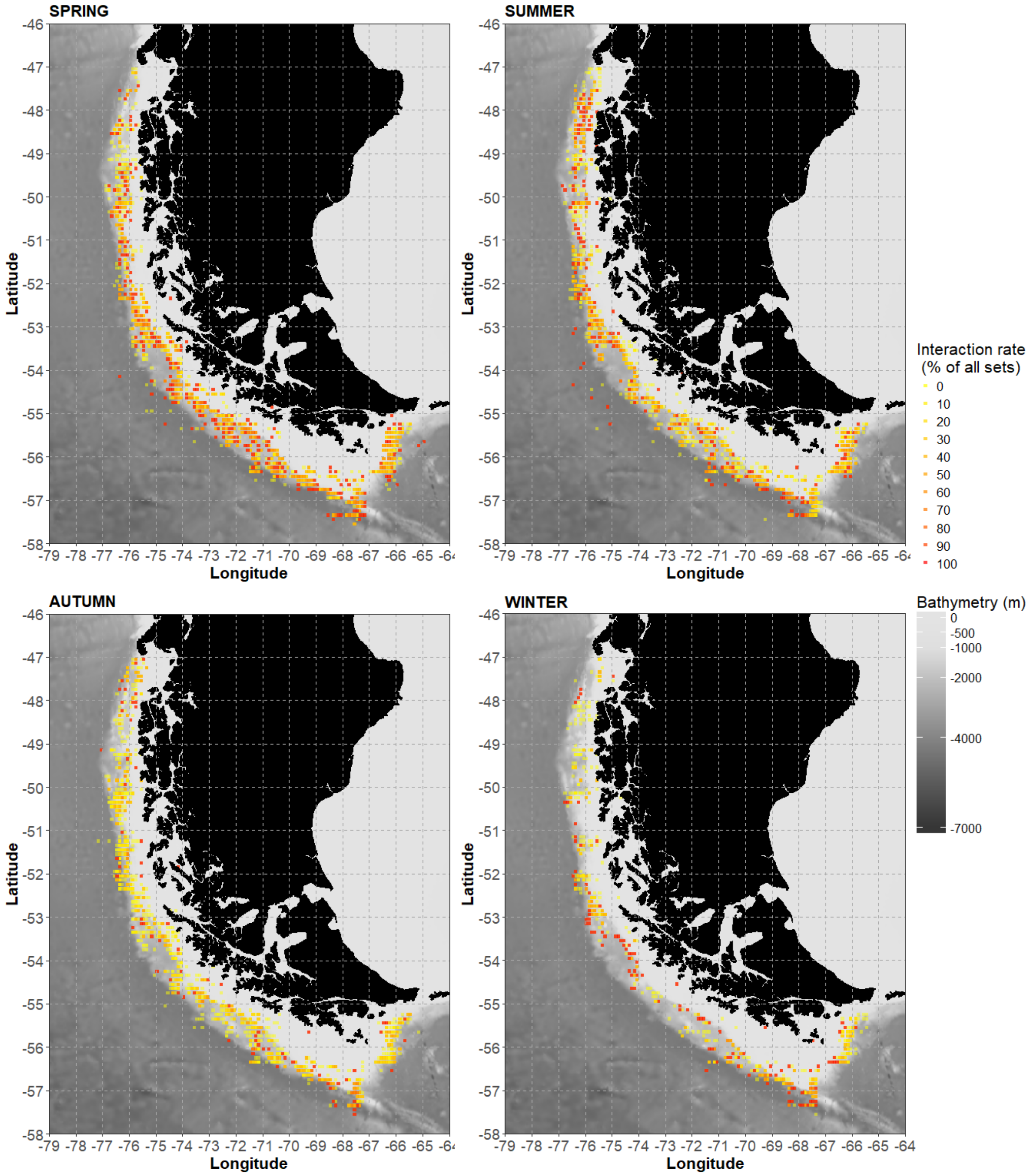

Figure 7. Distribution of sperm whale depredation around southern Chile. Depredation was calculated as the proportion of longline sets hauled in presence of depredating sperm whales out of all longline sets in 0.1 x 0.1 ° grids using all data per season.

2.2.2. Killer whales

Over the 2006-2016 period, killer whale depredation was recorded on average on 21.8 ± 3.1 % of the sets, 48.9 ± 4.7 % of the fishing days and 37.4 ± 2.7 % of the fishing area per year (Figure 8). Even if 2006 was removed from the time series, for which the data partially covered the year, there was an overall declining trend in killer whale depredation. Over the 2014-2016 period, killer whale depredation occurred on 12.7 ± 2.3 % of sets, 29.8 ± 3.6 % of fishing days and 27.7 ± 4.1 % of the fishing area. Whether this decline is due to a different method of collecting data on whale depredation over the 2014-2016 period, or due to changes in fishing operations (the fishing activity was greatly reduced in 2014), better avoidance of depredation by fishers or killer whales depredating less, is a question that will be addressed during the remaining part of the study.

Observed killer whale depredation varied between months, December being the month with the lowest proportions of sets (11.4%) and fishing area (18.4%) with depredation, and August with the lowest proportion of fishing days with depredation (19.5 % - Figure 8). The maximum proportion of sets depredated was in July (30.5%), the maximum proportion of the fishing days and fishing area with depredation was in October (60.1% and 39.5 % respectively).

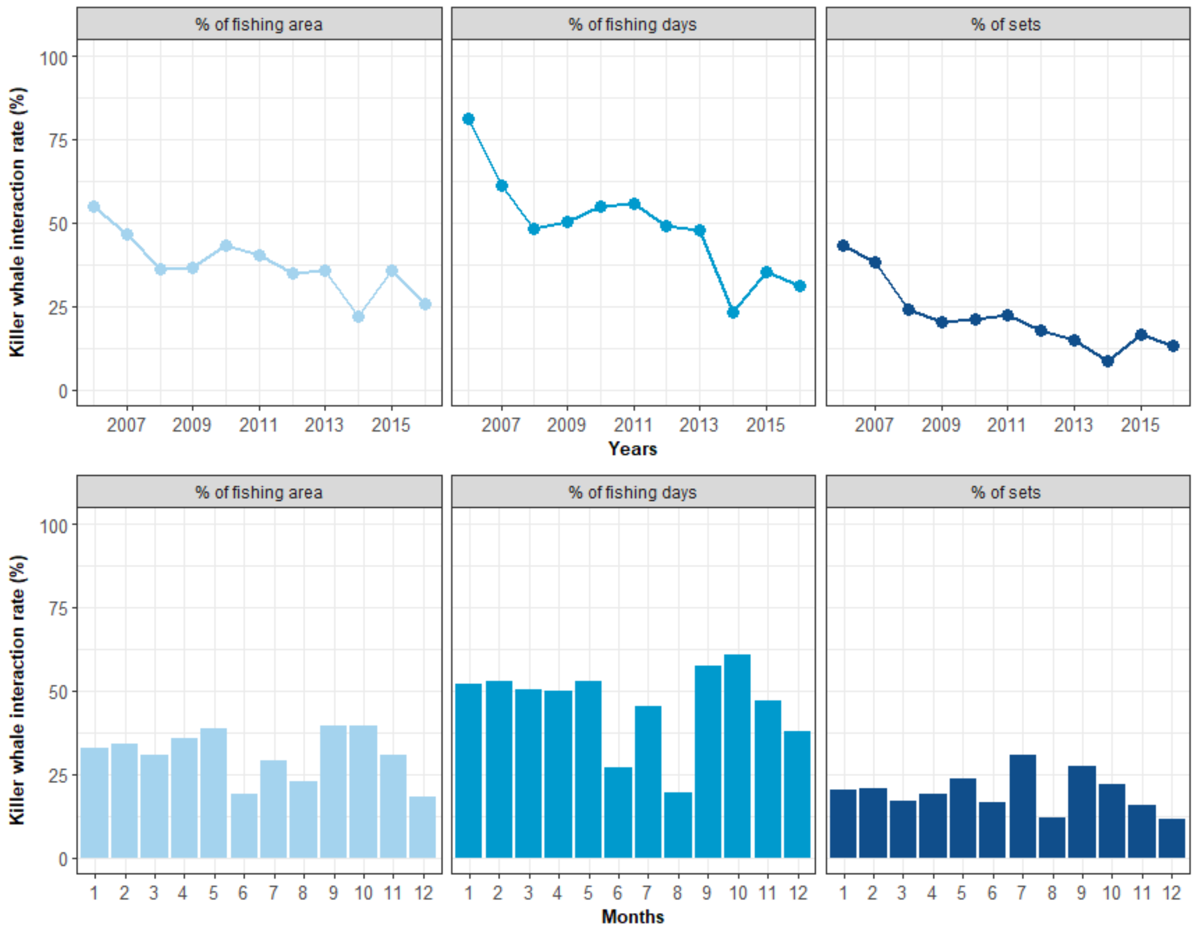

Figure 8. Observed levels of killer whale depredation per year (top) and per month (mean across years - bottom) over the 2002-2016 period.

Killer whale depredation events were more spatially restricted than sperm whale events. Most of the sets depredated by killer whales were hauled south of latitude 54° South (Figure 9). Fishing grounds located in between latitudes 56° and 58° South appeared to be a consistent hotspot of killer whale depredation across the seasons (Figure 10).

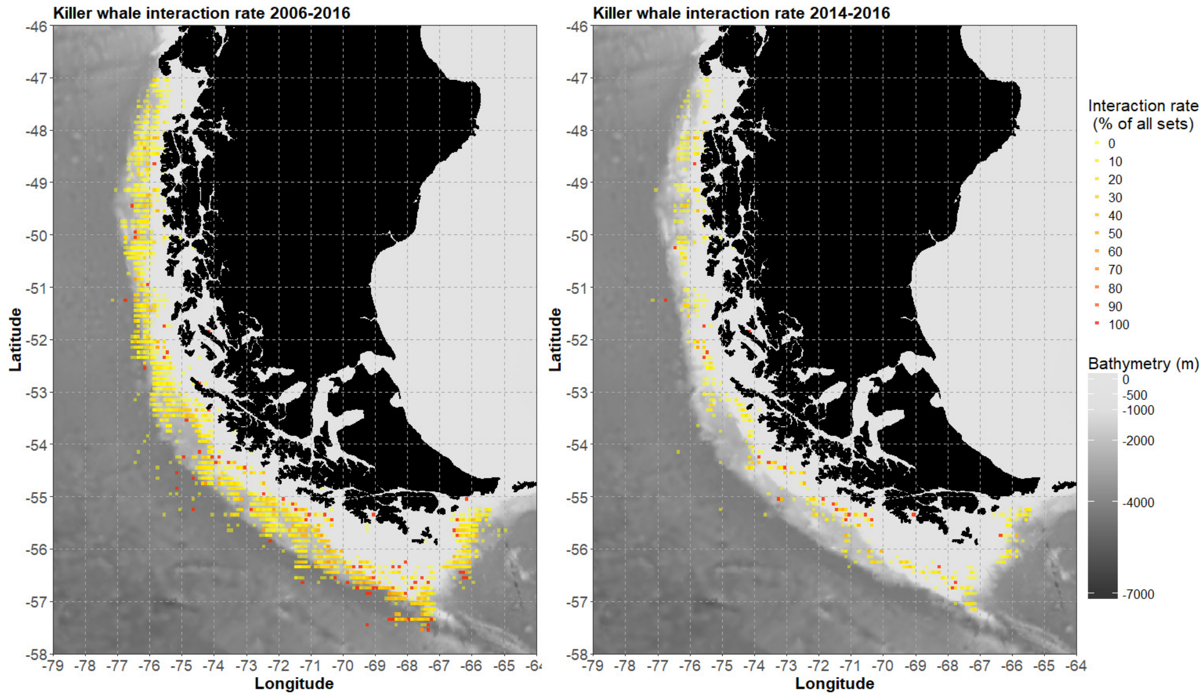

Figure 9. Distribution of killer whale depredation in southern Chile. Depredation was calculated as the proportion of longline sets hauled in presence of depredating killer whales out of all longline sets in 0.1 x 0.1 ° grids using all data (left) and data from 2014-2016 only (right).

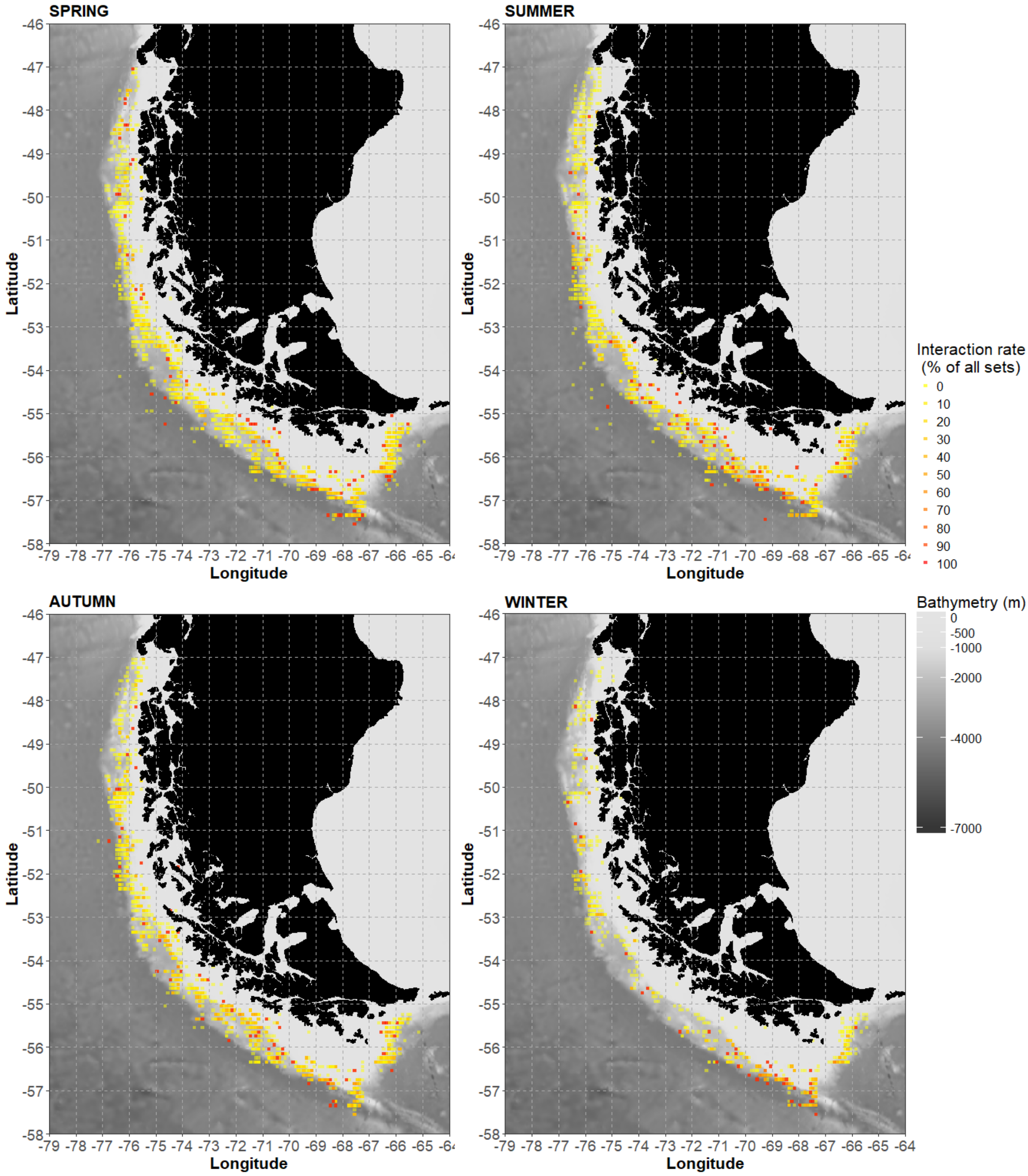

Figure 10. Distribution of killer whale depredation in southern Chile. Depredation was calculated as the proportion of longline sets hauled in presence of depredating killer whales out of all longline sets in 0.1 x 0.1 ° grids using all data per season.

2.3. Influence of fishing operations

In order to provide the captains and the fishing companies with guidance on strategies of avoidance of depredation, this section investigated the influence of two variables on levels of depredation by sperm and killer whales: the time of year and the distance travelled from one depredated set to the next. The effect of these two variables, which can be controlled by skippers as part of the decisions taken before and/or during fishing operations, was examined on the proportion of sets depredated.

2.3.1. Time of the year

Generalized Additive Models (GAMs) were here used to assess the intra-annual variations of the proportion of sets depredated by sperm whales or killer whales. A model was fitted using a binomial distribution and a log link function. The month was the variable to be tested, and was included in the model as a numeric smooth predictor. Other predictors included the year (factor), the vessel (factor), the fishing system (autoline or trotline with cachalotera), the latitude and longitude (bivariate smooth), the number of vessels operating simultaneously (smooth) and the depth of sets (smooth). Model selection was performed by using backward stepwise selection based on AIC.

For sperm whales, the best model was the full model including all predictors. This model indicated a significant month effect ($\chi^2 = 487.1$, $P < 0.001$). The probability of sperm whale depredation as estimated by the model decreased to <0.4 in autumn/winter months, from March to July, and was the highest (>0.7) in October and November (Figure 11a). For killer whales, the best model was the full model excluding the depth as a predictor. The month effect was also significant ($\chi^2 = 156.63$, $P < 0.001$), and the estimated probabilities of depredation were the lowest in November and December (<0.2), and the highest from March to July (>0.3 – Figure 11b).

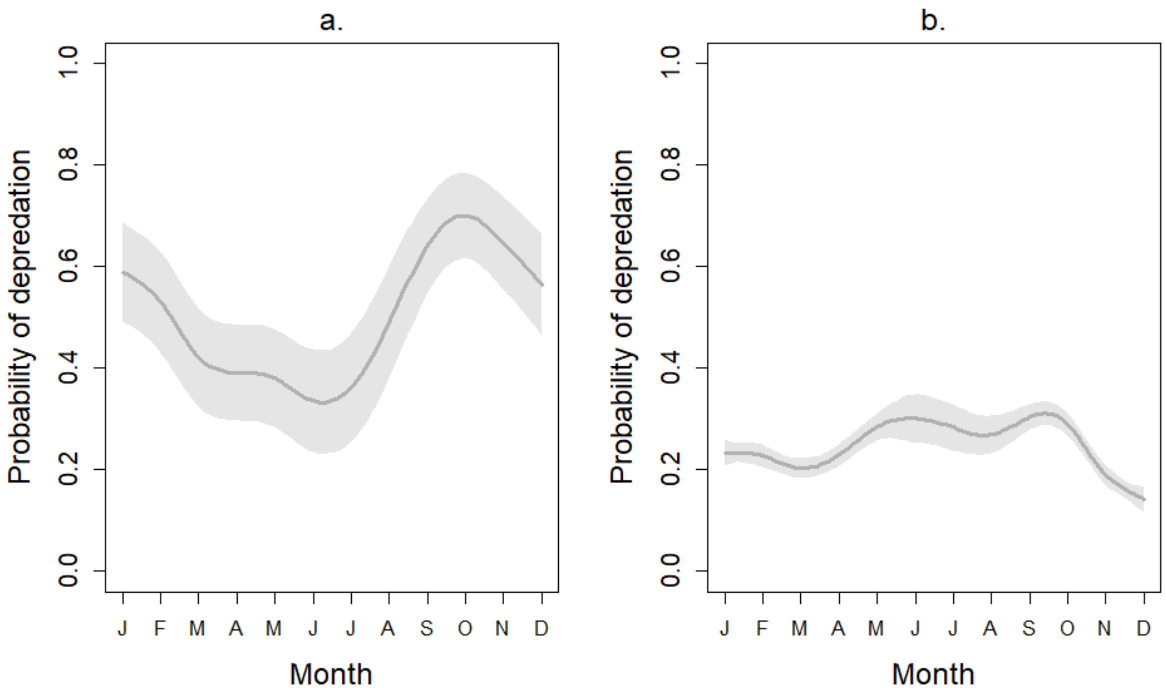

Figure 11. Probability of a. sperm whale and b. killer whale depredation as a function of the month as estimated by the best GAMs fitted on the proportion of longline sets depredated (dark grey line) and 95% confidence intervals (grey shade).

2.3.2. Distance travelled between sets

When whale depredation was recorded during hauling of a given set, the distance between this set and the set next hauled was calculated from the mean GPS coordinates of each set. Generalized Linear Models (GLMs) were then used on this restricted dataset to assess the effect of this distance on the proportion of sets next hauled depredated by sperm whales or killer whales. A model was fitted using a binomial distribution and a log link function. The distance between sets was included as a numeric quadratic predictor. Other predictors included the year (factor), the vessel (factor), the latitude and longitude (numeric), the number of vessels operating simultaneously (numeric) and the depth of sets (numeric). Model selection was performed by using backward stepwise selection based on AIC. The best model was further developed by adding one segmented (i.e., piece-wise linear) relationship to identify a distance breakpoint beyond which this predictor had no effect on the proportion of sets next hauled depredated.

For sperm whales, the best model was the full model including all predictors. This model indicated a significant effect of the distance travelled to the set next hauled ($z = -6.424$, $P < 0.001$) with a breakpoint of 173.9 ± 19.1 km. When a vessel faced sperm whale depredation on a given set, the probability of the next set to be also depredated by sperm whales was > 0.7 if these two sets were located less than 100 km from each other (Figure 12a).

For killer whales, the best model was the full model excluding the depth as a predictor. The effect of the distance travelled to the set next hauled on the probability of this next set to be depredated again was significant ($z = -3.105$, $P = 0.002$). A breakpoint of 108.1 ± 11.6 km could still be estimated. When a vessel faced killer whale depredation on a given set, the probability of the next set to be also depredated by killer whales was > 0.7 if these two sets were located less than 10 km from each other (Figure 12b). When this distance was greater than 108.3 km, the probability of killer whale depredation on the next set dropped to < 0.5.

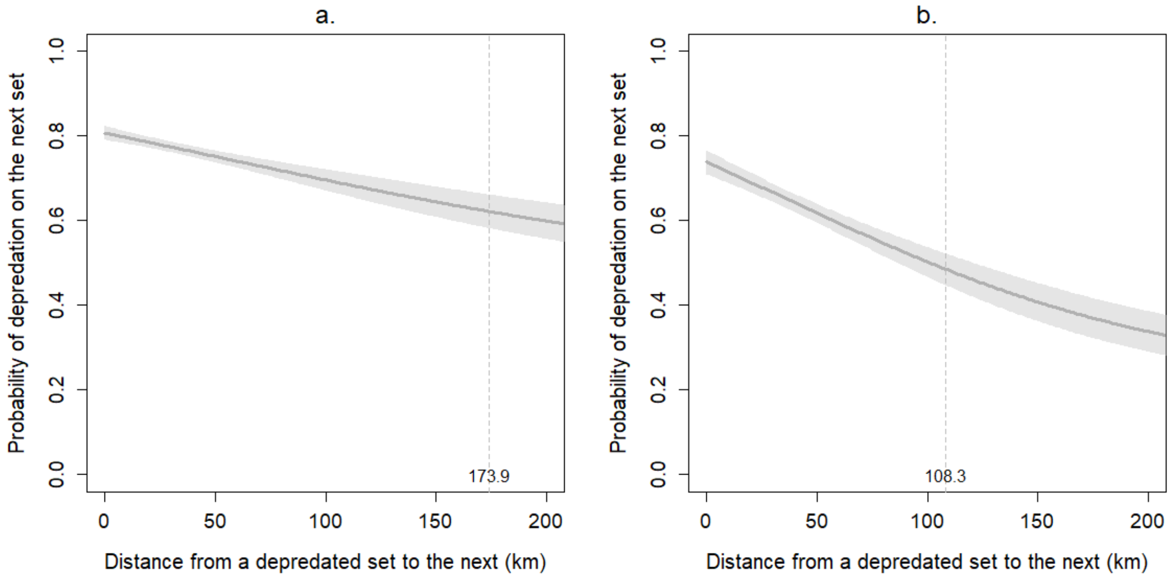

Figure 12. Probability of a. sperm whale and b. killer whale depredation on a set that was successively hauled after a depredated set as a function of the distance travelled between these two sets as estimated by the best GLMs fitted on the proportion of longline sets next hauled depredated (dark grey line) and 95% confidence intervals (grey shade). The vertical dashed line indicates the breakpoint in the relationship.

Because large seasonal variations in the probability of depredation by sperm whales were detected, the distance travelled by vessels between sets was also modelled as a function of the time of year (here the season). Results indicated that for sperm whales, the correlation between this distance and the probability of depredation was stronger than during other seasons, decreasing from 0.7 for distances < 10 km to 0.45 for distances > 100 km (Figure 13).

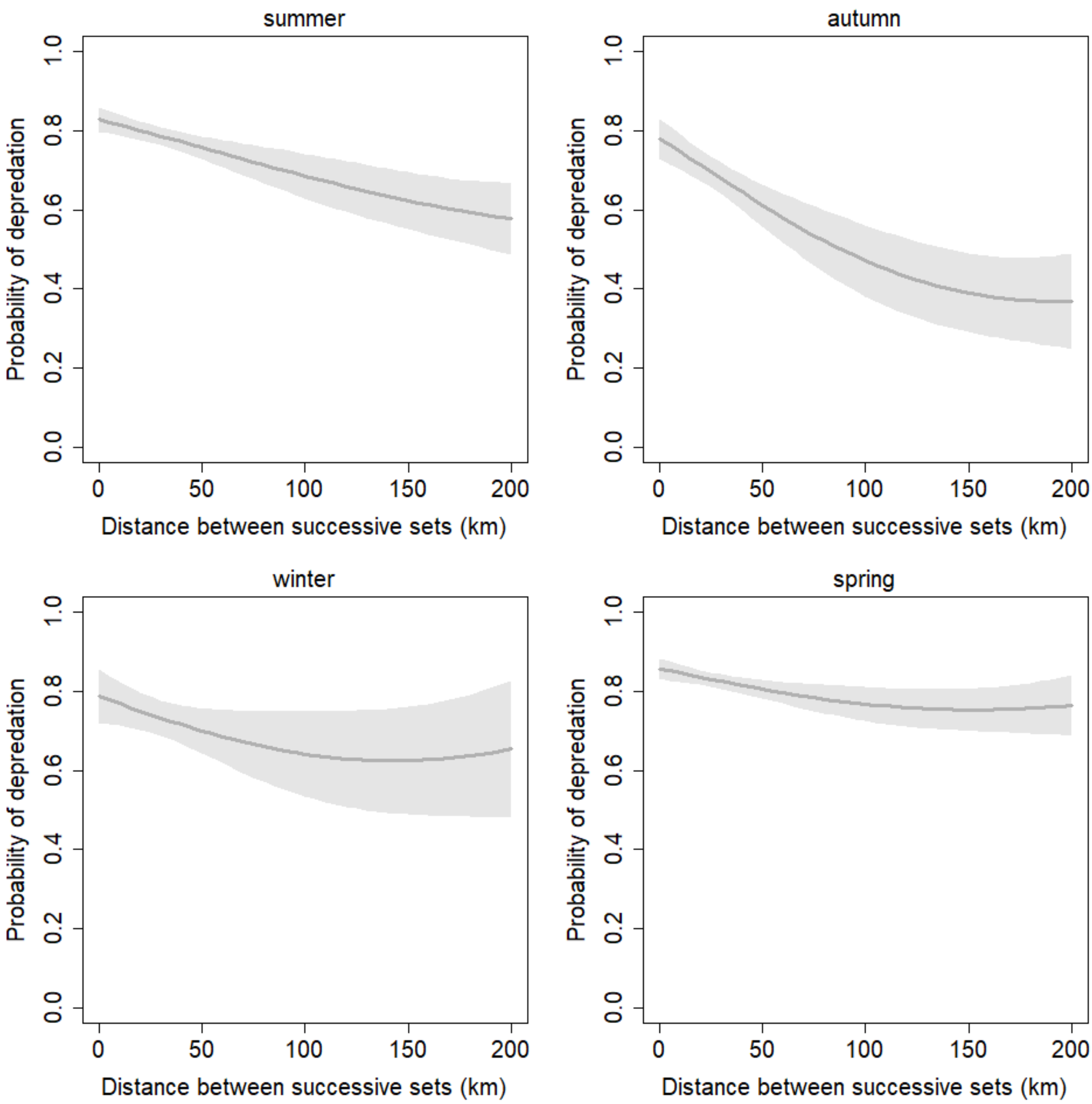

Figure 13. Probability of sperm whale depredation on a set that was successively hauled after a depredated set as a function of the distance travelled between these two sets as estimated by the best GLMs fitted on the proportion of longline sets next hauled, for each season of the year.

2.4. Influence of environmental variables

The influence of various environmental variables on the proportion of sets depredated by whales was examined through GAMs. The environmental variables included the toothfish productivity, in grams of fish per hook, the bathymetry (in metres) and the slope (in degrees) on which longlines were set, the sea surface temperature (SST, in °C) and the salinity (in grams per kilogram).

Average values of these environmental variables were calculated or extracted on a 0.25 x 0.25 ° spatial grid. The toothfish productivity was calculated using sets that were hauled in absence of whales (i.e., without depredation) and averaged in each grid using all values from 2006 to 2016. The bathymetry was extracted from the GEBCO 1-minute resolution database and used to calculate the bathymetric slope. The SST and the salinity were extracted from the COPERNICUS database providing average values per grid over the 2011-2016 period.

For sperm whales, the best model was the model including all variables. However, the toothfish CPUE and the slope were the only variables with a statistically significant effect (χ^2=7.187, P = 0.04 and χ^2=16.504, P < 0.001 respectively). The probability of sperm whale depredation occurring increased from <0.7 in areas with low toothfish productivity (<100 g/hook) to >0.9 in highly toothfish productive areas (>300 g/hook - Figure 14). Sperm whales were also more likely to depredate on steeper slope, with a probability >0.9 for slopes > 2°.

For killer whales, the best model was the model including all variables. However, the toothfish CPUE, the slope and the depth were the only variables with a statistically significant effect (χ^2=9.487, P = 0.01; χ^2=13.702, P = 0.002 and χ^2=9.022, P = 0.04 respectively). The probability of killer whale depredation occurring increased from <0.6 in areas with low toothfish productivity (<100 g/hook) to >0.8 in highly toothfish productive areas (>300 g/hook - Figure 15). Killer whales were also more likely to depredate on steeper slope, with a probability >0.8 for slopes > 3° and at deeper depths, with a probability >0.7 for depths >1000m.

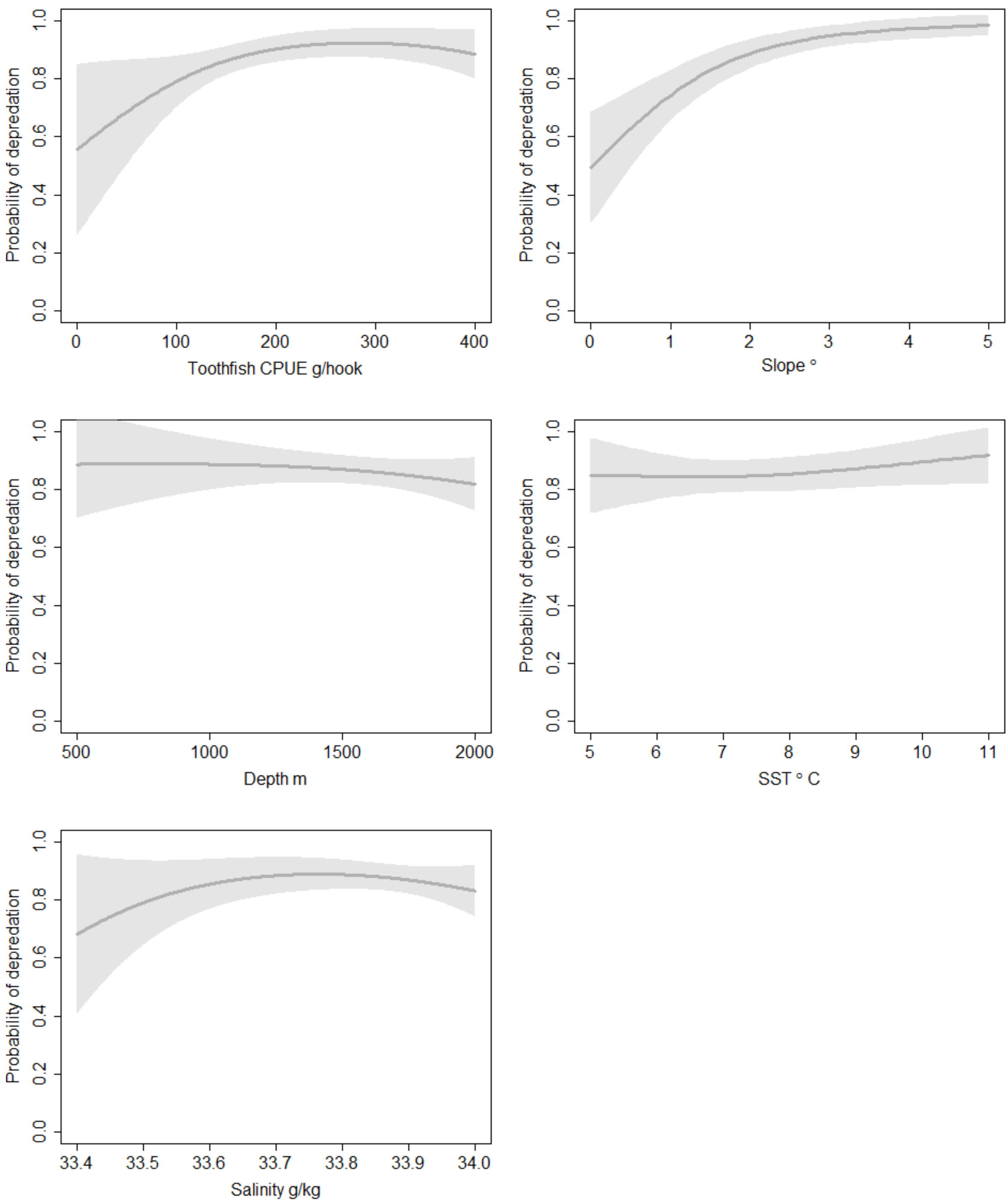

Figure 14. Probability of sperm whale depredation in 0.25 x 0.25° spatial grids as a function of the natural toothfish productivity (CPUE calculated in absence of depredation), the bathymetric slope, the bathymetry, the SST and the salinity as estimated by the best GAMs fitted on the proportion of longline sets depredated (dark grey line) and 95% confidence intervals (grey shade).

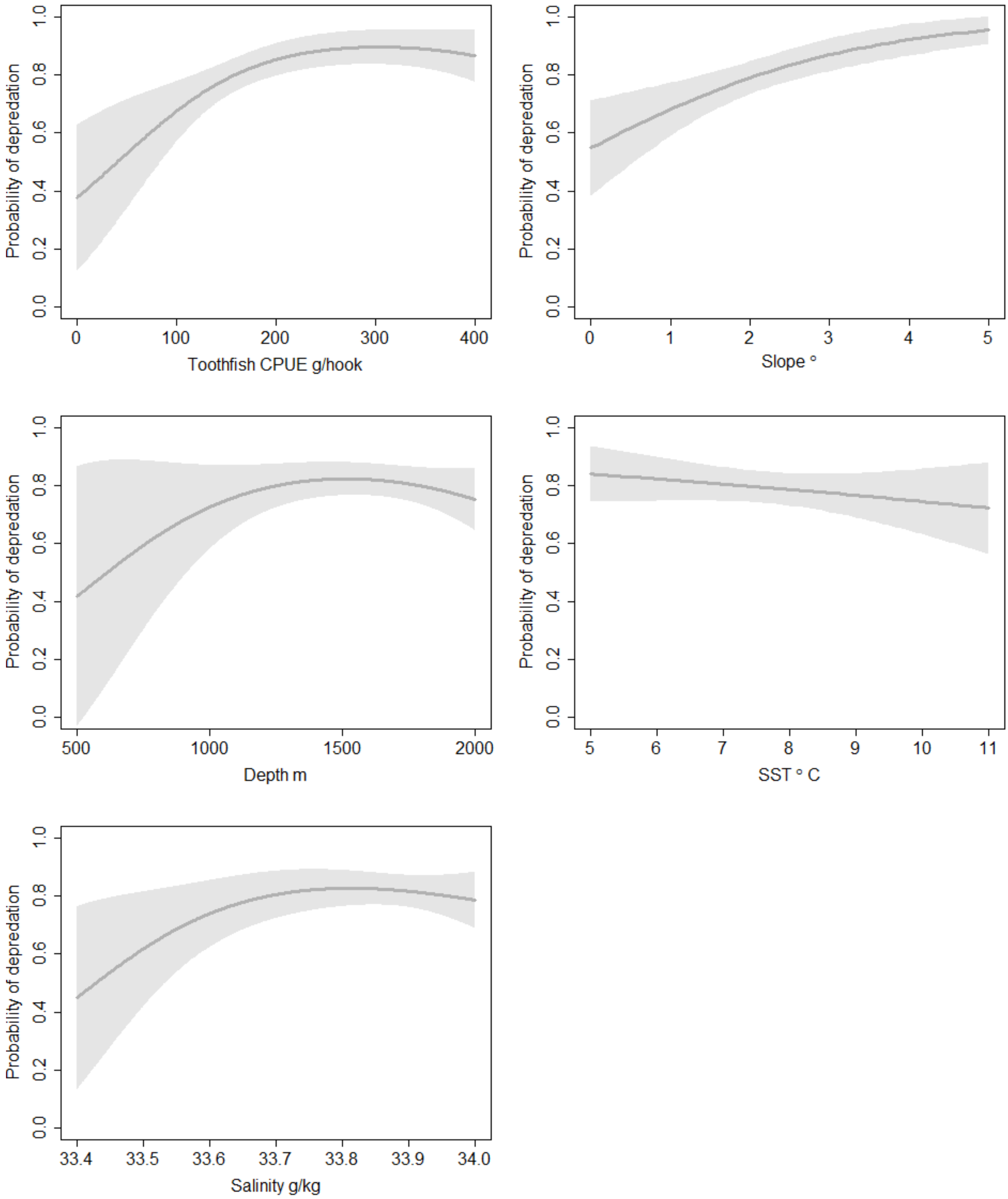

Figure 15. Probability of killer whale depredation in 0.25 x 0.25° spatial grids as a function of the natural toothfish productivity (CPUE calculated in absence of depredation), the bathymetric slope, the bathymetry, the SST and the salinity as estimated by the best GAMs fitted on the proportion of longline sets depredated (dark grey line) and 95% confidence intervals (grey shade).

3. Number of depredating whales

3.1. Number of individuals per depredated set

When depredation was recorded during hauling, the number of whales simultaneously depredating was estimated for both sperm whales and killer whales. Over the 2006-2016 period, the mean number of individuals per depredated set was 3.5 ± 0.04 for sperm whales and 6.4 ± 0.1 for killer whales. For the latter, the annual means indicated a maximum of 8.4 ± 0.4 in 2016 (Figure 16a). The number of sperm whales showed a sharp decline from 2007 (7.2 ± 0.2) to 2008 (3.0 ± 0.1), which then dropped to less than 3 individuals from 2012 to 2016. At the intra-annual level, the minimum number of sperm whales was recorded in June (2.0 ± 0.2) and the maximum in May (4.4 ± 0.2) – Figure 16b). For killer whales, the lowest average was in August (4.6 ± 0.4 individuals) and the highest mean was in January (6.9 ± 0.3 individuals).

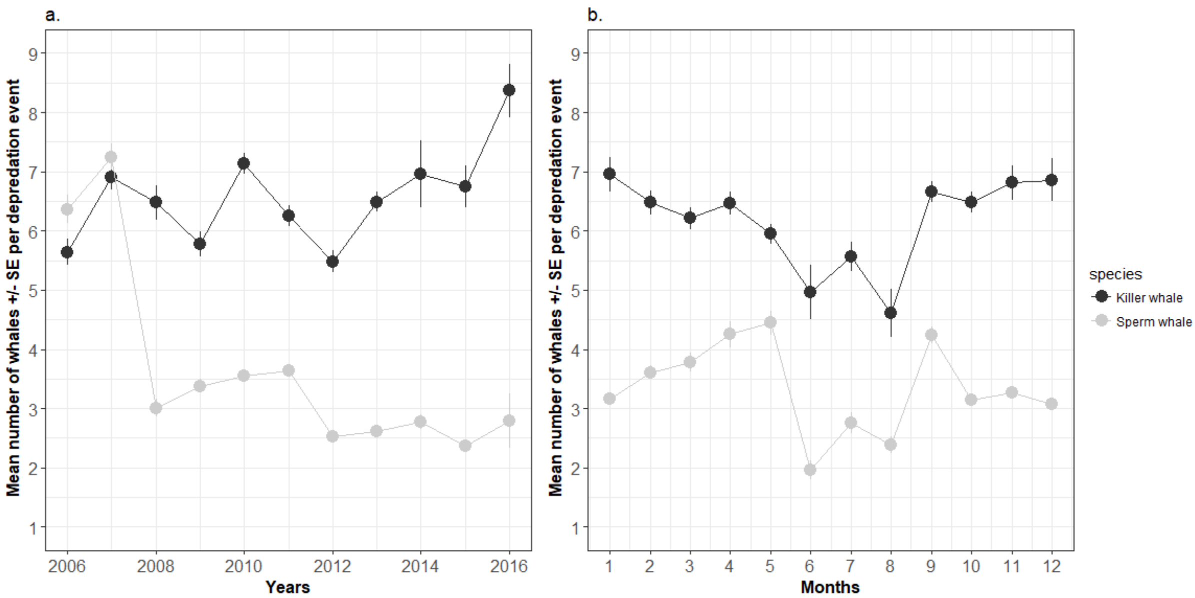

Figure 16. Mean number of sperm whales (grey) and killer whales (black) simultaneously depredating the same, a. per year and b. per month over the 2002-2016 period. Error bars are the Standard Error of the mean.

3.2. Total number of depredating individuals.

The primary methodology used to estimate the total number of whales depredating on longline sets, or the local size of whale populations, is to implement a long-term consistent photo-identification program from fishing vessels. This program was implemented in January 2017 for the commercial Chilean fishery in collaboration with AOBAC and IFOP. IFOP fishery observers were provided with camera equipment and received training on photo-identification protocols used for both killer whales and sperm whales.

Two batches of pictures were received from Eduardo Infante (Global Pesca, AOBAC) on May 10th and July 24th 2017. These pictures were taken by observers and crew from two vessels (Global Pesca I and Puerto Williams) during one trip each. A total of 413 pictures of sperm whales and 751 pictures of killer whales were taken. Pictures of killer whales first revealed the presence of two morphotypes of killer whales, a Type-A like type and Type Ds.

In collaboration with Jorge Acevedo (CEQUA), the pictures of the killer whales from the first of these two types were analysed and the first photo-identification catalogue was produced (Figure 17). 26 individuals including 3 adult males, in possibly 5 distinct groups, could be identified when interacting with Global Pesca I from January 9th to April 13th 2017. Two of these groups depredated on two occasions, 45 days apart, in two different areas (>630km apart).

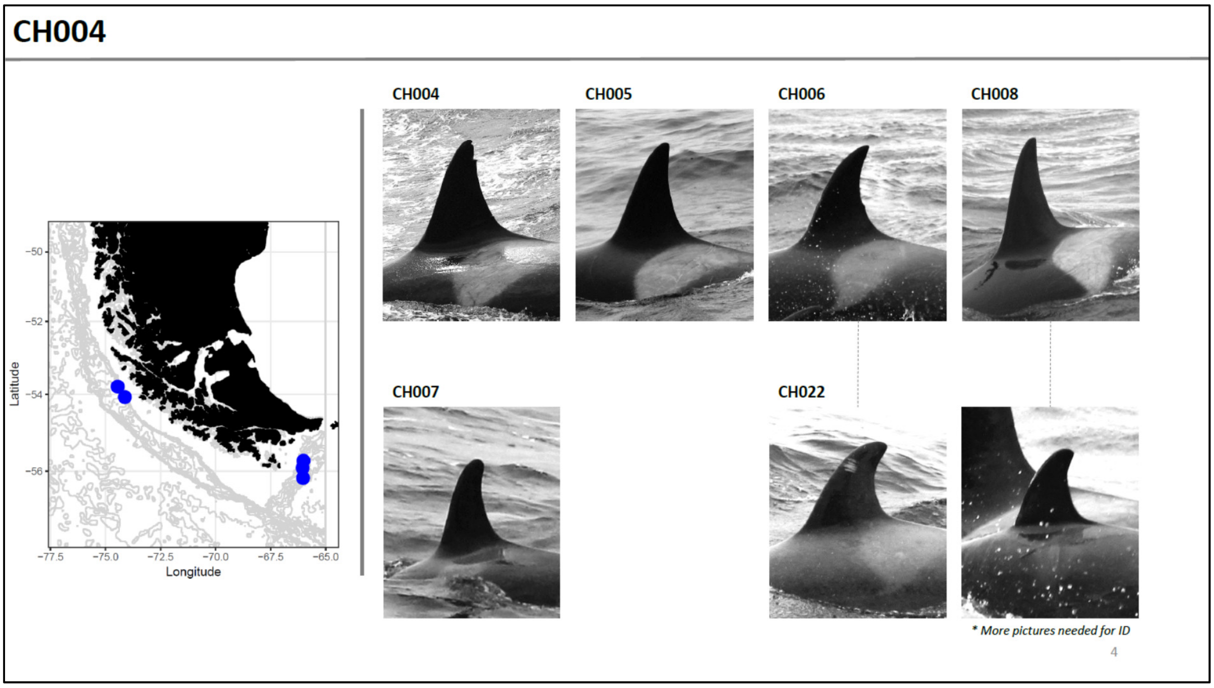

Figure 17. Sample of the first photo-identification catalogue of the killer whale individuals depredating on toothfish in southern Chile, built from pictures taken by fishery observers and crews in 2017.

4. Depredated fish biomass

4.1. Methods

Whales primarily depredate Patagonian toothfish and disregard other fish species caught on longlines. Whales usually remove the entire fish from a hook, which increases the difficulty to reliably assess the amount of depredated fish biomass. Previous methods to estimate biomass losses were primarily based on comparisons of CPUE between sets hauled in absence and sets hauled in presence of depredating whales, and performed at varying spatio-temporal scales.

As part of this COLTO study on whale depredation, one of the aims is to develop a standardised methodology leading to more accurate estimates of the amount of depredated fish in fisheries. The work is ongoing and the results that are presented in this report are preliminary, and should thus be interpreted with that in mind at this stage.

A new GAM was developed to model the Patagonian toothfish CPUE in southern Chile, using data from 2007 to 2016 (2006 was excluded because of the limited amount of data available for that year). The model was fitted using a Gaussian distribution and a log link function.

The full model included the calendar year, the month and the vessel as factors, and the depth, the longitude, the latitude and the soaking time as numeric covariates. The occurrence of whale depredation during hauling of sets was then added to the model as a factor with two levels (0,1).

Outliers for the numeric covariates were excluded. For the soaking time (which is the time elapsed between the time the first hook of a longline is set in the water and the time the last hook is hauled and landed), the outlier values of < 5 hours and > 70 hours were excluded. For the depth, the analysis was restricted to sets with depths < 3000m. The analysis was also restricted to the fishing system "trotline" equipped with "cachaloteras".

When estimating depredation from a given whale species, sets that were hauled with both killer and sperm whales simultaneously depredating were excluded from the analysis. The analysis was run separately for sets that were depredated by sperm whales only, killer whales only, and by the two species co-occurring.

Model selection was performed by using backward stepwise selection based on AIC.

Once the best model was identified, the CPUE predicted by this model in absence of whale depredation was used to estimate a predicted catch (in kg) using the total number of hooks set per calendar year. The depredated toothfish biomass was then estimated by calculating the difference between the predicted catch (estimating what should have been caught if all sets were hauled in absence of whale depredation) and the observed catch. The same procedure was applied to the 95% confidence intervals of the predicted CPUE to calculate uncertainty around the final depredation estimates per year.

4.2. Results

Sperm whale depredation was first estimated using 7,331 sets (58% of all sets) after the filters described above were applied. The best model was the model including all covariates and sperm whale depredation. When sperm whales were the only depredating species during hauling (n = 2,837 sets), the toothfish CPUE was significantly reduced ($t = -8.618$, $P < 0.001$). The estimated amount of depredated fish varied from 3.4 tonnes [95%CI -6.0 – 12.8] in 2007 to 161.5 tonnes [95%CI -97.2 – 420.2] in 2010 (Table 1). From 2007 to 2016, the total loss was estimated to 498.7 tonnes, which represented 6.7 % of the total catch (observed catch + estimated depredation) over this period.

Killer whale depredation was then estimated using 5,369 sets (42% of all sets) after the filters described above were applied. The best model was the model including all covariates and killer whale depredation. When killer whales were the only depredating species during hauling (n= 641 sets), the toothfish CPUE was significantly reduced ($t = -11.006$, $P < 0.001$). The estimated amount of depredated fish varied from 0 in 2011 and 2013 to 110.8 tonnes [95%CI -128.3 – 349.9] in 2010 (Table 1). From 2007 to 2016, the total loss was estimated to 239.5 tonnes, which represented 4.5 % of the total catch over this period.

Finally, depredation was estimated for sets hauled in presence of both killer and sperm whales depredating (n= 1,717 sets). The analysis was performed on 6,204 sets (49% of all sets). From 2007 to 2016, the total loss when the two species depredated was estimated to 712.1 tonnes, which represented 11.0% of the total catch over this period.

Table 1. Preliminary estimates and 95% confidence intervals of sperm whale and killer whale depredation on Patagonian toothfish (in tonnes of fish taken from longlines) in Chile from 2007 to 2016 for sets that were depredated by sperm whales only, killer whales only, and both species together. Estimates were obtained from the difference between predicted catch values (produced from the best GAMs fitted to the CPUE) without depredation, and the observed catch.

	Estimated depredated toothfish biomass (tonnes) [95% CI]		
	Sperm whales only	*Killer whales only*	*Killer & sperm whales*
2007	**3.4** [-6.0– 12.8]	**1.5** [-11.2 – 14.1]	**124.8** [67.4 – 182.2]
2008	**73.9** [-27.9 – 175.9]	**35.8** [-44.2 – 115.7]	**98.1** [2.5 – 193.6]
2009	**98.6** [-63.4 - 260.6]	**57.0** [-89.7 – 203.8]	**91.3** [-59.5 – 242.1]
2010	**161.5** [-97.2 - 420.2]	**110.8** [-128.3 – 349.9]	**215.7** [-45.8 – 477.3]
2011	**33.3** [-129.7 – 196.2]	**0**	**17.2** [-107.0 – 141.5]
2012	**32.8** [-104.6– 170.3]	**12.8** [-95.5 – 121.1]	**85.8** [-46.7 – 218.3]
2013	**28.6** [-87.7 – 145.0]	**0**	**55.1** [-60.6 – 170.7]
2014	**19.9** [1.6 – 38.2]	**4.4** [-7.6 – 16.4]	**7.7** [-5.1 – 20.5]
2015	**7.1** [-22.4 – 36.6]	**14.7** [-22.0 – 51.5]	**5.4** [-21.8 – 32.7]
2016	**39.6** [10.6– 68.7]	**2.5** [-6.9 – 11.9]	**11.0** [-0.3 – 22.3]

5. Conclusion/Summary

This interim report presented the observed levels of both sperm whale and killer whale depredation on the commercial Patagonian toothfish longline fishery operating off Chile. Using long term datasets spanning from 2006 to 2016, the observed spatio-temporal patterns of both the depredation levels were assessed and a preliminary analysis on the impact of depredation on the catch was performed. This report also provided preliminary insights on a number of variables influencing the probability of depredation events, which is the first step in the process of developing mitigation strategies to depredation, which could be achieved at the end of the study by combining datasets from all fisheries within this project.

This interim report assessed the current methodology used to investigate depredation in Chile and may be further used to identify ways to improve this methodology in the near future.

The section below provides a summary of the results including suggestions on possible methodological improvements to study depredation further in the year to come.

- Sperm whale depredation occurred on 44.6 % of the sets over the 2006-2016 period, but this proportion seems to have decreased in recent years. While it cannot be excluded that sperm whale depredation is declining, this decrease may also be due to variations in the methodology used to record depredation events. Further research will focus on understanding the between-years variations of depredation and assessing the influence of data collection procedures, fishing operations and whale behaviour/numbers on depredation levels.

- The occurrence of depredation may need to be more accurately recorded in years to come, for each whale species and for each set during hauling, as follows:
    - Absence: weather/light/visibility conditions are good, observation effort is provided by the observer/crew, and the absence of depredating whales around the vessel is confirmed;
    - Presence: weather/light/visibility conditions are good, observation effort is provided by the observer/crew, and the presence of whales around the vessel depredating on the line (repeated dives towards the line, seabird activity around the whales at the surface, fish oil slick visible on the water, etc.) is confirmed;
    - Unknown: Weather and/or light and/or visibility conditions are poor and/or observation effort could not be performed by the observer/crew, and therefore whether whales were present and depredating or absent during hauling of this set is not known.

- Killer whale depredation has been high (< 21% of the sets) but appears to be spatially heterogeneous, with a depredation hotspot in the southern part of the fishery. Preliminary results from photo-identification suggested that i) depredation may be occurring by a limited number of individuals, possibly a subset of the population; and ii) the same killer whales may move over distances >600 km within the fishing area. However, the analysis of distance between sets indicated that vessels are less likely to be followed by the depredating killer whales if leaving the area and travelling >100 km to a new fishing area. It is thus still strongly encouraged to continue avoiding killer whale depredation by implementing a "non-reward" fishing behaviour whenever possible, e.g., buoying off the fishing gear at the bottom as soon as the killer whales show up around the vessel, and leaving the fishing area by travelling a distance >100 km as suggested by this study. The gear remaining in the water can be picked up several days/weeks later.

- Two spatio-temporal variables were found to influence the probability of sperm whale depredation, and may be used to avoid this depredation by adjusting the fishing practice:

  - The probability of sperm whale depredation was significantly lower in winter months, likely due to biological aspects of the species (individuals present in the Southern Ocean are primarily adult males that may migrate to tropical/sub-tropical waters in winter for reproduction purposes).
  - When facing depredation, vessels are less likely to be followed by the depredating sperm whales if leaving the area and travelling >170 km to a new fishing area. However, this distance threshold is high, higher than in other fisheries (67 km for the Falkland Islands for example). This is likely due to a combination of features of the Chilean fishing area: narrow profile / small size of the fishing area (steep slope on the shelf edge) and higher densities of sperm whales, resulting in a high probability for vessels to encounter new sperm whales in the new fishing area.

- The preliminary habitat modelling performed in this study indicated that sperm whale depredation was more likely to occur in areas of high natural toothfish densities and steep slopes, with limited influence of the depth, the sea surface temperature and the salinity. Together, these results provide the first insights on the natural foraging preferences (Patagonian toothfish is a likely natural prey item), and thus the natural distribution, of sperm whales around southern Chile. While this analysis is still ongoing, these first results may explain the rather homogeneous distribution of sperm whale depredation across the full latitudinal range of the fishery. Killer whale depredation was also more likely in areas of high toothfish densities and steeper slopes, but also at great depth. Whether these killer whales naturally feed on toothfish is unknown, and further research is needed to understand the feeding ecology of local populations, considering that photo-identification indicated that two morphotypes, likely ecotypes, depredate on fisheries in Chile (Type A like whales and Type Ds).

- The number of depredating whales; the population trend; and whether depredation is spreading across individuals of the population or if the same individuals are increasingly depredating on longlines, remain unanswered questions due to the lack of historical photo-identification from fishing vessels. A photo-identification program was implemented in 2017 and it is strongly encouraged that this program be continued, and reinforced by deploying cameras and taking pictures on all vessels during all trips in years to come to be able to assess the current and future evolution (spreading/learning/habituation processes and increase of whale population sizes) of depredation.

- Preliminary estimates of the Patagonian toothfish biomass caught on longlines but depredated/removed by whales were provided in this report. These estimates are not final estimates and should therefore be interpreted with caution. The confidence intervals were large and their accuracy needs to be increased. The modelling work dedicated to this aspect of the project is still ongoing, with further improvements to increase the accuracy of the models and depredation estimates to be implemented in early 2018.

Acknowledgements

All fishing companies of AOBAC (PESCACHILE, PESCACISNE,GLOBAL PESCA SpA.), Eduardo Infante and Eduardo L Infante (GLOBAL PESCA SpA), Renzo Tascheri and Patricio Galvez (Instituto de Fomento Pesquero), Rhys Arangio (COLTO), Prof Mark Hindell and Assoc. Prof. Mary-Anne Lea (University of Tasmania), Dr Paul Burch, Dr Christophe Guinet (CEBC-CNRS), Australian Research Council. Fishery observers and fishing crews working on commercial Patagonian toothfish longliners off Chile, Jorge Acevedo (CEQUA).